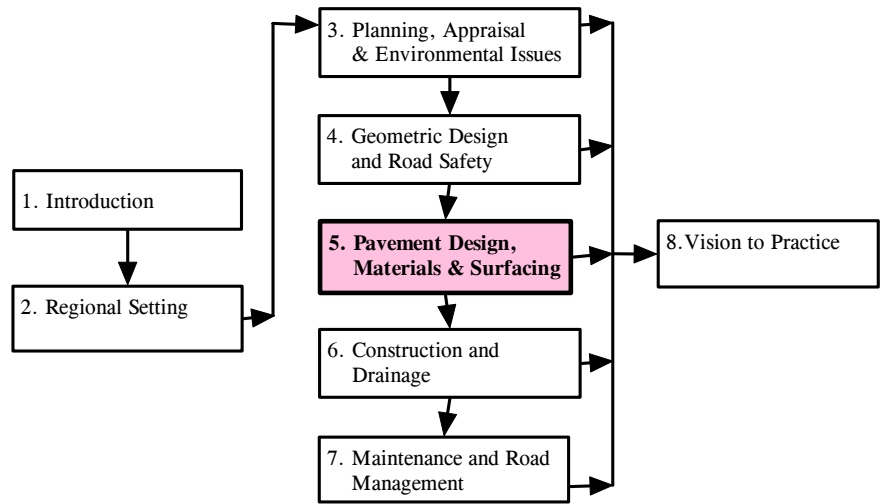


Chapter 5



Pavement Design, Materials & Surfacing

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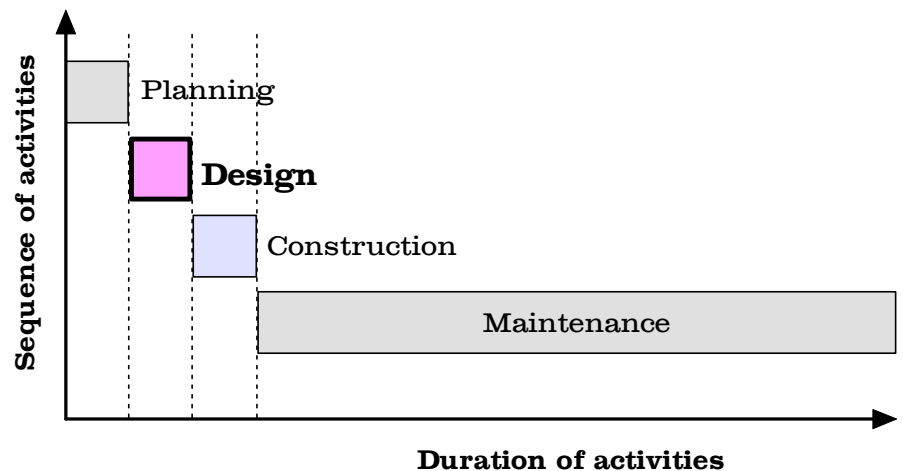
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Pavement Design, Materials & Surfacing

5

5.1 Introduction

5.1.1 Pavement Design



The objective of pavement design is to provide an economic structure, in terms of material types and thicknesses, that can withstand the expected traffic loading over a specified time without deteriorating below a predetermined level of service. This provides a particular challenge for designers as existing methods of pavement design, even those developed in the SADC region, generally cater to relatively high volumes of traffic (> 0.5 million Equivalent Standard Axles (ESAs)). As a result, such methods are often inappropriate for application to LVSRs for which environmentally induced, rather than traffic induced, stresses tend to play a dominant role in pavement deterioration. Thus, there is a need to be very discerning in the application of current pavement design methodologies and to adapt them, where necessary, to suit the prevailing conditions of climate, materials, traffic loading and other related factors.

Calcrete and laterite are typical examples of natural gravels which, although occurring throughout southern Africa, had been generally considered to be unsuitable for use as base course. However, experience and full-scale trials in a number of SADC countries, have demonstrated that these materials can be used successfully in the upper layers of pavements.



Naturally occurring calcrete found under a thin layer of overburden.

The term “natural gravel” refers to a gravelly material occurring in nature as such, (e.g. laterite) or which can be produced without crushing. Some processing to remove or breakdown oversize may still be necessary. However, a distinction is made between these “natural” gravels and material produced from crushed hard rock which is referred to as “crushed rock base”.

The outcome of the design process, in terms of the type of structure chosen, is influenced by the preceding planning and geometric design phases and, in turn, determines many aspects of construction requirements. It also influences the level and type of maintenance necessary to keep the pavement at the design serviceability level. In order to ensure a successful outcome, there is a need to ensure that the design process is undertaken in a holistic manner which takes full account of a variety of influential factors as discussed in Chapter 3.

5.1.2 Materials

Naturally occurring soils and gravels are an important source of material for use in the construction of a LVSR. This is because these materials are relatively cheap to exploit compared to, for example, processed materials such as crushed rock. Moreover, in many SADC countries, they are often the only source of material within a reasonable haul distance of the road. Thus, because of the substantial influence that naturally occurring materials exert on the cost of a LVSR, typically of the order of about 70 per cent, it is essential that the benefits of using them is exploited in road construction.

Unfortunately, many of the naturally occurring road building materials in the SADC region are disparagingly described as being “non-standard”, “marginal”, “low-cost”, or even “sub-standard”! This is because such materials are often unable to meet the required specifications which are usually based on European or North American practice that did not always allow for local conditions. However, there are many examples of naturally occurring materials, such as laterite and calcrete, that have performed satisfactorily despite being “sub-standard” with respect to their grading, plasticity or strength. Where failures have occurred, investigations have generally shown that poor-quality construction or drainage problems were the cause rather than the materials themselves.

The use of local materials requires not only a sound knowledge of their properties and behaviour but also the traffic loading, physical environment, and their interactions. In addition, it will require the use of appropriate pavement design methods and the application of appropriate design standards and materials specifications coupled with construction quality that complies with the required standards and specifications.

Box 5. 1 - The challenge of using natural gravels

- Because of their mode of formation, involving intensive processes of weathering, many road building materials in the SADC region tend to be highly variable and moisture sensitive. This requires the use of appropriate construction techniques and provision of adequate internal and external drainage.
- Standard methods of test which, for the most part, have evolved as a result of experience of soils in temperate zones, do not always give a true assessment of the performance of locally available materials when used in road construction.
- Conventional specifications apply to “ideal” materials and often preclude the use of many naturally occurring materials (laterites, calcretes, etc.) despite their good performance in service.

5.1.3 Surfacing

In situations of rapidly dwindling sources of gravel for maintaining un-surfaced roads, the bituminous sealing of a gravel offers numerous technical, economic and environmental advantages and, in many cases, is unavoidable. However, because of the relatively low levels of traffic carried, there is need for providing a durable surfacing at the lowest possible life cycle cost. Unfortunately, current specifications for traditional bituminous surfacings are demanding and exclude the use of local materials that could be suitable.

Providing a surfacing for a gravel road calls for the innovative use of local materials which may often be of a non-standard nature in situations where the use of conventional materials would be prohibitively expensive. Fortunately, in addition to the traditional chip seal or surface treatment, there are a number of alternatives which, although not yet widely used, can provide eminently cost-effective solutions.

5.1.4 Purpose and Scope of Chapter

The main purpose of this chapter is to provide a generic guide to the design of low-volume sealed road pavements using locally occurring materials to the maximum extent possible. This is based on research work and developments that have taken place in the SADC region with respect to the emergence of more appropriate design methods, specifications and test methods. The principal aim of this approach is to maximize implementation of previous research which exists in a disparate fashion and has not been adequately synthesized and packaged in an easily retrievable format for dissemination and implementation.

5.2 Pavements, Materials and Surfacing Terminology

5.2.1 Components

A road pavement typically consists of the following three primary components:

- surfacing
- pavement structure (base and subbase)
- subgrade

A typical LVSR pavement structure consists of a thin bituminous surfacing underlain by one or more layers of natural gravel.

Surfacing

The surfacing is the uppermost layer of the pavement and forms an interface with traffic and the environment. It normally consists of some kind of non-structural, impermeable bituminous surface treatment or a structural layer of premixed bituminous material (asphaltic concrete).

Base

The base is the main load bearing and load-spreading layer of the pavement and normally consists of natural gravel, gravelly soils, decomposed rock, sands and sand-clays. The weaker materials are often stabilized with cement, lime or bitumen. On relatively highly trafficked roads, asphalt concrete and crushed stone may also be used.

Subbase

The subbase is the secondary load-spreading layer underlying the base and normally consists of a material of lower quality than that used in the base. This layer protects the subgrade and, importantly, acts as a construction platform as well as providing a stiff platform against which the base can be adequately compacted.

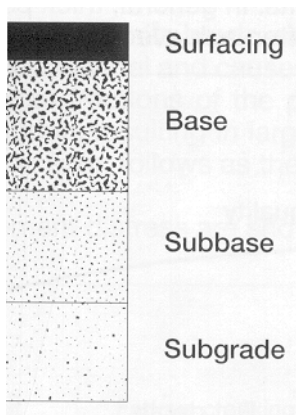
Subgrade

The subgrade is the upper layer of the natural soil that supports the pavement structure. It may be undisturbed local material or soil imported from elsewhere and placed as fill. In either case, it is compacted during construction to give added strength. The ultimate strength characteristics of the subgrade dictate the type of pavement structure required, in terms of layer thickness and material quality, to spread the applied surface load to a magnitude that can be supported without unacceptable permanent deformation by traffic or the environment.

Carriageway

The carriageway is that section of the roadway which is normally reserved for use by vehicular traffic. In many SADC countries such traffic may be both motorised and non-motorised.

Typical pavement structure.



The shoulders provide a number of functions including lateral support for the pavement structure and accommodation for stopped vehicles. The shoulders may be sealed or unsealed, the implications of which are discussed further in Section 5.4.3.

Each of the components of the pavement structure form part of a typical road cross-section as shown in Figure 5.1.

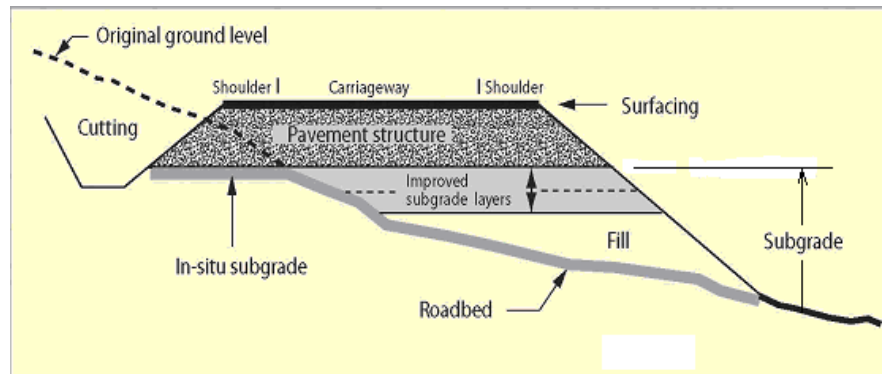


Figure 5.1 – Cross-section of a typical road pavement

The design of a LVSR may require a different approach to each of the pavement parameters compared with conventional design.

5.2.2 Requirements of a Pavement

A pavement must be designed to meet both functional and structural requirements. Functionally, it should serve traffic safely, comfortably and efficiently at minimum or “reasonable” cost. Structurally, it is a load bearing structure that is required to perform under the prevailing traffic and environmental conditions with minimum maintenance.

The pavement structure transfers the wheel loads from the surface to the underlying subgrade. As shown in Figure 5.2, the wheel load or pressure at the surface is effectively reduced within the pavement structure by being spread over a wide area of subgrade. The strength characteristics of the roadbed soil dictate the type of pavement structure required to spread the applied load and to reduce it to a magnitude that can be supported by the subgrade.

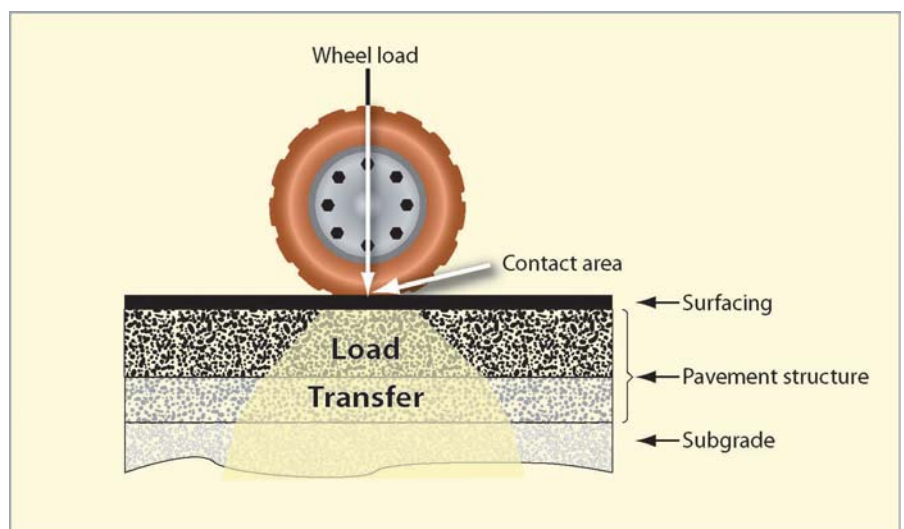


Figure 5.2 – Spread of wheel load through pavement structure

5.2.3 Performance

Pavements deteriorate gradually with time for a number of reasons, the two most important being:

- environmental effects
- traffic loading, comprising effects caused by wheel loads, and tyre pressures, and dependent on the stresses and the number of times they are applied

These factors have the effect of reducing the riding quality of the pavement as manifested by obvious visible features such as surface roughness, rutting and cracking in the manner illustrated in Figure 5.3.

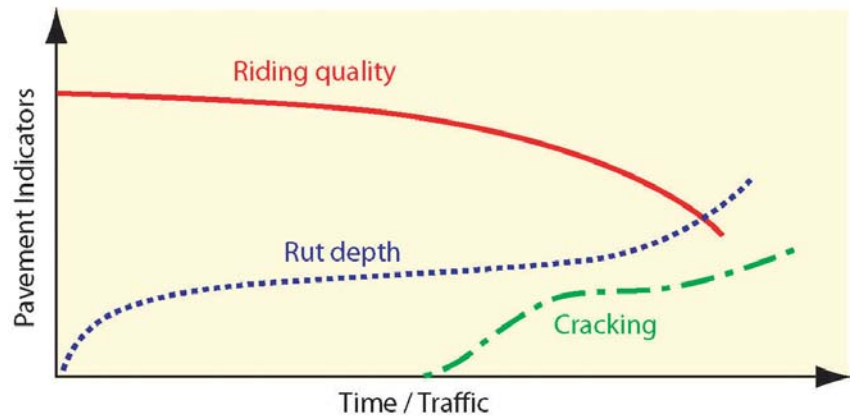


Figure 5.3 – Generalised pavement behaviour characteristics and indicators

Ultimately, the challenge of good pavement design is to provide a pavement that 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 will be necessary to ensure that the assumptions of the design phase hold true over the design life.

Environmental Effects

Environmentally induced distress through climatic influences, including temperature and rainfall, play a particularly important role in the performance of low volume road pavements. For example, high temperature can accelerate hardening of binders in road surfacings through loss of volatiles and oxidation, resulting in their loss of flexibility and consequent raveling of the aggregate and brittle fracture of the layer.

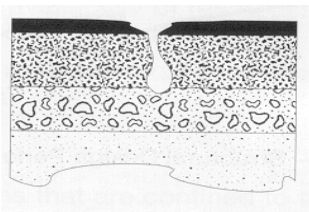
High rainfall can also result in a change in the moisture content of the pavement and subgrade materials which, under poor drainage conditions and moisture sensitive materials, can adversely affect the pavement structure and its performance under traffic (Section 5.3.2).

Carbonation of materials stabilised with lime and cement can also occur. This is a reaction between the stabilising agents and carbon dioxide in the air or under road pavements and leads to a weakened material (Section 5.3.3).

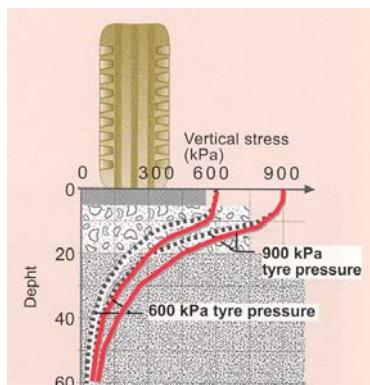
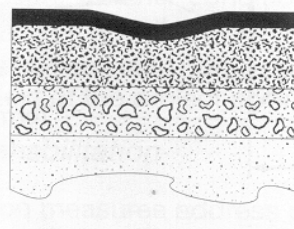
Damage can occur to road surfacings due to salt crystallisation. This effect is especially prevalent in dry climates and/or in circumstances where pavements have been constructed with materials or water with a relatively high salt content (e.g. minewaste). (Section 5.3.3).

On low-volume roads, benefits accruing from savings in vehicle operating costs will be small. As a result, in contrast to high-volume roads, lower levels of riding quality (roughness) can be tolerated over the life of the pavement.

Cracking of surfacing due to oxidation and consequent hardening of bituminous binder.



An example of rutting due to permanent deformation of the base layer caused by densification of material.



Stress distribution versus depth in a pavement subjected to wheel loading².

Hydrogenesis is the upward migration of water vapour in the road pavement which, under certain climatic conditions condenses under the road surfacing. The adverse affects of hydrogenesis on road pavements has not been fully quantified (Section 5.4.4).

Traffic Loading

Traffic loading is responsible for the development of ruts and for cracking that initiates within the pavement structure. Every vehicle using the road causes a small temporary deflection and a small permanent deformation in the pavement structure. The passage of many vehicles has a cumulative effect that gradually leads to significant permanent deformation and/or fatigue cracking. Overloaded vehicles, which are prevalent in the SADC region, cause a disproportionate amount of damage to the pavement structure, accelerating such deterioration.

On low-volume roads, the lack of traffic can also lead to raveling and surface cracking. This arises because the kneading action of traffic keeps bitumen “alive”, i.e. flexible.

It is noteworthy that most available manuals on pavement design tend to focus on load-associated factors whereas environmentally induced distress is often the major mechanism of distress for LVRs. The significance of these factors is discussed further in Section 5.4.3.

Tyre Contact Pressure

Tyre inflation pressure is an important parameter that can influence the performance of LVSRS. Prevailing tyre contact pressures have risen steadily over the years and are now considerably higher (of the order of 900 – 1000 kPa) than those used on key road performance experiments, such as the AASHO¹ Road Test (550 kPa), on which many empirical pavement design methods have been based.

The effect of repeated high tyre contact pressures is to generate high shear strains in the upper layers of pavements. This is not normally a problem where pavements have been well designed and constructed. However, in certain situations, e.g. steep grades or in poorly drained areas where moisture sensitive, low-strength materials are used, it can be problematic and can result in the cracking of surface layers, rutting from plastic deformation of one or more of the pavement layers causing shoving (shear failure) and breakdown of weak aggregates. In such situations, appropriate design and construction countermeasures should be observed.

5.2.4 Perceived Causes of Deterioration of LVSRS

Table 5.1 summarises the perceived deterioration effects for LVSRS emanating from workshops carried out in a number of SADC countries:

Table 5.1 - Deterioration effects on LVSRS

Parameter	Related Issues
Poor drainage	<ul style="list-style-type: none"> • water ingress to pavement structure • inadequate maintenance of drainage structures • poor roadside drainage/flood water scour • poor geometric design
Inadequate maintenance	<ul style="list-style-type: none"> • poor/lack of/insufficient maintenance • poor maintenance techniques • integrity of seal/delayed reseal/unsealed cracks

Overloading	<ul style="list-style-type: none"> • unexpected heavy loads after design • very high tyre contact pressures sometimes associated with weakening of upper base layers due to crushing or carbonation
Quality of construction	<ul style="list-style-type: none"> • inadequate/poor compaction • poor workmanship/supervision/construction standards • inadequate use of appropriate plant • poor mixing of materials/permeable pavements
Materials quality	<ul style="list-style-type: none"> • inadequate classification of soils • non-availability of good natural gravels/poor subgrade soils • salt damage • low quality of surfacings • sodic, dispersive and other problem soils
Environmental extremes	<ul style="list-style-type: none"> • climatic (temperature and weather) extremes • erosion of shoulders and side slopes
Design	<ul style="list-style-type: none"> • inadequate pavement design/design specifications • poor shoulder design/lack of sealed shoulders • flat terrain/low embankments/inadequate camber • increased generated traffic

The above perceived causes of deterioration of LVSRs are indicative of the range of important issues that should be addressed when considering the pavement, materials and surfacing aspects of such roads (dealt with in this chapter) as well as other aspects pertaining to construction and maintenance (dealt with in Chapters 6 and 7 respectively).

5.2.5 Terminology

Materials

Naturally occurring materials: These include natural soils, gravel-soil mixtures and gravels. Little or no processing is implied other than, possibly, loosening the in situ material by ripping and breaking down (usually with a grid roller) or removing oversize particles. Such materials cost, typically, about 25% of that of crushed stone. They may be used in their natural state or modified with small amounts of lime, bitumen or cement. Crushing may occasionally be required.

Standard/traditional material: These are defined as those materials which meet traditional specifications such as those of the American Association of State Highway and Transportation Officials (AASHTO). Such materials are tolerant of construction mishandling and adverse environmental conditions and will probably perform well in most cases. However, when used as specified, their use is often excessively conservative for the level of performance required in LVSRs.

An essential feature of most traditional specifications for standard materials is a requirement for strict compliance with limitations on particle size distribution (grading), plasticity index and aggregate strength. This is to avoid the use of any materials in pavement layers that are susceptible to the weakening effects of water and frost. Crushed rock and river-washed and fluvio-glacial gravels are thus the predominant materials used for building roads in temperate climates. The export of these practices to tropical and subtropical regions has meant that the potential of natural gravels, especially in drier areas of such regions, have often been neglected.



As-dug, nodular laterite gravel used in LVSR construction.



Crushed limestone is a typical "standard" material that is produced by crushing of blasted, massive rock to a defined grading.



Laterite is a typical example of a “non-standard” material that has been successfully used in LVSR construction despite its non-compliance with traditional strength and plasticity requirements.



A typical surface treatment operation – spraying a thin layer of bitumen onto a road surface prior to the application of a layer (s) of aggregate.

Non-standard/non-traditional materials: These comprise any material that is not wholly in compliance with the specifications used in a country or region for a standard or traditional material, for example, grading or PI. Nonetheless, it has become increasingly recognized worldwide that, under favourable circumstances, many such materials can and, indeed, have been used successfully. However, this requires an in-depth knowledge and experience of the properties of such materials and the conditions necessary for successful performance – requirements which have been facilitated by the extensive research work undertaken in the SADC region in the past 20 – 30 years.

It should be noted that the concept of “marginal” in relation to materials is specific to a particular time and place associated with our level of understanding of the behaviour of the material and knowledge of how to use it. For example, forty or fifty years ago, gravel was considered a non-standard material because crushed stone, the “standard” material, was used in the construction of Macadam and Telford pavements.

Surfacing

A number of different terms are used to describe a road surfacing which, as described in Section 5.2.1, normally consists either of some kind of non-structural bituminous surface treatment or a structural layer of premixed bituminous material. Typical terms include:

- surface treatment
- surface dressing
- chip and spray
- chip seal
- sprayed seal
- asphaltic concrete

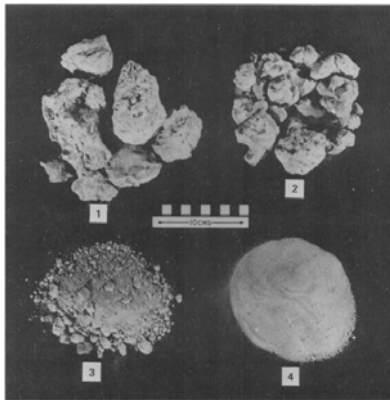
The above terms all essentially describe a similar product in that, in the construction of these seals, a thin layer of bitumen is sprayed onto the existing road surface (base or existing seal) and one or more layers of aggregate or sand are applied.

5.3 Materials

5.3.1 Formation and Classification

In contrast to the abundant deposits of clean durable, fluvioglacial gravels such as those used over much of Europe and the USA, the materials available for pavement construction in southern Africa are mostly derived from considerable depths of weathering and pedogenesis³. The materials are therefore mostly residual weathered igneous rocks (e.g. basalt, dolerite and granite), metamorphic rocks (e.g. gneiss and quartzite) and sedimentary rocks (e.g. shale and mud-rocks) and pedogenic materials (e.g. laterite, calcrete and ferricrete). These pavement materials are generally weaker than those of northern Europe and North America but road subgrades, other than in localized problem areas, e.g. “black cotton” soils or collapsible sands, tend to be generally stronger.

A simplified view of the formation of soils and rocks that form the backbone of road construction materials in the region is given in Figure 5.4. The manner in which such materials differ from conventional road building materials is presented in Table 5.2.



Four types of calcrete found in some SADC countries: (1) Boulder, (2) Nodular, (3) Powder, (4) Calcified Sand.

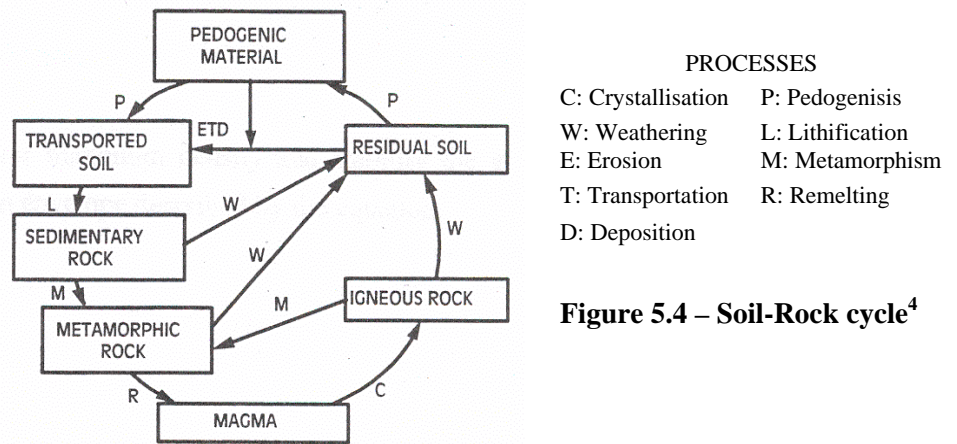


Figure 5.4 – Soil-Rock cycle⁴

Table 5.2 – Differences between conventional and pedogenic materials³

Property	Conventional (crushed rock base, river gravels, glacial outwash)	Pedogenic (laterites, calcretes, ferricretes, silcrettes)
Climate	Temperate to cold	Arid, tropical, warm temperate
Composition	Natural or crushed	Varies from rock to clay
Aggregate	Solid, strong rock	Sometimes porous, weakly cemented fines
Clay minerals	Mostly illite or montmorillonite	Wide variety, e.g. halloysite, attapulgite
Cement/bonding agent	None (usually)	Iron oxides, aluminium hydroxide, calcium carbonate, etc
Chemical reactivity	Inert	Reactive
Grading	Stable	Sensitivity to drying and working
Solubility	Insoluble	May be soluble
Weathering	Weathering or stable	Forming or weathering
Consistency limits	Stable	Sensitive to drying and mixing
Salinity	Non-saline	May be saline
Self-stabilisation	Non-self stabilising	May be self-stabilising
Variability	Homogeneous	Extremely variable

Soils and granular materials in the SADC region are inherently variable in terms of their engineering properties such as plasticity, grading and strength. When considering their appropriate selection for LVSRs, it is important to consider how the compacted material will interact with the “road environment”, i.e. moisture susceptibility, swell and collapse characteristics, particle degradation, durability, etc. Specialist testing may be required with basic rocks, pedocretes (calcrete, silcrete, etc) and various weathered materials.

Weinert’s N-Value

The Weinert N-value is calculated from climatic data as follows:

$$N = \frac{12 \cdot E_j}{P_a}$$

Where E_j = evaporation during hottest month (January)
 P_a = annual precipitation

The road-making materials commonly used in the construction of LVSRs in southern Africa can mostly be classified as crushed or natural, residual or transported gravels and soils derived from the following main groups⁵:

- basic crystalline (e.g. dolerite, andesite, basalt)
- acid crystalline (e.g. granite, gneiss)
- high silica rocks (e.g. quartzite, hornfels, chert)
- arenaceous rocks (e.g. sandstone, conglomerate)
- argillaceous (e.g. mudstone, shale, slate, schist)
- carbonate rocks (e.g. limestone, dolomite)
- diamictites (e.g. tillite)
- pedocretes (e.g. calcrete, laterite, ferricrete, silcrete)

Each group has a characteristic range of properties and potential problems which should be taken into account by test methods and specifications. For example, a PI of up to 15 may be allowable in an unstabilised calcrete or laterite gravel base whereas a value of more than 1 or 2 may be problematic in a base composed of a basic crystalline rock, even if stabilised⁶.

Ultimately, the challenge of selecting pavement materials for low volume roads in southern Africa is essentially one of quantifying the risk associated with departing from the use of traditional, high quality materials. For such materials, specifications rely heavily on experience with traditional “ideal” materials from more temperate climates which, as emphasized previously in this chapter, do not necessarily apply to local materials. Fortunately, the extensive research carried out in the region over the past two decades has gone a long way in quantifying the conditions under which local materials can be used with confidence.

Influence of Climate

The southern African climate exerts a significant influence on the properties of natural road building materials as well as on the subsequent performance of roads that utilize such materials. In this regard, the various climatic zones in the SADC region may be characterized by the Weinert N-Value which correlates broadly with mean annual rainfall as shown in Table 5.3⁷.

Table 5.3 - Climatic zones: Approximate mean annual rainfall and N-values

Climatic Zone	Arid	Semi-arid	Sub-humid	Humid
Weinert N-Value	> 10	5 - 10	2 - 5	< 2
Mean Annual Rainfall (mm)	< 250	250 - 500	500 - 800	> 800

The climatic N-values for Southern Africa are also significant in that they provide some indication of the predominant mode of rock weathering and the related engineering properties of the resulting products. The values $N = 2$, $N = 5$ and $N = 10$ are of particular significance and their contours are shown in Figure 5.5.

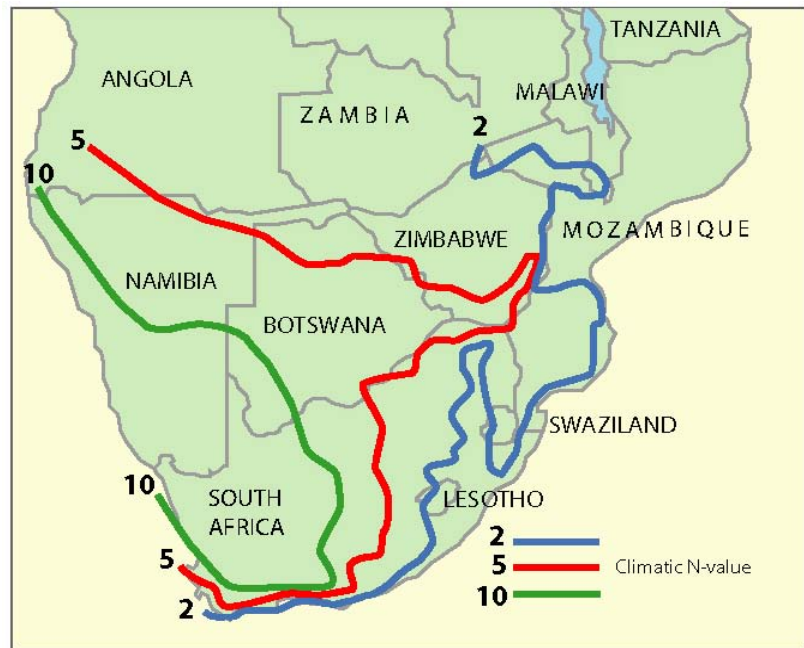


Figure 5.5 – Climatic N-value map of southern Africa⁷
(does not currently cover the entire SADC region)

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

In areas where N-values are greater than 5, mechanical disintegration – the physical breakdown of rock – tends to predominate. In areas where N-values are less than 5, chemical decomposition – the chemical alteration of a rock – predominates. This can lead to the transformation of certain minerals into some type of clay. From these divisions, very broad but important generalisations can be made about the soil profile, as indicated in Table 5.4.

Table 5.4 – Characteristics of materials in relation to climate (N-value)⁷

N-value	Material Characteristics	Significance of material properties
N < 2	Rocks are particularly deeply weathered, often to depths of several metres, and decomposition is pronounced. Smectite minerals are the principal products of the decomposition of basic crystalline rocks.	Materials tend to have relatively high plasticity and are moisture sensitive. Basic igneous rocks are often not durable and prone to degradation in service. Careful attention to internal and external drainage of pavement.
N = 2- 5	Similar conditions as above but thickness of residual soil cover gradually decreases as contour of N=5 is approached.	
N =5- 10	Thickness of residual soil cover gradually decreases even further than above. Disintegration is the dominant mode of weathering.	
N > 10	All rock types weather by mechanical disintegration alone, and the shallow residual soils are commonly granular and gravelly.	Materials have relatively low plasticity and are not particularly sensitive to moisture.

5.3.2 Characteristics of Pavement Materials

Materials used in pavement layers can be classified into four categories as follows:

- Unbound granular - 1. Unprocessed (naturally occurring, as dug).
 - 2. Processed (screened, mechanically stabilized).
 - 3. Highly processed (crushed to specified grading).
- Bound granular - 4. Cement, lime, bitumen or pozzolanic material.

The material types described above derive their strength from a combination of the following intrinsic properties⁸:

- inter-particle friction
- cohesive effects from fine particles
- soil suction forces
- physio-chemical (stabilization) forces

The relative dependence of a material, and the influence of moisture, on each of the above components of shear strength will significantly influence the manner in which they can be incorporated within a pavement. For example, unbound/unprocessed materials (e.g. calcrete or ferricrete) are highly dependent on suction and cohesion forces for development of shear resistance which will only be generated at relatively low moisture contents. Special measures would therefore have to be taken to ensure that moisture ingress into the pavement is prevented. Otherwise suction forces and shear strength will be reduced as illustrated (notionally) in Figure 5.6, which could result in failures.

Box 5.2 – Soil suction and its contribution to shear strength – basic concepts

Soil suction: As the grain size of a fine-grained material decreases, the total exposed surface area becomes very large in comparison with the volume of voids within it. Under these circumstances, molecular forces, which are only effective for very short distances from the surface, begin to play an increasingly important role. They are essentially attractive in nature and can provide significant additional strength. The forces are equivalent to, and can be described by, a reduction in pressure in the “pores” or voids in the material. This is referred to as *suction*.

The magnitude of soil suction can be very much greater than normal atmospheric pressure and therefore the effective pressure can become highly negative. Its value depends not only on the amount of fluid in the pores (voids) but also on its nature, i.e. dissolved salts. As the pores fill with water, the magnitude of the suction decreases rapidly.

Soil strength and stiffness: The shear strength of granular materials and normally consolidated fine-grained soils is described by the well known effective stress equation:

$$\text{Shear strength} = (\text{cohesion}) + [(\text{normal stress}) - (\text{pore pressure})] \tan (\text{angle of internal friction})$$

The strength and stiffness of a pavement layer are reduced if pore pressure is increased (at high moisture contents) and, conversely, are increased when pore water is decreased (at low moisture contents). When the pore pressure equals the total stress, internal friction becomes negligible and the shear strength is equal to the cohesion.

Thus, it is pore water pressure or suction of the water in the pavement, rather than the amount of water that affects pavement behaviour. Two soils of different texture may have similar strength and stiffness, even though their moisture contents are quite different.

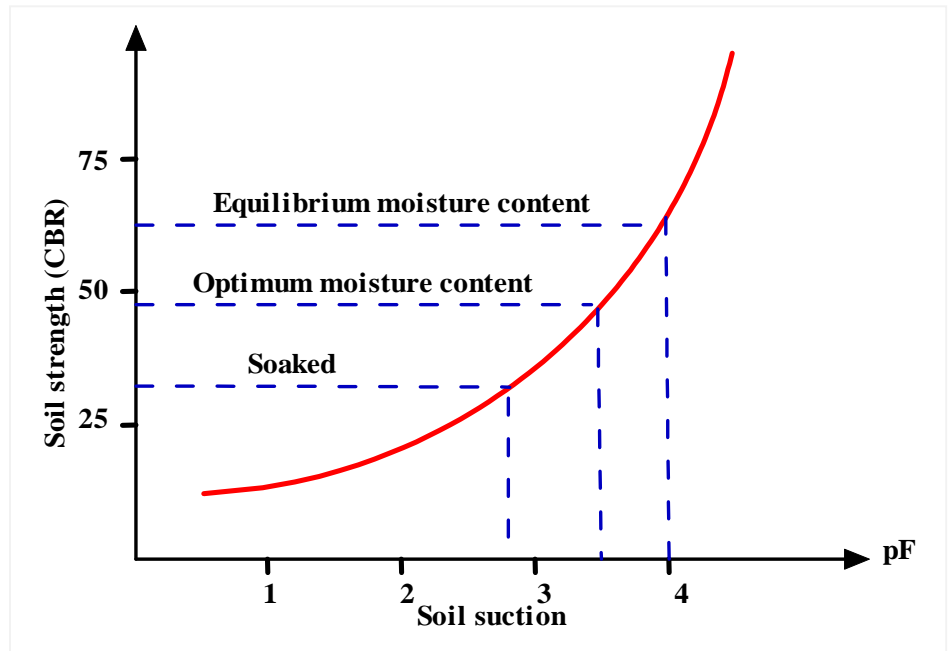


Figure 5.6 – Illustrative soil strength/suction relationship

Problem Soils and Materials

By virtue of their unfavourable properties, a number of soils and materials fall into the “Problem soils and materials” category and, when encountered, would normally require special treatment before acceptance in the pavement foundation. This category of soils and materials includes:

- low-strength soils
- expansive clays (“black cotton” soil)
- collapsible sands
- dispersive soils
- organic Soils
- saline soils or presence of saline water
- weathered materials

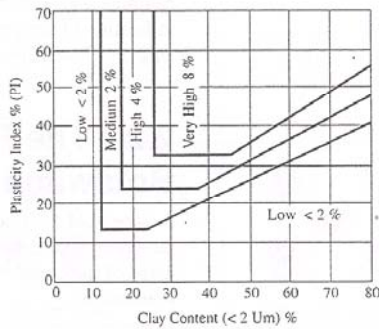
The characteristics, investigation, testing and design counter-measures to deal with problem soils are well covered in the literature and are not dealt with in depth in this Guideline. In dealing with such materials, a careful balance has to be struck between the cost of the counter-measures and the benefits to be derived, bearing in mind the relatively small user benefits generated from LVSRs.

The main characteristics of typical problem soils found in the SADC region are highlighted below:

Low-strength soils: Soils with a soaked CBR of less than 3 per cent (< 2 per cent in dry climates) are described as Low-strength soils. Typical treatment measures for such soils include:

- removal and replacement with suitable material
- chemical or mechanical stabilization (see section 5.3.3)
- raising of vertical alignment to increase soil cover and thereby re-define the design depth within the pavement structure.

Qualitative measure of soil expansiveness (Modified van de Merwe Chart).



N.B - PI to be carried out on material passing the 0.425 mm sieve.



Typical longitudinal cracking and pavement deformation caused by large volumetric changes of an expansive soil subgrade.



Collapse settlement in excess of 150 mm after impact rolling.

Expansive soils: These clay soils exhibit particularly large volumetric changes (swell and shrinkage) following their variations in moisture contents. They shrink and crack when they dry out and swell when they get wet. The cracks allow water to penetrate deep into the soil, hence causing considerable expansion. This results in deformation and unevenness of the road surface, since the expansion and the subsequent heave are never uniform. Furthermore, these volume changes may produce lateral displacements (“creep”) of the expansive soil, if the side slopes are not gentle enough. When dry, some expansive soils present a sand-like texture and are prone to erosion to a much greater extent than that normally expected from their plasticity and clay content.

The chosen measures to minimize or eliminate the effects of expansive soils for LVSRs need to be economically realistic and proportionate to the risk of potential pavement damage and increased maintenance and user costs. Typical methods include:

- realignment, where possible
- excavation and replacement
- chemical treatment
- minimising moisture changes
 - wide (at least 2 m), sealed shoulders
 - avoidance of side drains
 - gentle sideslopes (1:6 or flatter)
 - minimum earthworks cover of 0.6 m



Expansive “black cotton” soil exhibiting wide-spaced shrinkage cracks.

Collapsible sands: These sandy soils occur mostly in the arid and semi-arid regions of southern Africa, particularly in the Kalahari Desert regions of western Botswana and eastern Namibia. They exhibit a weakly cemented soil fabric which, under certain circumstances, may be induced to rapid settlement. A characteristic of these soils is that they are all unsaturated, generally have a low dry density and a low clay content. At the in situ moisture content they can withstand relatively large imposed stresses well in excess of the overburden pressure with little or no settlement. However, without any change in the applied stress, but an increase in moisture content, additional settlement will occur as shown in Figure 5.7. The rate of settlement will depend on the permeability of the soil. There is no simple test to determine a collapsible soil. Useful indicators include density and grading of the soil and, more definitively, collapse potential tests. These indicators are shown in Table 5.5.

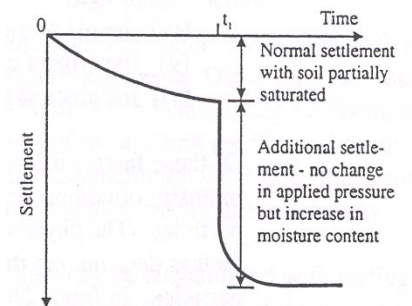


Figure 5.7- The basic concept of additional settlement due to collapse of soil fabric.⁹

Box 5.3 - Conditions to be satisfied before collapse settlement can occur:

- the soil must have a collapsible fabric
- it must be partially saturated
- the applied load must exceed the overburden pressure
- there must be an increase in moisture content after the load has been applied

Table 5.5 – Collapse potential indicators and severity of problem¹⁰

Property	Guide to Collapse Potential ^a	Collapse Potential (%)	Degree of Severity
Dry density (kg/m ³)	< 1600	0 – 1	No problem
% passing 2.0 mm and retained on 0.75 mm sieve	> 60%	2 – 5	Moderate trouble
% passing 0.075 mm sieve	< 20%	6 – 10	Trouble
Relative density	< 85%	11 – 20	Severe trouble
		> 20	Very severe trouble

a – See Botswana Road Design manual

Methods of dealing with collapsible soils include the following:

- Excavation of material to a specified depth below ground level and replacement in thin lifts (typically 200 mm).
- Ripping of the road bed, inundation with water and compaction with heavy vibrating rollers.
- Use of high energy impact compaction at in situ moisture content.

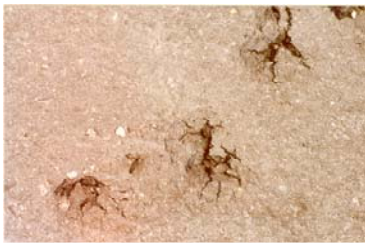
The above measures are all relatively expensive to accomplish and, in other than exceptional circumstances, are unlikely to be appropriate for application to LVSRs.

Dispersive soils: These soils, some of which are clayey gravels, are easily eroded in the presence of water – a property that makes them problematic where they occur in cut slopes and in drainage channels. They are generally found in areas where the climatic N-value is between 2 and 10. They have almost no resistance to erosion, are susceptible to pipe developments in earthworks, crack easily and have low shear strength. Their identification includes the use of a combination of indicator tests, observations of erosion patterns, soil colour, terrain features and vegetation.

The following measures are typically employed where dispersive soils are encountered:

- erosion protection in cut slopes and drainage channels
- modification with 2% to 3% lime

Saline soils or presence of saline water: The presence of soluble salts in pavement materials or subgrades can cause damage to the bituminous surfacings of LVSRs. This problem occurs mostly in the semi-arid regions of southern Africa where the dry climate, combined with presence of saline materials (often calcrete or minewaste) and/or saline ground or surface water, create conditions that are conducive to the occurrence of salt damage. Such damage occurs when the dissolved salts migrate to the road surface, mainly due to evaporation, become supersaturated and then crystallize with associated volume change. This creates pressures which can lift and physically degrade the bituminous surfacing and break the adhesion with the underlying pavement layer. Generally, the thinner the surfacing layer is, the more likely the damage, primes being the most susceptible and thick, impermeable seals the least susceptible.



Salt damage may appear in the form of “blistering”, “doming”, “heaving” and “fluffing” of the prime or surfacing.



An example of severe distress to a runway surfacing due to salt attack resulting in damage within two years of its construction.

It is quite feasible, and often cost-effective, to use saline materials in LVSR construction, rather than haul non-saline material great distances. However, this requires a sound knowledge of the project environment and the type of salts and salinity levels in the materials as a basis for designing and specifying appropriate preventative measures and monitoring of salt levels during and after construction.

Guidelines for the prevention and repair of salt damage to roads and runways have been developed based on research work carried out in the region and elsewhere^{11,12}. These guidelines provide guidance on methods of testing and measurement of salts as well as repair methods where damage has already occurred.

Weathered materials: Weathered materials, such as basic igneous rocks (e.g. basalt, dolerite), occur extensively in southern Africa and are commonly used in the construction of LVSRs, either in their natural (untreated) or chemically stabilised states. The properties of these materials are governed by their mineralogy and apparently sound rock containing secondary minerals liable to decomposition by weather or traffic must be avoided. Specialised testing may therefore be required to assess their long-term durability for which reference should be made to Draft TRH13: Cementitious stabilisers in road construction¹³.



Sample of weathered, decomposed basalt, showing altered clay minerals in rock vesicles and cavities.

Waste Materials

Numerous types of “waste” materials can be recycled into aggregates and additives for use in LVSRs. However, an imaginative approach is required to recognise their potential use – a use that would alleviate the need to open new gravel sources, thereby reducing the environmental impact of the provision of new, or upgrading/rehabilitation of existing infrastructure. The use of waste materials, where feasible, would also reduce the impacts associated with their stockpiling (e.g. dust from a dump).

Examples of waste materials that can be considered for use in LVSRs include:

- waste rock dumps at mines and quarries (base and surfacing aggregate)
- slags from metal processing (base course)
- crushed glass (surfacing aggregate)
- clinker ash (subbase and base course)
- fly-ash (mechanical stabilization agent on fines-deficient material)
- phosfogypsum (mechanical stabilization agent, subbase material)
- tyres (ground for bitumen rubber, chips for light-weight fill, complete for bank stabilization and slope-failure repairs)

Prior to use, materials should be subjected to a standard testing programme, as well as an environmental assessment to ensure that no significant environmental impacts occur as a result of the use of the material. Certain materials may also have relatively high soluble salt contents and additional tests should be carried out to ensure that their presence will not influence the performance of the surfacing.

Mechanical Stabilisation

The simplest, and often cheapest, form of stabilisation, as well as the easiest to construct, can be achieved by blending two natural materials, usually gravel with sand, to form a mechanically stable layer. This usually results in the following advantages:

- improved CBR
- lowering of PI
- lowering of OMC
- improved workability

The result of a laboratory investigation of the mechanical blending of a natural gravel (calcrete) with sand is shown in Figure 5.9. As is evident from the figure, the CBR of two distinct material types (A and B) increased significantly, by over 40 per cent and 25 percent respectively, with the addition of 20 – 30 per cent sand.

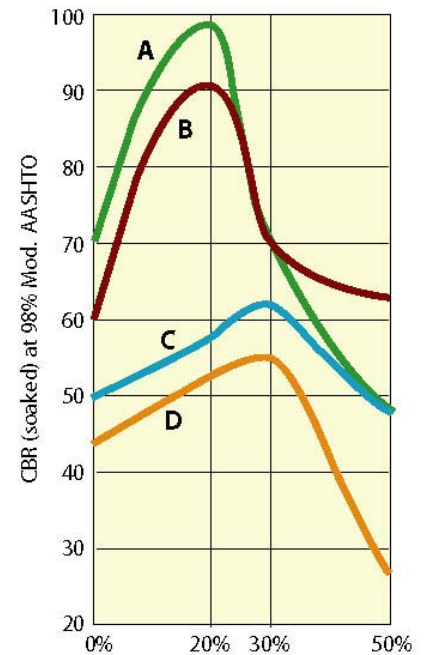
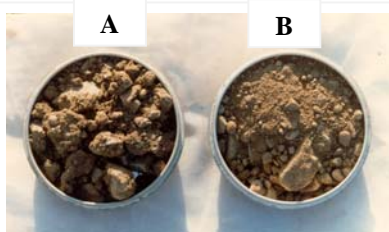


Figure 5.9 – Example of mechanical blending of calcrete with sand¹⁵.

In blending granular materials with finer-grained materials, care must be taken to ensure that the plasticity of the fines fraction is not increased to such a degree that there is a loss in stability.

Improved workability of clayey materials



A: Untreated - relatively unworkable.
B: 3 % lime-treated - more workable.

Chemical Stabilisation

The main objective of chemical stabilisation is to enhance the suitability for pavement construction of locally available natural gravels, thereby avoiding the need to import other materials. This can often lead to more cost-effective use of available materials with the following beneficial properties compared to the untreated parent material:

- increased strength or stability
- improved load-spreading capability
- increased resistance to erosion
- reduced sensitivity to moisture changes
- improved workability of clayey materials

As indicated in Figure 5.8, the choice of chemical stabiliser will depend on the material to be stabilised and the position in the road pavement it is to occupy. These stabilisers are generally applied at relatively low dosages, typically between of 3 and 6 per cent. However, if problems are to be avoided, they must be subjected to careful and well-controlled processing and construction.

Specifications for chemically treated materials vary in different parts of the world and for different road authorities. For southern African conditions, reference should be made to Draft TRH13.

Potential problems or pitfalls with these types of materials include:

- propensity to cracking through traffic loading or environmental conditions, particularly with cement treatment
- degradation of the cementing action due to carbonation, specifically for cement and lime treatment
- requirement for greater levels of skill and control during construction (compared with untreated materials) to achieve satisfactory materials

Box 5.4 - Effects of carbonation

Lime and, to a lesser degree, cement stabilised soils can lose strength through carbonation. This effect is particularly evident in lime stabilised fine-grained, relatively weak soils (especially calcrites). When used as base course material, prolonged exposure of these stabilised soils to the air before sealing can also result in a weak upper layer being produced prior to surfacing. Subsequent crushing of the aggregate as well as poor bonding between the surface and the base can occur, leading to pavement failure. Measures that ameliorate the effects of carbonation during the stabilisation process include:¹⁶

- immediate covering with the next layer of material
- immediate application of a bitumen prime coat
- full moist curing (with no drying of the surface)
- construction of layer with a sacrificial thickness to be bladed off.

Proprietary Chemicals: A variety of proprietary chemicals and road additives are sometimes used to improve the properties of natural gravels for use as pavement materials. However, their use is very project specific and they should be used with caution. There is relatively limited and well-documented experience of their successful use and well-controlled trials are required to confirm their suitability for use with specific materials. The more common chemicals include:

- wetting agents to improve compaction
- natural polymers (e.g. ligno sulphonates)
- synthetic polymer emulsions (e.g. acrylates)
- modified waxes
- sulphonated oils
- biological enzymes

5.3.4 Specifications

Specifications are meant to exclude most unsatisfactory materials for use in roads by placing limits on their various properties such as grading, plasticity and strength. The derivation of appropriate limits requires an intimate knowledge of local material performance in a specific environment (climate and drainage measures) and for specific traffic loading. The challenge is basically to relate the materials' physical properties with performance in a particular environment.

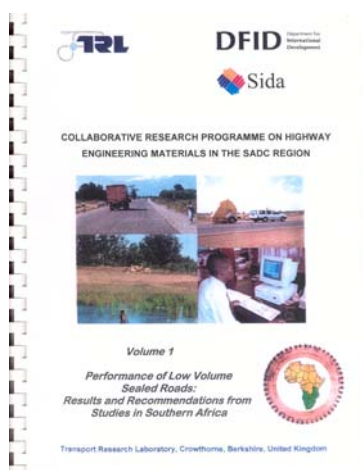
Until relatively recently, most of the specifications used in the SADC region tended to reflect temperate zone specifications emanating from Europe and North America. Typical conventional specifications rely heavily on experience and "ideal" materials having the following properties:

- restrictive grading requirements
- low plasticity (PI < 6)
- high road base strength (soaked CBR > 80 per cent at 98 per cent modified AASHTO compaction)

Inexperience tends to cultivate a rigid adherence to specifications.

Traditional specifications for base gravels typically specify a soaked CBR @ 98% modified AASHTO of $\geq 80\%$, PI of ≤ 6 and adherence to a tight grading envelope. However, research in the region has shown that when due consideration is given to factors such as traffic, subgrade strength, drainage, pavement cross-section, etc, substantial relaxations can be made on selection criteria with significant cost savings.

The art of the roads engineer consists, for a good part, in utilizing specifications that will make possible the use of materials he finds in the vicinity of the road works. Unfortunately, force of habit, inadequate specifications and lack of initiative have suppressed the use of local materials and innovative construction technologies.



Volume 1 of a five-volume series of reports on the outcome of the 4-year programme of research on highway engineering materials.

The above limits originate from situations very different to those prevailing in much of the SADC region in terms of material types, climate, traffic characteristics, standards, etc. and, when applied, would rule out many natural gravels available for use in LVSR construction. Standard specifications cannot address all possible variations in environmental conditions or cover all material types. Judicious interpretation of existing specifications and application of local knowledge can produce project specific and more appropriate specifications.

Box 5.5 – Transferability of materials specifications

Materials specifications are simply not always transferable from one region to another. What may be appropriate in one region, in relation to such factors as material type, climate and traffic loading, may well be quite inappropriate in another region where these factors may be quite different. In the final analysis, every material has its uses and limitations and must simply be matched to the traffic, climatic and other conditions influencing its performance. *Costly failures in some cases as well as over-conservative, uneconomic designs in others can result when conventional materials specifications are rigidly applied in the region.*

It is also important to bear in mind that specifications are tied directly to the test methods used in carrying out research work. For example, most of the research work carried out in the region on pedocretes is tied to ASTM-type methods. It would therefore be inappropriate and risky to apply BS standards to evaluate pedocretes unless suitable compensatory adjustments are made to the test results.

The successful use of non-standard materials is largely dependent on the availability of a local specification developed for specific operating environments. The formulation of these “customized” material specifications has enabled the use of many materials that otherwise would be rejected by the use of traditional specifications.

Based on a 4-year programme of research in highway engineering materials¹⁷, specifications have been developed for a variety of commonly occurring natural gravels which recognize their geological origin as well as climatic and traffic loading factors relevant to the region. The research focused on how existing sealed road pavements performed with time and traffic in different climatic conditions and found that:

- The minimum standard of 80 per cent soaked CBR for natural gravel bases is inappropriately high for many LVSRs. *New limits are recommended depending on traffic, materials and climate.*
- The grading envelopes for natural gravel bases are too narrow. *Alternative (wider) envelopes are recommended for relatively lightly trafficked roads.*
- Traffic below 500,000 cumulative ESA was not a significant factor in pavement deterioration. Many road sections performed well even when subjected to a high degree of overloading and with PIs up to 18. *New limits for PI have been recommended.*
- Drainage was a significant factor on performance, even in dry areas. *A minimum crown height of 0.75 m above the invert level of the side drain is recommended.*

As a result of the SADC regional research work, revised specifications have been derived for the major groups of natural gravel roadbase materials found in the region (quartzitic gravels, weathered rocks, lateritic gravels, calcareous gravels and sand) for a range of traffic levels up to 500,000 ESA and subgrade types not currently catered for in existing guides. Thus, they should be incorporated in country documents and considered for use in the design of LVSRs.

5.3.5 Prospecting

Large quantities of natural gravel are required for constructing and maintaining LVSRs. It is therefore essential that optimum use is made of all materials available at the lowest possible cost. Very often, gravels occur as relatively small localized deposits scattered around the landscape, and are usually overlain by a cover of soil and vegetation which makes it very difficult to find them. Consequently, modern exploration techniques must be employed to ensure that available materials are located as efficiently as possible, instead of the “haphazard random” methods often used.

The art of prospecting involves looking for clues as to the occurrence of useful materials and then digging to see what may be there. Learning to identify features that indicate the presence of gravel from interpretation of maps and other information is a key activity in prospecting. However, the most important parts are the desk study followed by the field survey and pit evaluation. Information about gravels in the landscape typically comes from four main sources, viz:

- geological information from geological maps and reports
- soils information from agricultural soils maps and reports
- botanical indicators
- landscape information from topographic maps, aerial photos and satellite images
- other local information

The above sources of information are analysed all together to assess the likelihood that gravel may occur at a particular place. A typical flow diagram for materials prospecting is shown in Figure 5.11.

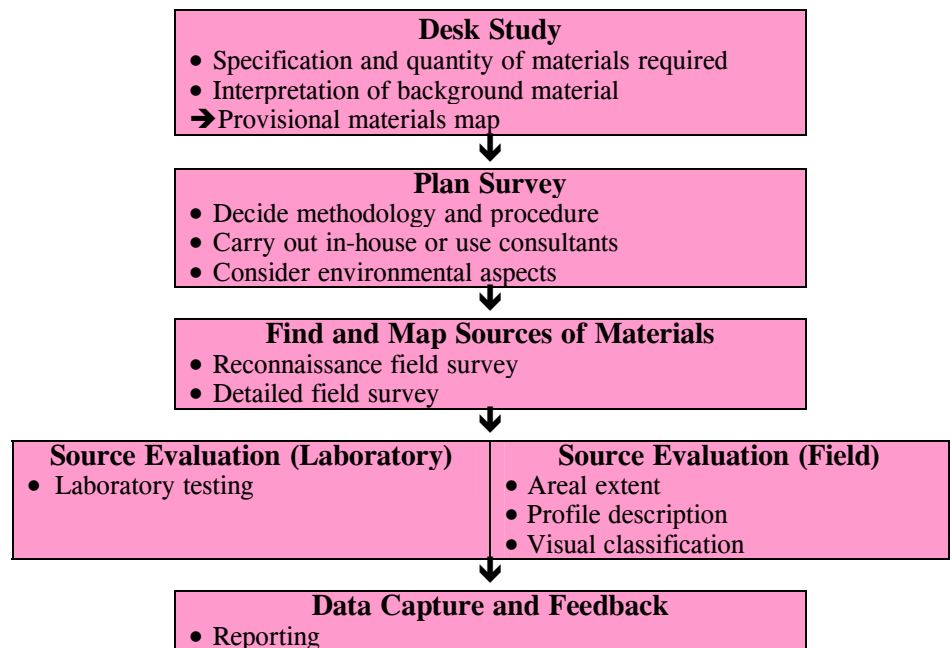


Figure 5.10 – Flow diagram stages for material prospecting ²⁶



Proper planning is essential for a successful materials prospecting survey.

Experience has shown that a significant amount of material used is often located during construction when excavation equipment is more readily available than in the pre-construction, site investigation phase.



Aerial photographs and satellite images are valuable sources of information which can be used for materials location.

5.3.6 Testing

Standards

Materials testing is normally prescribed in standards put out by various countries, of which the BS (British), ASTM (American) and TMH (South African), are in common use in the region. Unfortunately these methods differ in many respects with regard to the actual test procedure and the method of testing. For example, authorities employing a BS Liquid Limit device will obtain a Plasticity Index (PI) that is, on average, 4 units higher than those using an ASTM Liquid Limit device¹⁸. It is important, therefore, not to mix testing standards because the differences in test procedure alone are sufficient to explain the difference in material quality apparently tolerable by pavements in different SADC countries⁶. Ideally, materials testing standards in the SADC region should be standardized so as to facilitate intra-regional research efforts, technology transfer and reporting.

Tests

Materials testing is carried out to assess the various properties of road construction materials as an indicator of their likely performance in service. A wide variety of laboratory tests is available for this purpose and includes:

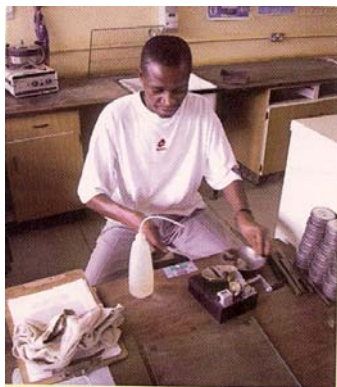
- classification
- moisture content
- density
- strength
- stiffness
- durability
- chemical
- special

In addition, there are various field tests which may be used to assess the properties of the placed material such as:

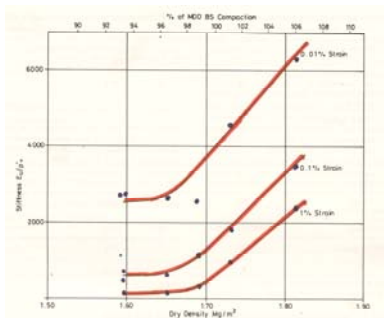
- in situ strength (in situ CBR test, Dynamic Cone Penetrometer or Clegg Hammer)
- stiffness (deflection testing, e.g. Falling Weight Deflectometer, Benkelman Beam, Plate Bearing)
- permeability (water permeability test)

The two critical properties which are known to exert a major control on the performance of natural gravels in road construction are *strength and stiffness*. They are both dependent on moisture content and density and can be affected by the wetting and drying history or the compaction process to which the material has been subjected in reaching the density involved. Ideally, therefore, *for pavement design purposes, the strength and stiffness properties of natural gravels should be assessed from samples made up at the densities and critical moisture contents likely to occur in the road and not at pre-determined values*. A number of tests are used for assessing the suitability of natural gravels for use in road pavements. The more common ones are discussed below:

California Bearing Ratio (CBR): One of the most important strength tests in common use is the CBR test, an arbitrary test that was originally devised as a method of comparing subgrade soils with crushed rock. Because of its ease of use in comparison with the more complex methods of strength measurement, it is widely used in many empirical methods of pavement design. However, its use as a primary means of selecting natural gravels for LVSRs has long been questioned.



Liquid Limit device used in the determination of the plasticity index of a soil.



Stiffness-dry density relationship, lateritic gravel (Kenya)¹⁹.

Strength assessment of pavement materials

There is a tendency to attach a strength rating to a material without realizing that this is of little value if divorced from an appreciation of the probable in-service moisture content and density condition. Irrespective of what strength criteria are advanced, they will be abused if no attempt is made to test for strength at moisture content and density conditions in the region of those expected in the field.

The **Resilient Modulus** of a soil is a measure of its resistance to displacement, i.e. its susceptibility to rutting under a wheel load.

The **Elastic Stiffness** of a soil reflects its load spreading characteristics. Thus, a high *E* value implies good load-spreading ability while a low *E* value implies that loads will be concentrated on the subgrade and high flexural strains will occur.

Box 5.6 – How appropriate is the CBR test as a means of selecting natural gravels for use in LVSR pavements?

- The CBR test is an empirical test that was developed using empirical observations of satisfactory pavements over a number of subgrades with the objective of establishing subgrade bearing capacity, *not the adequacy of the pavement material*.
- The test has a poor reproducibility with an overall coefficient of variation of the order of 20 per cent²⁰. This characteristic makes the interpretation of test results, especially for inherently variable natural gravels, very imprecise. For example, for a true mean value of 80, the CBR can range from 48 to 112, range that can lead to vastly differing interpretations of the suitability of the soil for use as a pavement material.
- The test does not measure any of the fundamental engineering properties of soil that critically influence its performance, such as elastic stiffness (*E_r*) and resistance to permanent deformation or resilient modulus (*M_r*). As indicated in Figure 5.9, materials with the same CBR could have very different elastic stiffnesses and, as a result, in similar service conditions could perform quite differently because of their different load-spreading ability.

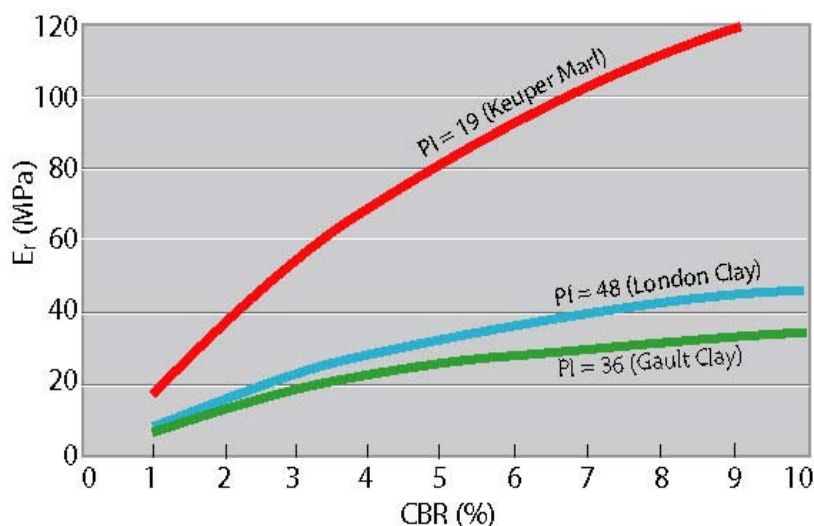


Figure 5.11 - Relationship between elastic stiffness and CBR for a stress pulse of 40 kPa²¹

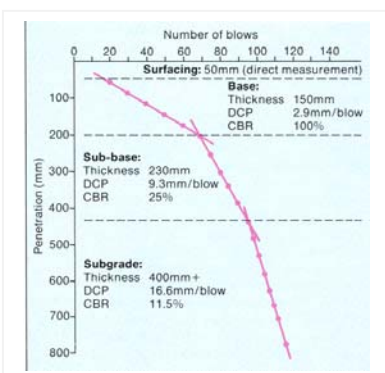
In view of the above, it may be concluded that if the CBR test is used to justify the use of a material which departs substantially from the traditional grading and plasticity limits (as is the case with most pedogenic materials) then, on its own, it may well not be appropriate.

Whilst it is not suggested that the CBR test be discarded, it is recommended that other tests, such as the Texas Triaxial and K-Mould tests, could be very useful supplementary tests for selecting natural gravels for use in LVSR pavements. These tests can provide information that is often more discriminating as regards material performance than the CBR test²².

Texas Triaxial Test: An alternative to the CBR test, which is used in Texas, Australia and Zimbabwe, is the *Texas Triaxial* test. This test is based essentially on the relative stiffness of the material in the form of stress strain characteristics and measures the fundamental strength parameters – cohesion and angle of internal friction. It is less empirical than the CBR test in that more of the coarse fractions of gravels can be subjected to test. Moreover, in the test the sample is tested as a whole, and the results are less prone to specific conditions under the CBR plunger.



The DCP test in progress.



Typical DCP test result

Of particular importance is the ability of the Texas Triaxial test to assess the potential benefits gained by allowing the moisture content at compaction (optimum moisture content) to decrease to the predicted equilibrium value in the pavement. This makes the test particularly suitable for predicting the sensitivity of the strength of the material to changes of moisture, thereby allowing the material strength to be assessed at in-service moisture/density conditions. The test is somewhat more time consuming to carry out than the CBR test.

K-Mould Test: The K-Mould test is a laboratory soil strength test that was developed in the USA in the late 1970s²³ because of the need for a rapid, direct measure of soil strength under conditions that are reasonably representative of those anticipated in the field. The test is essentially a compression test in which a cylindrical soil specimen is constrained in an axially rigid but laterally flexing steel mould such that, as axial compression occurs, the lateral expansion of the soil is met with a constantly increasing lateral resistance, much as occurs in field loading conditions.

Research carried out at the CSIR shows that the K-Mould test is able to determine the elastic moduli of untreated road building materials with relative simplicity and a great degree of accuracy in a single loading cycle²⁴. Thus, although not yet commonly used, the K-test may provide a useful means of determining the elastic stiffness of natural gravels where required in contrast to the more complex, time-consuming and costly repeated load triaxial tests that can hardly be justified for LVSRs.

Dynamic Cone Penetrometer (DCP): The DCP test is particularly worthy of mention because LVSRs are very often constructed on existing gravel roads with necessary improvements in vertical and horizontal alignment. The use of the DCP can provide a rapid, effective, low cost, non-destructive method of estimating the strength of in situ materials. Methods have been developed in the region for strengthening existing gravel roads to provide LVSRs designed on the basis of the in situ DCP-CBR and design traffic level²⁵. This information can then be used with existing catalogue pavement structures to provide the most economical pavement structure for a particular set of conditions.

5.3.7 Materials Inventory

As part of the materials prospecting process, considerable benefits can be realised through the development and use of materials inventories, particularly at the planning and design stages of LVSR projects. The common uses of such inventories are summarized in Table 5.6.

Table 5.6 – Common uses of materials inventories

Common Use	Related Factors
Record keeping	<ul style="list-style-type: none"> Central record keeping Source of readily available/ easily retrievable information Reference for future development
Reducing costs	<ul style="list-style-type: none"> Reduced consultancy costs
Materials management	<ul style="list-style-type: none"> Rapid/easier materials location and identification Input into National Engineering Geological maps
Link to other management systems	<ul style="list-style-type: none"> Development of pavement performance relationships for input into pavement management systems Interface with existing laboratory management systems Input into road failure investigations

Specifications and research	<ul style="list-style-type: none">• Support to on-going research• Fine-tuning local materials and design specifications• Development of local materials/performance correlations
Other	<ul style="list-style-type: none">• Potential source of revenue

Despite the potential benefits of establishing materials inventories, their sustainability needs to be given careful consideration in terms of such factors as:

- institutional capacity
- regular system maintenance, updates and upgrades
- staff training

A first step in establishing a comprehensive inventory is to assemble, in a simple database, materials information from existing materials reports prepared by contractors and consultants.

5.4 Pavement Design

5.4.1 Objective

The challenge of pavement design for low-volume roads.

“I have always felt that in many respects it is easier to design a pavement for a high volume rather than a low-volume road for several reasons. On the low-volume road, for example, we are continually striving for low cost, which makes our design extremely sensitive from the standpoint of thickness, quality of pavement and surfacing materials, geometric design, and many other factors”.

Eldon Yoder – one of the most prominent pavement designers of our time.

The objective of pavement design is to produce an engineering structure in terms of thickness and composition that is in “harmony” with the local environment, will distribute traffic loads efficiently and provide a satisfactory level of service, whilst minimizing the whole-life cost of the pavement, i.e. both initial construction and subsequent maintenance costs. To achieve this goal, sufficient knowledge of the materials, traffic, local environment (particularly climate and drainage) and their interactions is required to be able to predict reasonably the performance of any pavement configuration. In addition, there should be a clear view as to the level of performance and pavement condition that is considered satisfactory in the circumstances for which the pavement structure is being designed.

Pavement design for low-volume 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 was a large one. Moreover, pavement engineers are required to carefully consider the environment within which LVSRs have to be provided in a manner which is often much more demanding than with HVRs.

5.4.2 Pavement Design System

The many variables and interactions that influence the final choice of road pavement make it appropriate to adopt a “systems” approach to pavement design in which all influential design factors are considered within an appropriate pavement design system. Figure 5.12 shows such a Pavement Design System. The various elements that comprise the system are discussed below, with particular emphasis on their relevance to LVSRs.

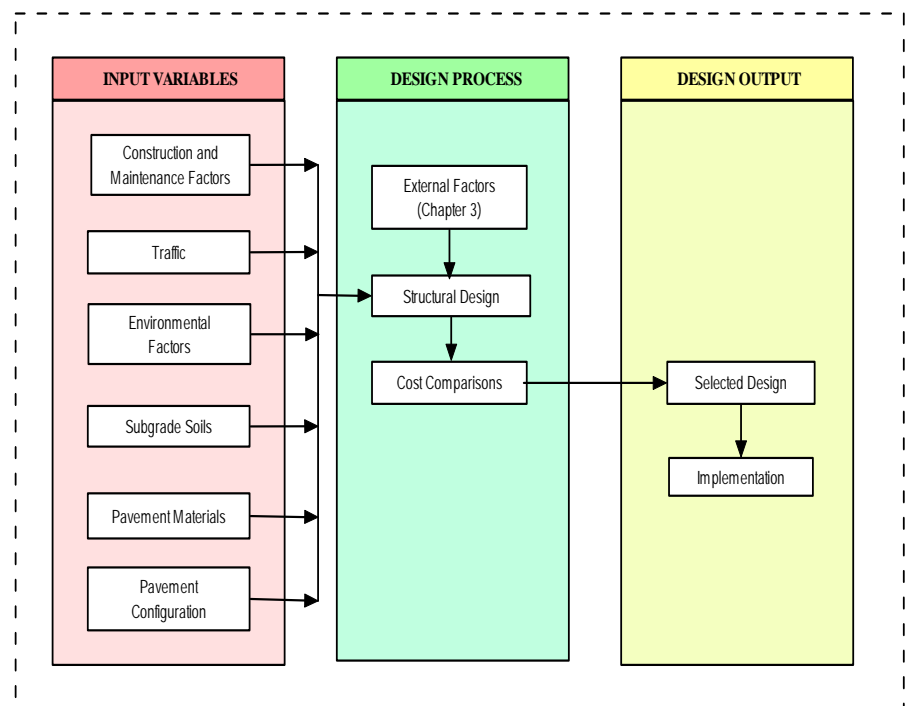


Figure 5.12 - Pavement design system

5.4.3 Input Variables

Construction and Maintenance Factors

Construction and maintenance policies can influence the type of pavement structure which is adopted. In addition, the properties of many materials are dependent on construction influences, including level of compaction and extent of sub-surface drainage provided. These latter factors are particularly important in the context of low-volume roads and are discussed further in this section. The more general construction and maintenance issues are discussed further in chapters 6 and 7.

Traffic

The deterioration of paved roads caused by traffic results from both the *magnitude* of the individual wheel loads and the *number of times* these loads are applied. For pavement design purposes it is therefore necessary to consider not only the total number of vehicles that will use the road but also the axle loads of these over the design life of the road.

Design life (Years): The design life of a pavement depends on a number of factors including, particularly, its function, as well as other uncertainties. Thus, a major trunk road fulfilling an obvious economic function and carrying high volumes of traffic, for which any major disruption would be very costly, would normally be designed for a longer design life than a tertiary/access road serving a primarily developmental or social function and carrying relatively low volumes of traffic. Table 5.7 provides some guidance on the selection of design life.

Table 5.7 – Pavement design life selection guidance

Design data reliability	Importance/level of service	
	Low	High
Low	10 yrs	10 – 15 yrs
High	10 – 15 yrs	15 – 20 yrs

Notwithstanding the attraction of employing staged construction strategies from a purely economic point of view, this approach is not recommended if there is any risk that maintenance and upgrading will not be carried out correctly at the appropriate time.

Traffic estimation: This is determined on the basis of appropriate traffic surveys to establish the traffic volume by each traffic class in terms of the [Annual] Average Daily Traffic [A](ADT). The various types of traffic surveys available for determining *baseline* traffic flows have been dealt with in Chapter 3, Section 3.2.7.

Following the establishment of baseline traffic, further analyses are required to establish the total design traffic based on a forecast of traffic growth in terms of normal, diverted and generated traffic. Such forecasts are very sensitive to economic conditions in developing economies and the various factors to be considered are dealt with in detail in various texts on pavement design such as Overseas Road Note 31²⁷. Moreover, for relatively shorter term design strategies (traffic <0.1 million ESA), an elaborate traffic analysis is seldom required, as environmental rather than traffic loading factors often dominate the performance of the roads.

Design life – the period during which a pavement would be expected to carry the anticipated traffic at a satisfactory level of service without requiring major rehabilitation work.

The ADT is defined as the total annual traffic summed for both directions and divided by 365. However, for pavement design purposes, the traffic loading in one direction (in the heavier loaded lane) is required.

Construction traffic can be a significant proportion (sometimes 20 – 40 per cent) of total traffic on LVSRs as shown in Figure 5.13 and should be taken into account in the design of the pavement.

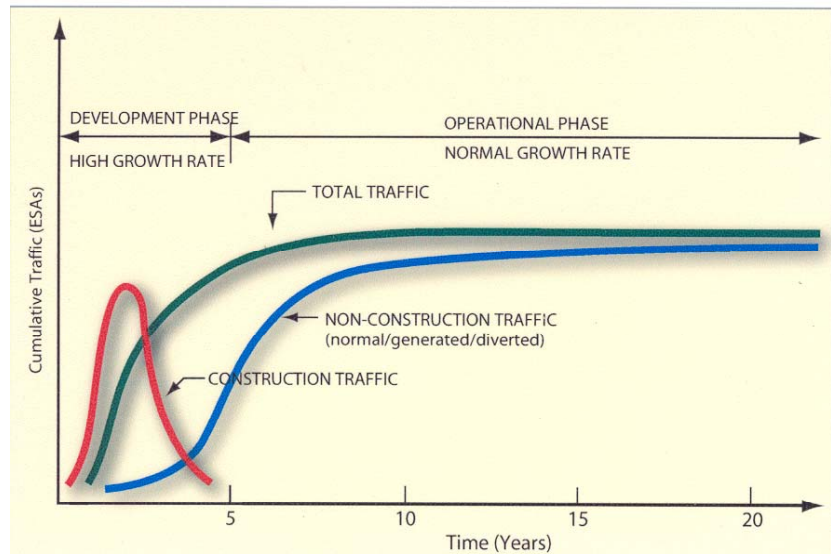


Figure 5.13 – Typical traffic growth pattern for a LVSR

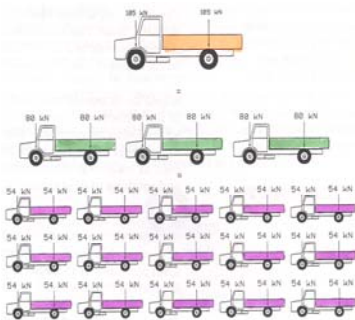
Axle loading: The damage inflicted on road pavements depends very strongly on the axle loads of the vehicles and the number of times they are applied. Axle load data for design purposes can be obtained from surveys of commercial vehicles using the existing road or, in the case of new roads on new alignments, from existing roads carrying similar traffic. Methods of carrying out such surveys have been described in Chapter 3, Section 3.2.7.

The damaging power of a particular axle-load is generally expressed in terms of an equivalent “standard axle” – a concept that effectively reduces the varied nature of the traffic loadings to a single parameter in terms of structural damage to a pavement. The expression that is used for defining the equivalence factor of any axle load is based on the Fourth Power Law derived from the AASHO Road Test ¹, as follows:

$$N = (W/W_s)^n \quad \text{where} \quad \begin{array}{l} N = \text{load equivalence factor} \\ W = \text{axle load} \\ W_s = \text{standard axle} \\ n = \text{power law exponent} \end{array}$$

For design purposes, the power law exponent, n, is generally assumed to lie in the range 4 - 4.5 (typically taken as 4.2). It is noteworthy, however, that the value of n is strongly influenced by pavement type (granular, cemented, etc) and mode of distress (rutting, fatigue, subgrade deformation, etc), strength of subgrade and stiffness and may vary from less than 1 to over 18! ²⁸

There is some evidence in the SADC region to indicate that the value of the exponent of 4.2 may not be appropriate for some LVSRs constructed with natural gravel road bases in which the main deterioration mode is often rutting. The significantly different axle loading on the two lanes of a road in the region, where a range of “sub-standard” calcareous materials were used as road base, enabled an estimate to be made of the damage law exponent. This was found to be between 2 and 3, a value which has been confirmed by other investigations carried out in the region. ²⁹



Three groups of heavy vehicles with equal damaging effect.

Cumulative equivalent standard axles: Following the traffic and axle load surveys described above, the cumulative equivalent standard axle loading over the design life of the road is determined by multiplying the number of axle loads in each load group of the entire load spectrum in the heaviest trafficked lane by the relevant equivalency factor.

Environmental Factors

Environmental factors - essentially in terms of moisture and temperature - have a profound affect on pavement performance. This is particularly the case with low-volume roads where environmentally induced distress rather than load-associated distress dominates pavement performance¹⁷. As illustrated in Figure 5.14, it is only at relatively higher traffic levels that load-associated distress plays the dominant role in pavement performance.

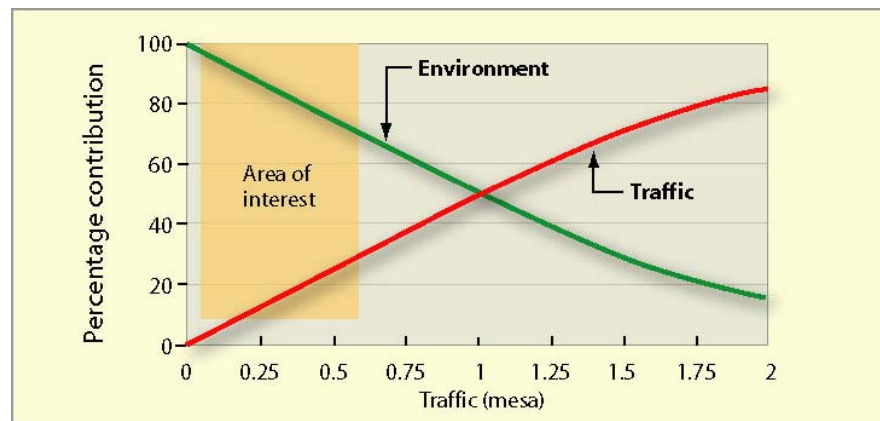


Figure 5.14 – Traffic loading versus dominant mechanism of distress

Investigations carried out in the region indicated quite clearly that traffic below about 300,000 to 500,000 ESA was not a significant factor in pavement deterioration.

Most design methods used in the SADC region cater for relatively high volumes of traffic, typically in excess of 0.5 million ESA over a 10 – 15 year design life, for which attention is focused on load-associated distress. However, for the large proportion of low-volume roads that exist in the region, carrying typically less than 0.30 million ESA over their design life, priority attention should really be paid to ameliorating the effects of the environment, particularly rainfall and temperature, on their performance, as discussed below.

Climate: The moisture environment in which a pavement operates is a major influence on its performance because the strength and stiffness of the pavement materials and subgrade are critically dependent on moisture content. In turn, moisture content is influenced by the climatic zone in which the pavement is located.

Moisture environment: Thus, arguably the most important challenge faced by the designer is to provide a pavement structure in which the detrimental effects of moisture are contained to acceptable limits in relation to the traffic loading, nature of the materials being used, construction/maintenance provisions and degree of acceptable risk. This challenge is accentuated by the fact that most low-volume roads will be constructed from natural, often unprocessed, materials which tend to be moisture sensitive. This places extra emphasis on drainage and moisture control for achieving satisfactory pavement life for which the following factors require careful assessment at the design stage.

- rainfall and evaporation pattern
- permeability of surfacing
- depth of water table relative to the pavement structure
- type of subgrade material
- relative permeability of pavement layers (permeability/no-permeability inversion)
- pavement configuration
- whether shoulders will be sealed or not

The various sources of moisture infiltration into a pavement are illustrated in Figure 5.15.

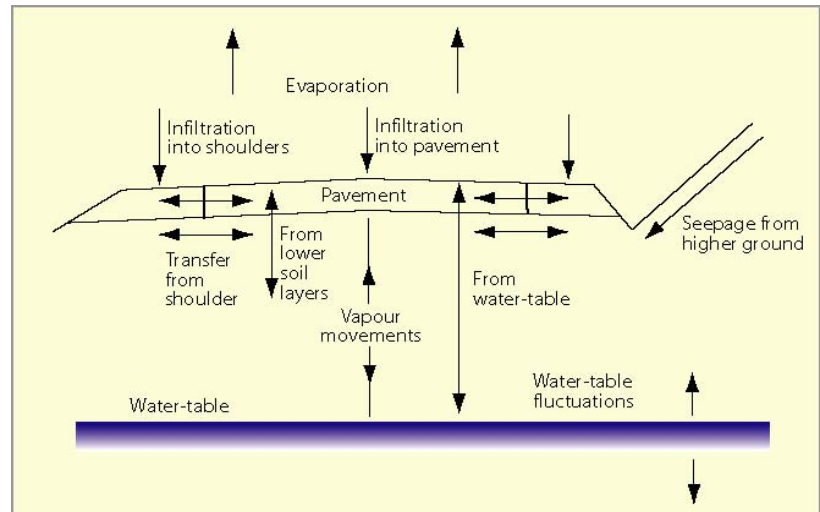


Figure 5.15 – Moisture movements in pavements and subgrades (NAASRA,1987)³⁰

Permeability: Moisture movements of any of the types illustrated in Figure 5.15 are controlled not only by the availability of moisture from the various sources but also by the *permeability* of the pavement, subgrade and surrounding materials. The permeability of the material will control the rate at which moisture moves through the material. The relative permeability of adjacent materials may also govern moisture conditions. A significant decrease in permeability with depth or across boundaries between materials (ie permeability inversion) can lead to saturation of the materials in the vicinity of the permeability inversion.

Box 5.7 – Significance of material permeability in pavement design

No permeability inversion: It is essential for good internal drainage that permeability inversion does not occur. This is achieved by ensuring that the permeability of the pavement and subgrade layers are at least equal or are increasing with depth. For example, the permeability of the base must be less than or equal to the permeability of the subbase in a three-layered system. To achieve this, it is necessary to measure or assess the permeability of the pavement and subgrade layers.

Permeability inversion: A permeability inversion exists when the permeability of the pavement and subgrade layers decreases with depth. Under infiltration of rainwater, there is potential for moisture accumulation at the interface of the layers. The creation of a perched water table could lead to shoulder saturation and rapid lateral wetting under the seal may occur. This may lead to base or subbase saturation in the outer wheeltrack and result in catastrophic failure of the base layer when trafficked. A permeability inversion often occurs at the interface between subbase and subgrade since many subgrades are cohesive fine-grained materials. Under these circumstances, a more conservative design approach is required that specifically caters for these conditions.

Where permeability inversion is unavoidable, the road shoulder should be sealed to an appropriate width to ensure that the lateral wetting front does not extend under the outer wheeltrack of the pavement. Lateral drainage can be encouraged by constructing the pavement layers with an exaggerated crossfall wherever a permeability inversion occurs. Although this is not an efficient way to drain the pavement it is inexpensive and therefore worthwhile. Full under pavement drainage is rarely likely to be economically justified for LVSRs.

In order to make due allowance in the design process for the effects of moisture changes on subgrade and pavement strengths, assessment of these strengths should be made at the highest moisture contents likely to occur in the materials during the design period.

In terms of pavement design, the two moisture zones in the pavement which are of critical significance are:

- the equilibrium zone
- the zone of seasonal moisture variation

Box 5.8 – Prediction of moisture content for use in pavement design

From extensive research work carried out in South Africa (in locations representative of much of southern Africa), it was found that³¹:

- In LVSR pavements over a deep water table (which covers much of the rural road network of the SADC region), moisture contents in the equilibrium zone normally reach an equilibrium value after about two years from construction and remain reasonably constant thereafter.
- In the zone of seasonal variation, the pavement moisture does not reach an equilibrium and fluctuates with variation in rainfall. Generally, this zone is wetter than the equilibrium zone in the rainy season and it is drier in the dry season.
- The zone of seasonal variation of moisture extends from 600mm to 1000mm from the edge of surfaced pavements, and was more prominent in the upper layers.
- To reduce substantially the probability that the part of the pavement immediately under the wheel load is influenced by seasonal variations, it has been found that the minimum width of sealed shoulder needs to be one metre for design traffic of less than 3 million ESA and 1.2 metres for design traffic greater than 3 million ESA.

Shoulder sealing is highly beneficial to the performance of LVSRs, especially where moisture sensitive materials are used.

From the above, it follows that if the pavement of a typical LVSR has unsurfaced shoulders, the outer wheeltrack will lie over the zone of seasonal variation, and the field material strength in this zone becomes critical in the design of LVSRs (see Figure 5.16). However, for LVSR pavements with sealed shoulders of at least one metre, the traffic loads will lie over the equilibrium zone where the field material strength may be more confidently predicted, and the use of unsoaked material strengths in design become possible.

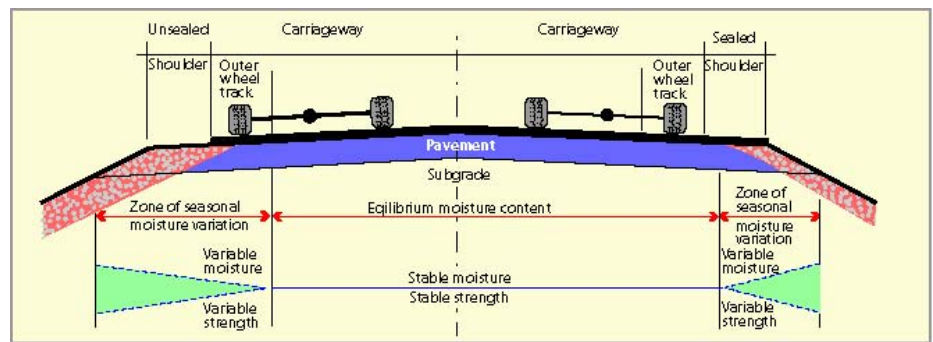


Figure 5.16 – Moisture zones in a typical LVSR

Temperature and humidity: Temperature and humidity play an important role in the performance of a road pavement, especially on low-volume roads. For example, ultraviolet radiation from sunlight causes a continuous slow hardening, reduction in elasticity and consequent embrittlement and cracking of the bitumen. Once the surface integrity has been lost, water can then penetrate the cracks into the underlying pavement structure leading to a reduction in pavement strength and an increased rate of deterioration under repeated wheel loads.

Various combinations of temperature and humidity can also give rise to *hydrogenesis* (i.e. the aerial-well effect) and the migration of water under a bituminous surfacing. An explanation given for this phenomenon is that ambient air, after penetrating the porous shoulders of the pavement, flows through the aggregate pavement layer³². Under certain temperature conditions, water vapour in the air is then transferred to the surfaces of the aggregate particles where it forms a liquid water film. From this explanation, it is tentatively suggested that hydrogenesis could occur under the surfacing of bituminous pavements with a mean basecourse temperature above 20°C and especially if the diurnal base course temperature range is greater than 10°C. These conditions are usually found in the arid and semi-arid areas of the SADC region in summer. Thus, with moisture sensitive natural gravels, some allowance may have to be made for hydrogenesis in the design of the pavement.

Measures to overcome the adverse effects of temperature, including a judicious choice of surfacing type and binder, are discussed further in Section 5.5.5.

Subgrade Soils

The support provided by the subgrade, in terms of its stiffness, is the most important factor determining pavement design thickness, composition and performance. The stiffer the subgrade, the less the layer thicknesses and component material strengths required to carry a given traffic loading. As emphasized in Chapter 6, every effort should be made to exploit the maximum stiffness potential of the subgrade by compacting to refusal with the heaviest plant available. However, care should also be taken to avoid over-stressing of some soils, especially those with a bonded fabric which can break down under excess compaction.

For a given material type, the subgrade strength and stiffness are dependent on the conditions at construction and during service in terms of *moisture content* and *density*. It is therefore essential that estimates of these two parameters are obtained as a basis for establishing the *design subgrade condition* which provides a basic input into most low-volume road design methods.

The density to which a subgrade material is compacted can have a significant effect upon its strength. Variability in density is also a matter of concern as it will result in differential deformation due to traffic compaction.

Consideration should be given to the depth to which effective compaction can be achieved. In some circumstances, the strength of the unimproved subgrade below the depth of effective compaction may be a critical consideration in the design of the total pavement system.

From investigations carried out across a wide range of climatic regimes and soil types in the SADC region^{31,17}, the field/optimum moisture ratios measured at the wettest time of the year are given in Table 5.8.

Table 5.8 – Variation of subgrade field/optimum moisture content with climatic zone¹⁰

Weinert N-Value	> 4 (arid/semi-arid)	2-4 (semi-arid/sub-tropical)	< 2 (sub-tropical/ humid)
FMC/OMC*	0.5 – 0.7	0.75 – 1.25	1.0 – 1.5

* Measurement made in outer wheel track of pavement

The conclusions drawn from this research¹⁷ provide critical inputs in the design of LVSRs and may be summarized as follows:

- the most important variables affecting equilibrium moisture content of the subgrade are material type and climate, with the effect of the former predominating
- subgrade moisture content increases with finer, plastic materials and generally varies inversely with maximum dry density, but directly with optimum moisture content and soaked moisture content
- the equilibrium moisture content in the subgrade increases with wetter climates; in the subbase and base it appears to be independent of climate
- the ratio of equilibrium to optimum moisture content in the subgrade, and to a lesser extent in the subbase, increases with wetter climates, but it is almost independent of climate in the base

These values highlight the effect of climate on subgrade moisture content and the importance of defining appropriate design subgrade conditions particularly for the weaker, more moisture sensitive materials.

Pavement Materials

Material Selection: Despite the innumerable influences that exist, there are some dominant factors in pavement performance that can be identified in order to design and construct LVSRs in a wide range of environments with reasonable confidence. These dominant factors are:

- traffic loadings (represented by the design ESAs)
- environment (represented by the Weinert N-value/rainfall)
- material properties (represented by the material’s plastic modulus given by PI x percentage passing 0.425mm sieve)
- pavement configuration (cross-section)

Table 5.9 summarises the characteristics of various material types which critically affect the way in which they can be incorporated into an appropriate pavement configuration in relation to their properties and the prevailing conditions of traffic, climate, economics and risk assessment.

Parameter	Pavement Type			
	Unbound			Bound
	Unprocessed	Processed	Highly processed	Very highly processed
Material types	As-dug gravel	Screened gravel	Crushed rock	Stabilised gravel
Variability	High	————— Decreases —————		Low
Plastic Modulus	High	————— Decreases —————		Low
Development of shear strength	Cohesion and suction	Cohesion, suction and some particle interlock	Particle interlock	Particle interlock and chemical bonding
Susceptibility to moisture	High	————— Decreases —————		Low
Design philosophy	Material strength maintained only in a dry state	Selection criteria reduces volume of moisture sensitive, soft and poorly graded gravels		Material strength maintained even in wetter state
Appropriate use	Low traffic loading in very dry environment	Traffic loading increases, environment becomes wetter		High traffic loading in wetter environments
Cost	Low	Increases	High	High
Maintenance reliability	High	————— Decreases —————		Low

Table 5.9 – Pavement material categories and relative characteristics

Pavement Configuration

As highlighted above, pavement configuration is influenced by the properties of the materials being utilized and the influence of water on their performance. Thus, attention to detail in drainage design and construction is essential for optimum performance. Based on the broad material categories and their characteristics, as summarized in Table 5.9, the corresponding pavement configurations have been developed for the following three zones:

Zone A Configuration: The principal features of the Zone A environment are relatively low traffic, a dry climatic environment and materials which are highly dependent on soil suction and cohesive forces for development of shear resistance. These forces may well be the only source of shear strength in these relatively weak materials because a deficiency of durable stone prevents reliance on inter-particle friction. Thus, even modest levels of moisture (> 60% saturation) are enough to reduce confining forces sufficiently to cause distress and failure.

Satisfactory performance with the use of Zone A materials can only be achieved whilst the pavement remains in a relatively dry, stiff condition, (i.e. < 80% of OMC). Achievement of this state depends on the success of design features used to inhibit excess moisture movement into the pavement layer from the shoulders and from the embankment beneath the pavement. This can be achieved by such measures as sealing the shoulders, as illustrated in Figure 5.17, or by using relatively low permeability unsealed shoulders, if they do not otherwise impede internal drainage (Section 6.7).

Depending on the climatic environment, naturally occurring pavement materials may need to be brought near to saturation moisture content for efficient compaction, but it is imperative that they be allowed to dry back to at least equilibrium moisture content before sealing. Specifications will be necessary to ensure that premature sealing does not lock in construction moisture.

Use of sealed shoulders will maintain the zone of seasonal moisture variation outside of the outer wheel track.

Good external drainage can be achieved with a raised embankment and provision of sufficiently deep side drains, ie: increasing crown height.

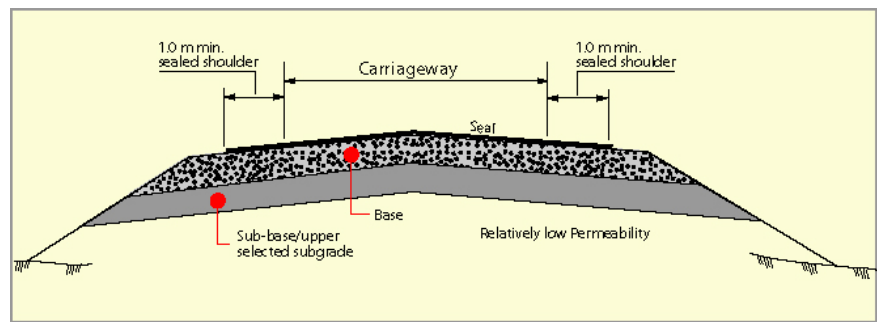


Figure 5.17 – Pavement configuration for Zone A materials (unprocessed, unbound materials)

Zone B Configuration: The principal features of Zone B are low to medium traffic, a dry to moderate climatic environment and materials that have a moderate dependency on all forms of shear resistance – friction, suction forces and cohesion. Because of the moderate strength potential of such materials, concentrations of moisture in the range 60% – 80% saturation may be enough to reduce the strength contribution from suction or cohesion sufficiently to cause distress and failure³³. Because of the variable nature of these materials and their poor internal drainage, emphasis is best placed on keeping moisture away from the pavement system by employing a pavement configuration similar to that for Zone A materials.

Zone C Configuration : The principal features of Zone C are medium to high traffic and a moderate to wet climatic environment with materials that have a minor dependency on suction forces and cohesion and either rely on:

- (a) internal friction which is maximized when the aggregate is hard, durable and well-graded (granular, unbound materials), or
- (b) physio-chemical forces which are not directly affected by water (bound, granular materials)

Very high levels of saturation (80% – 100%) will cause distress which will usually result from pore pressure effects under wheel loads and mobilization of plasticity in the fine fractions³³. To avoid this situation, various positive design features are required including:

- sealed shoulders
- use of low permeability selected lower sub-base to protect the subgrade from moisture movements
- a sub-base layer to be at least as permeable as the base layer, free to discharge into deep side drains

5.4.4 Design Process

External Factors

A number of factors, which are often of a non-technical nature, can have a significant influence on the pavement design process. These factors (political, social, institutional, etc.), have been discussed in Chapter 3 and are not repeated in this section.

Structural Design

Over the past 25 years several methods of pavement design have been developed in southern Africa based on both mechanistic and empirical methods. In addition, several methods have also been imported and adapted from overseas practice for use in the region.

Mechanistic/Analytical methods: Mechanistic methods are derived from laboratory studies of the mechanical behaviour of the pavement, in which materials are exposed to measured stresses and strains. A suitable theory to compute the stresses and strains in the actual pavement is then used together with a transfer function (or calibration factor) that relates the mechanical response expected from the laboratory studies to the actual behaviour of the real pavement.

Mechanistic/analytical design methods require a considerable amount of material testing and computational effort before they can be properly used. Moreover, their application to highly variable, naturally occurring materials, which make up the bulk of LVSR pavements, is questionable.

The South African Mechanistic Design Method (SAMDM)³⁴, which is based on a linear elastic model, and the Elasto-Plastic Design Method (S-N method), based on a non-linear elastic model, are examples of mechanistic methods used in the SADC region for pavement design. These methods have been used in the SADC region (South Africa) in the preparation of simplified design manuals such as a catalogue of structures in which the materials commonly available in the region have been tested and the results used to prepare thickness designs³⁵.

Empirical methods: Empirical methods are derived from empirical studies of pavement performance in which the design is based on past successful practice. Empirically based methods are likely to be satisfactory provided the materials, environment and conditions of loading do not differ significantly from those which applied during the original empirical studies on which the designs were based. Thus, the extension of empirical methods to different loadings, different materials and different environmental conditions can be achieved only by carrying out expensive and time consuming full-scale pavement experiments.

Empirically based methods have been used in the preparation of a number of simplified design catalogues of structures in the SADC region, such as the commonly used TRL ORN 31 (1993)²⁷ and the DCP Design catalogue³⁶.

Appropriateness of Design Methods: Ideally, an appropriate pavement design method should be based on experience and fundamental theory of structural and material behaviour developed over time. It should also take account of local conditions of climate, traffic, available local materials and other environmental factors. By so doing, it should allow the designer to produce an ap-

appropriate pavement structure of sufficient bearing capacity to carry the anticipated traffic over its design life to a pre-determined terminal level of service.

The following factors provide a benchmark against which the appropriateness of current design methods may be evaluated for application to LVSRs:

- subgrade design classes: Should be narrow so as to take advantage of the range of strong subgrade materials which predominate over extensive parts of the region
- design traffic classes: Should be relatively narrow to cater incrementally for design traffic loadings in the range up to 500,000 ESA
- materials classes: Sufficient number of classes to cater for the full range and differing properties of naturally occurring residual weathered rocks (e.g. granite, quartzite) and pedocretes (e.g. calcrete, ferricrete) that occur extensively in the region
- materials specifications: Should be based on proven field performance in relation to such factors as traffic, subgrade design class, sealed surface design and geo-climatic zone

Based on the above criteria, the various design methods generally used in the SADC region were assessed for their applicability to low-volume roads. Those shown in Figure 5.10 were found to be basically suitable, with the proviso that they should be used flexibly rather than prescriptively.

Table 5.10–Pavement design methods appropriate for use in the SADC region

Mechanistic-Empirical Methods	Empirical Methods
S-N Method (1993) ³⁷	DCP Method (1984) ³⁶
TRH4 (1996) ³⁵	SATCC Pavement Design Guide (1997) ³⁸
	TRL ORN 31 (1993) ²⁷
	TRL/SADC Pavement Design Guide (1999) ¹⁷

In addition to the above generic methods of pavement design methods, there are a number of other country specific guides/manuals which have been developed within a few countries in the region. The most prominent ones are as follows:

- Zimbabwe Pavement Design Guide (1975)³⁹.
- Botswana Roads Design Manual (1982)⁴⁰.
- Tanzania Pavement and Materials Design Manual (1999)⁴¹.
- None of the above methods are directly comparable, except on a case by case basis, because they differ with regard to a number of details such as the range of traffic and subgrade design classes, design subgrade strength (soaked versus in situ moisture content) etc. In this regard, some methods are more conservative than others. Nonetheless, they are all based on research/investigation work carried out in the region specifically for application to low-volume roads.

The designer should become fully conversant with the details of each of the recommended methods listed above before adopting any particular one in their area of the SADC region. These methods are fully documented in the literature.

A brief resumé of the generic design methods is given below:

S-N Pavement Design Method (1993): The S-N (Elasto-Plastic) design method is a mechanistic method based on elastoplastic behaviour of granular pavement materials and bituminous surfacings. It uses non-linear analysis to model the pavement together with empirically derived transfer functions calibrated with HVS testing to predict the plastic deformation (rutting) in the granular layers. This approach has provided the basis for the development of a catalogue of pavement structures catering specifically for low-volume roads.

TRH4 (1996): The TRH4 design method is based on the South African Mechanistic Design Method which uses linear elastic analysis to model the pavement in which the stresses and strains that are most likely to initiate failure in a particular material type have been related to traffic load, via appropriate transfer functions, some of which were calibrated from HVS testing.

Dynamic Cone Penetrometer (DCP) Method: The DCP design method is an empirical method developed in South Africa, which uses the in situ measured bearing capacities of existing pavements and correlating them with HVS tests on similar material and pavement types.

SATCC Pavement Design Guide (1997): The SATCC Pavement Design Guide provides a catalogue of pavement structures that were developed through a desk study of practice deemed appropriate to the region, primarily as exemplified by TRL Overseas Road Note 31 (1993) and the TRH4 (1996).

TRL ORN 31 (1993): This guide is based on research and experience in over 30 mainly tropical and sub-tropical countries. Previous editions have been used for the design of LVSRs worldwide. The latest (1993) edition covers a wider range of materials and structures with a catalogue of designs that cater for traffic up to 30 million standard axles.

TRL/SADC Pavement Design Guide (1999): This guide is based on the monitoring and testing of selected sections of road on the existing networks in Botswana, Malawi, Zambia and Zimbabwe to enable designs to be evaluated. The research focused on measuring how road pavements performed with time and traffic, and in different climatic conditions. It also identified features which need to be included in the road design to minimize risk including environmental influences, the performance of “non-standard” materials and actual modes of deterioration. The output of the research programme was the development of a set of new structural design charts and a materials design procedure for low-volume roads in the region based on a wide range of traffic levels, design subgrade classes, materials types and geo-climatic zones.

Pavement design process: The main steps to be followed in carrying out a design for a LVSR pavement include:

- estimating the amount of traffic and the cumulative number of standard axles that will use the road over the selected design life
- assessing the strength of the subgrade soil over which the road is to be built
- selecting the most economical combination of pavement materials and layer thicknesses that will provide satisfactory service over the design life of the pavement

As much as the above process may appear relatively simple and straight forward, there are a number of aspects pertaining to LVSRs which require careful consideration. These aspects are highlighted in the generic design process presented in Table 5.11.

Table 5.11 – Typical checklist of LVSR pavement design factors

Main Parameter	Influencing Item	LVSR issue
Design philosophy	- level of service - design standard - interacting environments	- appropriate to LVSRs - use of appropriate standards - need to cater for external factors
Design strategy	- road function/classification - analysis period - design life - staged construction?	- can be primary, secondary or tertiary - short, medium, long? - short, medium, long? - implications on design
Design traffic	- type and count - axle loads - equivalence factors - power exponent - tyre pressures	- reliability of data - seasonality factors; growth projections - motorised and non-motorised - damage factors - impact of overloading - construction traffic - basis of choice - basis of choice (<4?, >4?) - impact; design counter-measures
Materials	- availability and type - selection strategy - moisture sensitivity - problem soils(e.g. expansive) - testing	- properties and impact on design - specifications and test methods - impact on design and pavement x-section - design counter-measures - appropriate test methods
Environment	- climatic region - moisture regime - temperature and humidity - modifying influences - climate (e.g. El Nino)	- arid/semi-arid, semi-arid/sub-tropical, sub-tropical/humid? - soaked, unsoaked, equilibrium moisture contents for design? - age hardening of bitumen, hydrogenesis - irrigation, vegetation, deforestation - long-term consideration
Practical considerations	- drainage and hydrology	- internal and external drainage - embankment height; crown height above drain invert level
Structural design	- pavement design method	- use of appropriate methods of design - sealed or unsealed shoulders
Cost analysis	- economic life-cycle cost analysis	- economic analysis methods (producer surplus, consumer surplus?) - evaluation tools (HDM4, RED, etc)

Cost Comparisons

In order to arrive at an optimum pavement design solution, a life-cycle cost analysis should be made of all potential design alternatives capable of providing the required level of service for the lowest cost over the analysis period.

The main economic factors which determine the cost of the pavement facility include:

- analysis period
- structural design period
- construction costs
- maintenance costs
- user costs
- discount rate

The life-cycle cost associated with a particular design alternative is illustrated in Figure 5.18.

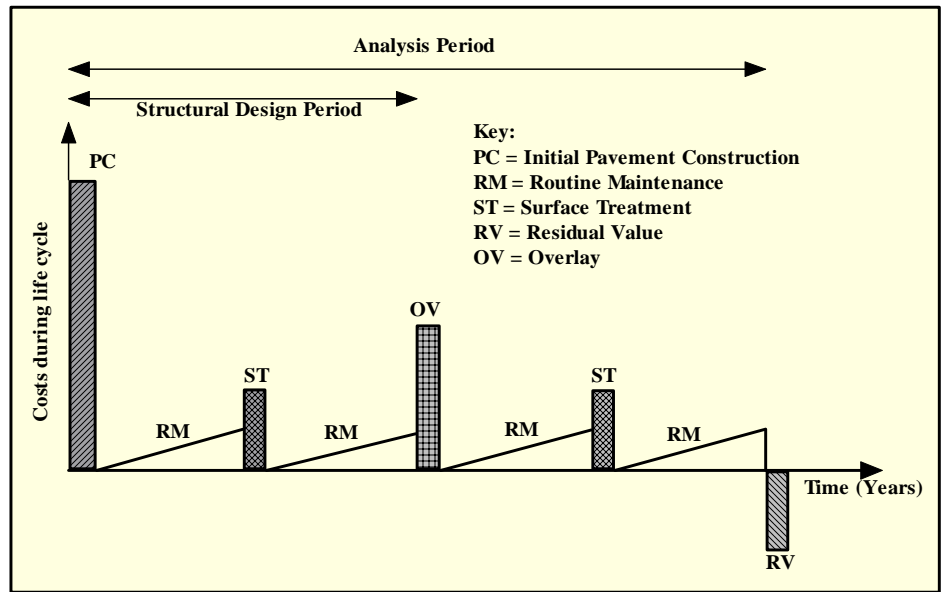


Figure 5.18 – Components of a typical life-cycle cost analysis

As indicated in Table 5.7, a relatively shorter design life is frequently used for low-volume-roads. Moreover, user costs are not necessarily traffic related and, especially at the low end of the traffic spectrum, may well be manifested otherwise.

The optimum pavement design solution, which should be the design objective, is a balance between construction, maintenance and road user costs and, as illustrated in Figure 5.19, is very much traffic related⁴². Thus, the optimum structural capacity pavement for a LVSR might well incur lower initial construction costs but, within its life cycle, this would be balanced by higher maintenance and VOC. Conversely, a higher capacity pavement would incur higher initial construction costs but lower maintenance and VOC.

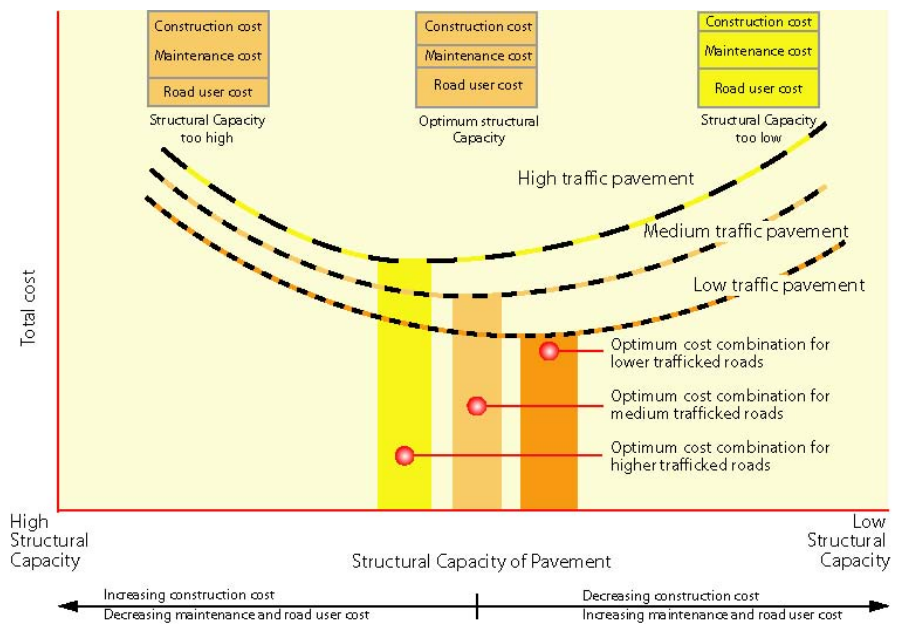


Figure 5.19 – Combined cost for various pavement structure capacities

5.4.5 Design Output

Selected Design

The cost analysis should be regarded as an aid to decision-making as it does not necessarily include all factors leading to a decision and should therefore not override all other considerations. These other considerations include the various exogenous factors discussed in Chapter 3 which are particularly important in the provision of low-volume roads.

Quantification and Mitigation of Risk

One of the major aspects concerning the use of marginal materials and thin pavement structures is the perceived increased risk of failure, particularly as regards the adverse impact of moisture on pavement performance. Thus, once the final design has been selected and pavement construction is undertaken, it is necessary to ensure that the critical design assumptions are incorporated into the pavement both during and after construction. These include:

- drainage provisions
- material quality
- subgrade bearing capacity
- construction control
- overloading
- maintenance

Depending on circumstances, some of these factors will be more important than others. Generally, the risk failure can be expected to increase if a number of factors are relaxed together. If one or the other of the design assumptions cannot be met due to some unforeseen constraint, it may be possible to adjust the overall design in a number of ways. For example, it may be feasible to reduce material standards but there might be a concomitant need to improve drainage and bearing capacity. Or, if design assumptions are not met in the lower pavement layers, it may be possible to adjust the overall design by using higher strength upper layer materials or thicker courses in the upper parts of the pavement.

Ultimately, as with all road projects, control of construction quality, maintenance and overloading will ensure that the maximum benefits will be obtained from the recommended design.

Performance

Box 5.8 – Why do gravel road bases often perform better than predicted?

Many bituminous pavements constructed of natural gravels have performed exceptionally well despite extensive overloading (according to the 4th power law) and poor maintenance. The following factors may explain the reason for this:

- reduced traffic loading (extended “life”) due to inappropriate damage exponent
- good (strong) sub-grade materials
- pavement design thickness based on unduly conservative saturated subgrade conditions
- predominantly dry environment
- stiffer pavement layers than anticipated at the design stage (base, sub-base and sub-grade)
- inappropriate materials specifications

The above uncertainties emphasise the need for developing local standards, specifications and pavement performance relationships.

5.5 Surfacing

5.5.1 Introduction

As highlighted in this guideline, gravel deposits in many SADC countries are not only a finite, non-renewable resource, but in many areas are either non-existent or inaccessible. There is also an increasing awareness that, even at relatively low traffic volumes, the upgrading of unpaved roads to a sealed standard can be cost effective compared with the cost of maintaining the unpaved gravel road. As a result, the use of bituminous surface treatments over light pavement structures for the upgrading of a substantial length of gravel roads in the SADC region is expected to become more widespread.

There is a wide variety of bituminous surface treatments that can be used on LVSRs. In addition to the traditional *chip seal* there are a number of relatively little known “alternative surfacings” which, in appropriate circumstances, allow non-standard local materials to be judiciously used in situations where the use of conventional materials would be prohibitively expensive. There is also a range of labour-based bitumen surfacing techniques which, although still inadequately exploited, offer scope for providing beneficial employment to small contractors and local communities.

5.5.2 Objective

The main objective of this section is to highlight the wide variety of bituminous surface treatment types that are available for use with LVSRs and to provide guidance on their selection in relation to a range of prevailing circumstances. In so doing, the section deals with the following aspects of surfacings for LVSRs:

- Role and Function of Surfacings
- Selection of Surfacings
- Types, Characteristics and Performance
- Surfacing Design

5.5.3 Role and Function of Surfacings

Pavement surfacings fulfil a variety of functions which offer a number of advantages over unsealed roads. These characteristics are:

- seals and protects the base and provides strength at the road surface so that the latter can resist the abrasive and disruptive forces of traffic
- transmits to the base the vertical and horizontal forces imposed by moving traffic. Has no significant load distributing properties
- protects the pavement from moisture ingress and, in so doing, prevents loss of pavement strength thereby permitting the use of many materials that would otherwise not be appropriate
- improves safety by providing a superior skid-resistant surface, free from corrugations, dust and mud, often increasing light-reflecting characteristics and allowing the application of pavement markings
- prevents gravel loss, resulting in elimination of the costs of replacing gravel, a finite, non-renewable resource
- generates savings in vehicle operating costs due to improved riding quality and lower maintenance costs to maintain an acceptable level of service



Typical gravel road.

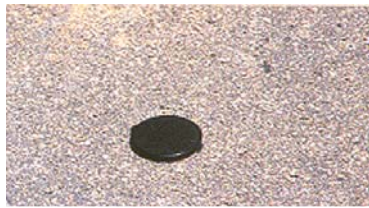


Typical LVSR offering many advantages over an unsealed road. In certain circumstances a bituminous surfacing may be warranted at traffic levels of less than 100 vpd.

5.5.4 Types and Performance Characteristics

Surfacing types

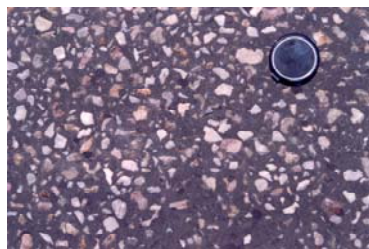
Various types of bituminous surfacing are available for use on LVSRs in the SADC region as listed in Figure 5.20.



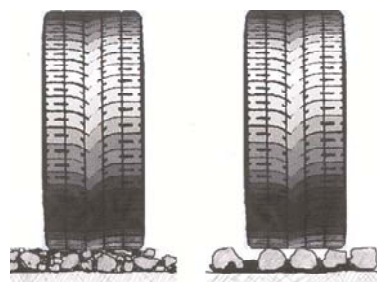
Sand seal surfacing



Double chip seal.



Single Otta seal with sand seal cover.



Category A Surfacing.

Category B Surfacing.

The Cape seal is a hybrid falling between Category A and Category B.

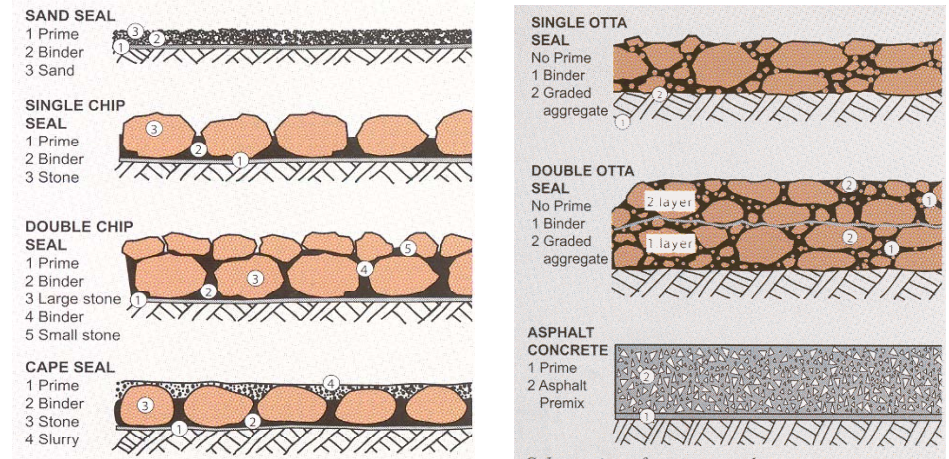


Figure 5.20 – Schematic common types of bituminous surface treatments

The above surfacing types offer a range of options and opportunities for addressing the particular challenge of providing appropriate, affordable and sustainable road surfacings. They have been developed to apply to specific situations relating to traffic volume and type, environment, pavement structures, material availability, etc. The challenge is to match the surfacing type to the prevailing circumstances in the most cost-effective and sustainable manner.

Mechanism of performance

The various bituminous surface treatments (excluding asphalt concrete) illustrated in Figure 5.20 may be placed in two categories as regards their mechanism of performance under traffic as follows:

Category A: (sand seal, slurry seal, Otta seal)

These seal types rely to varying extents on a combination of mechanical particle interlock and the binding effect of bitumen for their strength, similar to a bituminous premix. Early trafficking and/or heavy rolling is necessary to develop the relatively thick bitumen film around the particles. On this basis, the likelihood of stone becoming dislodged and whipped off the road by vehicles is relatively small.

Under trafficking, the seal acts as a stress-dispersing mat comprised of a bitumen/aggregate admixture – a mechanism of performance which is quite different to that of Category B surfacings.

Category B: (Chip seal)

This seal type relies on the binder to “glue” the aggregate particles to the base, this being the primary objective of the binder. Where shoulder-to-shoulder contact between the stones occurs, some mechanical interlock is mobilized. Should the bitumen/aggregate bond be broken by traffic or poor adhesion, insufficient material strength, water ingress or numerous other causes, “whip off” of the aggregate by traffic is almost inevitable. Under trafficking, the aggregate is in direct contact with the tyre and requires relatively high resistance to crushing and abrasion to disperse the stresses without distress.

The mechanism of performance of slurry seals is similar to a very thin bituminous premix, which tend to harden relatively rapidly and become stiff and brittle. The behaviour of sand seals is similar to that of slurry seals but they tend to remain flexible for longer. As a result of the difference in the mechanism of performance under traffic between Category A and Category B, they also differ markedly with respect to such factors as material requirements, design approach, construction features. Examples of these differences are listed in Table 5.12.

Table 5.12 – Relative differences in required properties between surface treatment types on LVSRs

Parameter	Category A	Category B
Aggregate quality	Relaxed requirements in terms of strength, grading, particle shape, binder adhesion, dust content, etc. Allows extensive use to be made of natural gravels.	Stringent requirements in terms of strength, grading, particle shape, binder adhesion, dust content, etc. Allows limited use to be made of locally occurring natural gravel.
Binder type	Relatively soft (low viscosity) binders are required.	Relatively hard (high viscosity) binders are normally used.
Design	Empirical approach. Relies on guideline and trial design on site. Amenable to design changes during construction.	Rational approach. Relies on confirmatory trial on site. Not easily amenable to design changes during construction.
Construction	Not sensitive to standards of workmanship. Labour-based approaches relatively easy to adopt if desired.	Sensitive to standards of workmanship. Labour-based approaches relatively easy to adopt if desired.
Durability of seal	Enhanced durability due to use of relatively soft binders and a dense seal matrix.	Reduced durability due to use of relatively hard binders and open seal matrix.

Performance Characteristics

The performance of a bituminous surfacing in terms of its life depends on a number of factors including:

- type of surfacing
- pavement structure (bearing capacity)
- traffic using the road
- environment
- road characteristics (geometry – curvature, gradient, camber, intersections, etc.)

Experience in the SADC region has indicated the approximate ranges of surfacing lives for the different seal types given in Table 5.13. In addition to the factors listed above, seal life will also depend on such factors as aggregate quality, bitumen type and durability and construction quality.

Table 5.13 – Expected service lives for some of the typical surface seals

Type of seal	Typical service life (years)
Sand seal	2 - 4
Slurry seal	2 - 6
Single chip seal	4 - 6
Double chip seal	7 - 10
Single Otta seal plus sand seal	8 - 10
Cape Seal (13mm + single slurry)	8 - 10
Cape seal (19mm + double slurry)	12 - 16
Double Otta seal	8 - 14



Example of a double Otta seal (using decomposed granite) plus after 10 years in service in a harsh, semi-arid environment with practically no maintenance.

5.5.5 Constituents, Properties and Specifications

The primary constituents of bituminous surface treatments are the aggregate and the bituminous binder which together fulfil different functions depending on the type of surfacing.

Aggregates

The main functions of the aggregate are to provide:

- adequate resistance to crushing and abrasion caused by moving wheel loads in order to transfer the tyre-induced stresses to the underlying pavement structure
- a skid-resistant surface in order to minimize skidding of vehicles, especially in wet weather
- a structure/matrix to accommodate the viscous and impervious binder
- protection to the binder from harmful ultra-violet radiation

The physical attributes which affect the performance of the aggregate in a surface treatment are related to their natural and processed properties as indicated in Table 5.14.

Table 5.14 – Requirements for surfacing aggregates

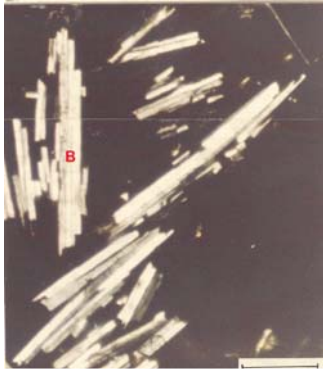
Property	Requirements/implications on performance
Strength	<ul style="list-style-type: none"> • need for adequate resistance to avoid crushing and abrasion under traffic and consequent loss of stone, bleeding/flushing; • affected by particle shape with cubical materials being stronger than flaky or elongated materials; • specification limits are placed in terms of: <ul style="list-style-type: none"> - Aggregate Crushing Value (ACV) - 10% Fines Aggregate Crushing Value (10% FACT) - Aggregate Impact value (AIV) - Los Angeles Abrasion (LAA) - Texas Wet Ball Mill (TBM) - Flakiness Index (FI) • The greater the percentage of weak/soft particles, the higher the ACV, AIV, LAA or TBM values and the lower the 10% FACT
Durability	<ul style="list-style-type: none"> • need for adequate resistance to weathering to avoid crushing, loss of stone and bleeding/flushing • related to weathering of material and alteration of primary minerals in the rock to secondary minerals (e.g. iron oxides, carbonates, clay minerals) • specification limits are placed in terms of: <ul style="list-style-type: none"> - wet/dry 10% FACT/ACV/AIV ratios - wet/dry 10% FACT/ACV/AIV ratios after 24 hour or 4-day soaking in ethylene glycol - Durability Mill Index (DMI) test - Magnesium/Sodium Sulphate soundness test - Methylene Blue Value (MBV)
Adhesion	<ul style="list-style-type: none"> • need for good adherence to binder and non-susceptibility to stripping to avoid loss of aggregate/ravelling • aggregates containing acidic minerals (e.g. quartzite, granite) or very fine-grained having smooth surfaces (e.g. silcretes or river gravels) tend to exhibit poor adhesion properties; • adhesion problems can be overcome through use of cationic bitumen emulsions and/or anti-stripping agents and/or pre-coating of aggregate • specification limits placed in terms of: <ul style="list-style-type: none"> - Riedel and Weber test - Static Immersion test (Modified Vialit adhesion test) - Fines and dust content



The operational characteristics of the Otta seal are such as to allow the use of as-dug natural gravel which can be screened, if necessary, to remove fines and over-size material.



Screened gravel used as surfacing aggregate in the Otta seal.



Photomicrograph of fresh basalt unaltered plagioclase microphenocrysts.



The need for cubical chipings is essential for good particle interlock in Chip seals.

Water and binder absorption	<ul style="list-style-type: none"> • need for minimum absorption to avoid high binder absorption and loss of stone if not compensated in design • related to water ingress and resulting decrease in strength/ durability of aggregate and susceptibility to stripping • need to allow for binder absorption when using absorptive aggregates (e.g. calcrete) by increasing binder application rates and/or pre-coating • specification limits are placed in terms of water absorption
Polishing	<ul style="list-style-type: none"> • need for good resistance to polishing to reduce scope for accidents due to skidding, especially in wet weather • related to micro-texture of aggregate which is a function of its mineralogy. Some aggregates (e.g. limestone) are more prone to polishing than others (e.g. dolerite) • specification limits are placed in terms of the Polished Stone Value (PSV)
Mineralogical composition	<ul style="list-style-type: none"> • need for “fresh” durable aggregates as manifested by no/low secondary mineral content to avoid loss/breakdown of stone • most secondary minerals are deleterious to the durability of aggregates and secondary mineral count is directly related to such properties as water absorption and indirectly to strength (e.g. 10% FACT) • specification limits are placed in terms of the secondary mineral content
Organic matter	<ul style="list-style-type: none"> • need for aggregate to be free of contaminants to avoid poor binder adhesion and loss of stone cover • related to material finer than 75 microns which normally has high binder absorption • no organic matter allowed in rocks
Grading	<ul style="list-style-type: none"> • need for control on grading and dust content for rational design purposes as well as to avoid problems with bitumen adhesion caused by dusty aggregates • larger single-sized stone in certain seals (e.g. chip seals) allows more latitude with binder application rate before voids are filled and flushing/bleeding becomes a problem • specifications limits are placed on grading
Particle shape	<ul style="list-style-type: none"> • for some seals (e.g. chip seal) need for aggregate to be as cubical as possible for better particle interlock • particle shape strongly dependent on type of crusher (e.g. cone crushers tend to produce better particle shape than impact crushers) • certain materials are prone to producing flaky material (e.g. silcrete, basalt) • specification limits are placed on the Flakiness Index

Binders

The functions of the bituminous binder are to bind the aggregate particles together and to the underlying surface as well as to provide a waterproof seal. The rheology of the binder allows it to deform and relieve stresses in the surfacing caused by deflections of the pavement. The binder should be capable of conforming to the deflections at the coldest conditions expected otherwise cracking will occur. Once the cracks have occurred, ingress of water will usually result in rapid degradation of the surfacing, particularly where moisture sensitive materials are used in the construction of the pavement.

The durability of the bituminous binder is a key factor in the performance of surface treatments. Being a thermoplastic material, bitumen stiffens with a decrease in temperature and softens with an increase. With time, the binder in the seal hardens until it can no longer withstand the movement caused by diurnal temperature changes or flexure under heavy vehicles and cracking occurs, or until the bond between the cover aggregate and the binder fails and stone particles are displaced by traffic. The life of such a surfacing is thus critically dependent on the rate of the hardening of the binder and depends on the following factors.

- climatic regime (solar radiation, maximum and minimum temperature)
- binder film thickness
- intrinsic resistance of the binder to thermal oxidation hardening. This can be measured by the ARRB Durability test or by the Rolling Thin Film Oven test (RTFOT)

In areas where low temperatures are experienced a may become sufficiently hard during cold periods for the surfacing to become distressed. On the other hand, if the same surfacing is in an area with a mild climate then distress will not occur until the binder has aged. Thus, the hardness level at which seals first show signs of distress (as indicated by viscosity measured at 45°C) will vary with climate.

Figure 5.21 shows the relationship between bitumen hardening and seal life for bitumen of a given durability in an environment (Australia) which is very similar in many respects to the SADC region. This relationship shows the significant effect of temperature on the ageing/hardening of bitumens. A 5°C difference in the yearly mean of daily maximum and minimum air temperatures causes a halving of seal life. Since the rate of ageing/hardening is dependent on the durability of a binder, every effort should be made to use bitumens with the highest levels of durability.

The ARRB Durability Test⁴³.

The ARRB Durability test measures the intrinsic resistance of a bitumen to thermal oxidation hardening. In the test, a 20 micron film of bitumen is deposited onto the walls of glass bottles and these are exposed in a special oven at 100 °C. Bottles are then withdrawn periodically, the bitumen is removed, and its viscosity measured at 45 °C. The durability of the bitumen, is the time in days for it to reach an apparent viscosity of 5.7 log Pa.s (distress viscosity).

The ARRB durability test has been used in Australia since the mid 1970s for measuring bitumen durability. Most Australian State Road Authorities specify a minimum durability requirement for their bitumen. This test or the RTFOT is certainly worthy of wider use in the SADC region in order to engender a keener appreciation of the quality of the bitumens being used and the effect of bitumen durability on seal life.

Cape seals and single or double Otta seals with a sand seal cover, are generally less susceptible to ageing and surface cracking than conventional chip seals as indicated in the empirical data in Table 5.13. The close textured surface provided by the graded aggregate in the Otta seals, together with the sand seal or the rich slurry (in the Cape seal), offer a higher degree of protection to the binder in the underlying layers than is provided by the second seal in the more open-textured chip seals.

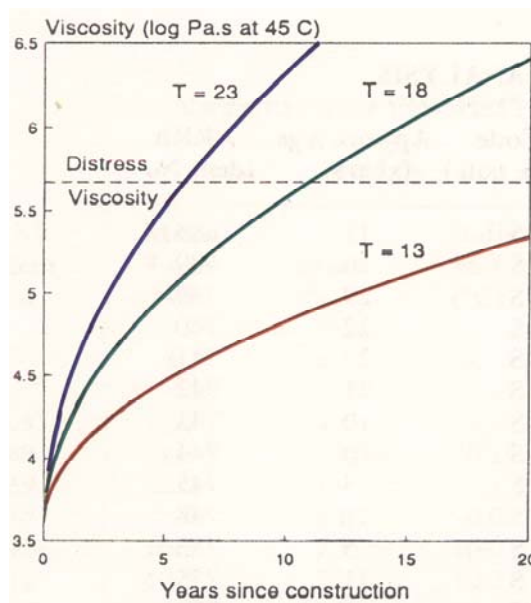


Figure 5.21 – Bitumen hardening graph for a given durability bitumen⁴⁴

The model illustrated in Figure 5.21 takes the following form:

$$\text{Log } \eta = 0.476TY^{0.5} - 0.0227DY^{0.5} + 3.59 \quad (\text{Pearson multiple correlation} = 0.93)$$

(Standard error of estimate of $\log \eta = 0.19$)

Where: η = the viscosity of the bitumen recovered from the sprayed seal (Pa.s at 45°C)

T = average temperature of the site calculated from the equation

D = ARRB Durability Test result (days)

Y = number of years since the seal was constructed

T = (Tmax + Tmin)/2 (Tmax = yearly mean of daily maximum air temperature (°C))
(Tmin = yearly mean of daily minimum air temperature (°C))

Commonly used binders: The following types of bituminous binders are in common use in the region:

- **Penetration grade:** 80/100 or 150/200 penetration grade is normally used with most surface treatments, except the Otta seal which requires softer grades, usually in the form of cutback bitumens.

As a general guide, the viscosity of the penetration grade binders is chosen with regard to the prevailing temperatures during construction and the stability under traffic. The harder (low viscosity) grades are more difficult to use but may be necessary to cater for heavy traffic in high ambient temperatures.

- **Cutback bitumen:** MC 3000 and MC 800 are commonly used, mostly in colder climates, where a relatively low viscosity binder is required to coat fine-grained aggregates (e.g. in an Otta seal), or damp aggregates, or to improve binder/aggregate adhesion. MC30 and MC 70 are used as a prime coat.

Cut-back bitumens are produced by diluting a penetration grade binder with the appropriate “cutter” to achieve the desired characteristics. After construction, the dilutants evaporate with time and the binder reverts back to its original penetration grade.

- **Bitumen emulsion:** Both anionic and cationic emulsions of high bitumen content (>60%) are used in most surface treatments and in a diluted form for the rejuvenation of surface treatments or in situations where it is not possible to use high cutter concentrations.
- **Tar:** This is known for its good adhesive and coating properties and good resistance to stripping by the action of water. However, certain tar binders (coke oven rather than gasifier) are no longer in common use because of potential environmental disadvantages. Low viscosity 3/12 EVT tar is used as a prime coat.
- **Modified bitumen:** Binders modified with rubber, or other constituents generally exhibit improved durability properties and are generally used in special circumstances, such as in very aggressive climatic (extreme temperature) environments.

Recommendations on the use of the above binders and the related safety aspects are covered in various SABITA manuals. Cut-back bitumens are produced by diluting a penetration

Health aspects of foamed tar⁴⁵

Tar is often perceived to be carcinogenic in all forms without considering the manner in which the constituents of the tar are produced.

The two main methods of tar production are pyrolysis of coal, which forms coke oven tar, and the Lurgi process, which produces gasifier tar.

Those components of tar which are believed to be carcinogenic are released to the atmosphere only at temperatures > 360°C. At that temperature, the harmful carcinogens are prevalent in coke oven tar but practically insignificant in gasifier tar. Thus, the use of cold-placed foamed tar is a safe, viable construction material for stabilisation of sub-standard pavement materials.

Specifications

Specifications for surfacing aggregates vary from country to country in the region both in the type of specifications and in the applied limits of similar test methods. Table 5.15 gives the specification limits for various aggregate tests for a representative selection of SADC and other countries. Some countries place more demanding limits than others while some countries qualify their specifications by traffic and others do not.

Table 5.15 – Some specifications for surfacing aggregates

Test Property	Botswana	South Africa	Zimbabwe (Traffic)	Australia (Traffic)
	-	-	(< 2x10 ⁶ ESA)	(AADT < 300)
10% FACT (kN)				
- Dry	> 210	> 210	> 120	> 135
- Wet/Dry ratio	> 0.75	> 0.75	> 0.65	> 0.60
Max. LAA (%)	-	-	35 25	-
MAX FI (%)	30	30	30	35
TBM Value	-	-	-	< 30
Unsound Stone Content (%)	-	-	-	8
Adhesion (R&W)*	< 1	-	-	< 2
Max(%) Sodium or magnesium sulphate soundness	-	-	20	12

* The scales used to describe the degree of stripping vary between countries.

Aggregate fitness for purpose



Example of a 10 year old crushed coral stone surfacing aggregate which does not meet traditional strength and durability criteria but, nonetheless, has performed very satisfactorily in a LVSR situation.

Box 5.9 – How appropriate are existing aggregate specifications?

Most existing national aggregate specifications are “blanket type” specifications covering materials for all categories of roads. They suffer from a number of shortcomings including:

- They are seldom traffic related and often rule out the use of non-standard aggregates. For example, a material that is marginal in terms of strength may fail when carrying high traffic volumes on a main road with high percentages of heavy vehicles, but may perform very satisfactorily in a low-volume rural road situation.
- They do not take into account the differing mechanisms of performance of the different seal types. For example, the need for a strong, cubically-shaped aggregate with a low flakiness index may be critical for the satisfactory performance of a chip seal but much less so for an Otta seal.
- The basis of derivation of some specifications, e.g. the minimum 10% FACT value of 210 kN, as employed in a number of countries, seems to be related to the traditional use of steel-wheeled rollers to embed the chippings and the related need for aggregate with a relatively high crushing strength. However, the current, common use of pneumatic-tyred rollers for this purpose does not require such high crushing strength, yet the limits remain the same as before.

The above examples indicate that in many instances traditional aggregate specifications are inappropriate for use with LVSRs and that there is considerable scope for relaxing them on the basis of experience and research evidence. Ultimately, the challenge is to fit the materials available to an appropriate seal type and design rather than vice versa.

Proposed Revision to Specifications

Revisions to the specifications for the commonly used chip seal are proposed and are given in Table 5.16. These are based on a review of international specifications, notably in Australia and New Zealand, as well as on experimental evidence and experience of the performance of surfacing aggregates in the SADC region. Specifications for the Otta seal are included for comparison.

Table 5.16 – Recommended revisions to chip seal specifications for LVSRs

Property	Design limits		
	Chip Seals		Otta Seals ¹
	Current	Proposed	
Strength 10% FACT (kN)	≥ 210	≥ 180 (> 500 vpd) ≥ 150 (100-500 vpd) ≥ 120 (< 100 vpd)	> 110 (> 100 vpd) > 90 (< 100 vpd)
Grading	As typically specified	As typically specified	Wide grading
Durability Wet/dry 10% FACT	≥ 75%	≥ 65%	> 75% (> 100 vpd) > 65% (< 100 vpd)
Flakiness Index (%) 19.0 – 13.2 mm 9.5 – 6.7 mm	≤ 25 ≤ 30	≤ 35 ≤ 35	If crushed material used. < 35 (weighted on 4.75 to 13.2 mm fractions)
Adhesion	R & W > 3	No relaxation. Precoat if R & W < 3	-
Water Absorption	-	≤ 5	Spray rate adjusted
Polished Stone Value	-	≤ 50 (> 500 vpd) ≤ 45 (< 500 vpd)	-

1 – Otta Seal specifications should comply with the Botswana Roads Department Guideline No. 1.

5.5.6 Selection of Surfacing Type

Factors affecting choice

The choice of the appropriate surfacing type in a given situation will depend on the relevance or otherwise of a number of factors, including the following:

- traffic (volume and type)
- pavement (type – strength and flexural properties)
- materials (type and quality)
- environment (climate – temperature, rainfall, etc.)
- operational characteristics (geometry – gradient, curvature, etc.)
- safety (skid resistance - surface texture, etc.)
- construction (techniques and contractor experience)
- maintenance (capacity and reliability)
- economic and financial factors (available funding, life-cycle costs, etc.)
- other (external factors)

Traffic volume and type: Practically any seal will be appropriate for low traffic situations, i.e. less than 750 equivalent light vehicles (elv)/lane/day. However, at very low levels (<250 elv/lane/day), lack of traffic moulding of the binder will result in relatively faster degradation of the seal, mostly through drying and oxidation of the binder with the development of shrinkage cracking. In such a situation, early rejuvenation of the seal may be required to retain the stone under traffic.

Traffic volume for surfacing selection and design purposes is often expressed as the number of “equivalent light vehicles” (elv) per day. This is equal to the sum of the number of light vehicles and 40 times the number of heavy vehicles.



Heavy braking and tight cornering situations require an appropriate choice of high stability surfacings. Asphaltic concrete and possibly Cape or double Otta seals would be preferred to sand, slurry, chip or single Otta seals.

The use of sand and slurry seals is generally not recommended for traffic levels of more than about 2000 elv/lane/day as they tend to “bleed” quickly and eventually break up. At traffic in excess of 5000 elv/lane/day, the use of a combination of a single chip and sand seal is also risky.

Where high percentages of heavy vehicles (particularly those with tandem and tridem axles) and/or harsh traffic actions (e.g. heavy braking and tight cornering) are likely, the use of sand, slurry and single seals should be avoided and, in such situations, asphaltic concrete, or a double chip, Cape or Otta seal is preferable.

Type of pavement: An evaluation of the performance of various seal types constructed on light pavement structures in southern Africa has revealed that seal life was very dependent on the stiffness of the pavement⁴⁶. The stiffer the pavement structure, the longer the life of the pavement before cracking. Deflection or “radius of curvature” measurements give an indication of the likely effects on seal life (Figure 5.22). Since surface deflection is directly related to the elastic modulus of the underlying pavement layers which, in turn, depends on in situ density then, *where feasible, every effort should be made to compact the pavement layers of LVSRs to the highest density practicable – i.e. “compaction to refusal”* (see Section 6.4.1).

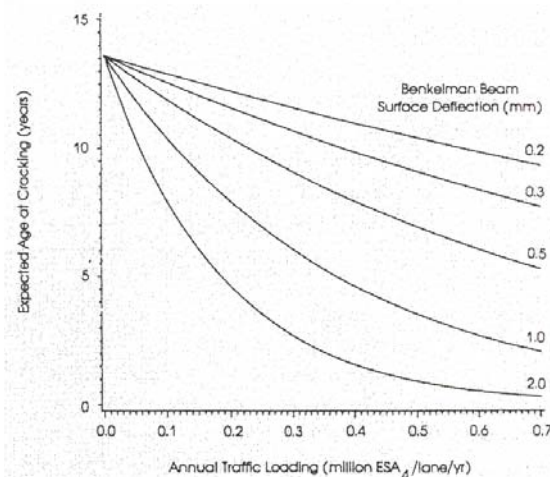


Figure 5.22 – Effect of surface deflection on seal life⁴⁶

In situations on LVSRs, where weak subgrades occur (e.g. in expansive or soft clay areas) or seasonal moisture variations are high (leading to relatively high deflections in the wet season), then the seal types which are more tolerant to relatively high deflections should be selected for use. For example, Otta seals or chip seals with appropriate modified binders are more tolerant of high deflections than others (e.g. slurry seals, Cape seals).



Bleeding due to embedment of surfacing aggregate in base.

A uniform, defect-free surface in the underlying layer is also required to avoid local distress in the seal. For example, soft bases will result in embedment of surfacing aggregate leading to loss of skid resistance and possible bleeding. This problem can be mitigated to some extent by the use of a low viscosity prime which will penetrate and strengthen the upper layer of the base and, in so doing, reduce embedment of the aggregate. In contrast, very hard bases could result in breakdown of soft surfacing aggregate during rolling. To reduce the severity of this problem, rubber-tyred pneumatic rollers, rather than steel wheeled rollers should be used.

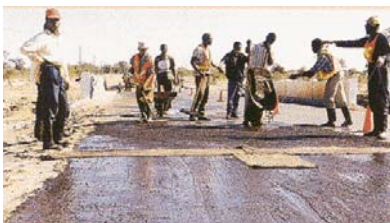
Materials: The type of aggregate available for use in a surface treatment has a major impact on the selection of the seal type. Where traditional aggregates are available within an economic haul distance, they lend themselves to use in conventional seals (e.g. slurry seals, chip seals, Cape seals). Conversely, where such aggregates are not available, then recourse to the use of more marginal aggregates in terms of, for example, strength or shape, is quite feasible with graded aggregate seals, such as the Otta seal. Table 5.17 indicates the types of seal that are best suited to various aggregates with marginal properties.

Table 5.17 – Seal selection based on marginal properties

Marginal Property	Recommended seals	Inappropriate seals
Grading	Otta, sand	Slurry, chip, Cape
Strength	Otta, sand, slurry	Chip, Cape
Durability	Otta, sand, slurry, Cape	Chip, slurry
Shape	Otta, sand, slurry	Chip, Cape
Dustiness	Otta, sand	Chip, slurry
Water absorption	Sand	Chip, slurry



Loss of second seal due to bitumen hardening and embrittlement.



The slurry seal lends itself to construction by labour-based methods.

Environment: Environmental conditions in terms of seal exposure to solar (ultra-violet) radiation, particularly in high temperature conditions, play a critical role in the performance of all seals. The thinner and more open textured seals, such as sand, slurry and single chip seals are particularly prone to early degradation due to oxidation and consequent embrittlement of the binder and ravelling of the aggregate. In contrast, Otta seals (single plus sand seal or double) and Cape seals, are especially suited to high temperature conditions due to the close interlocking aggregate texture and sand or slurry cover that protect the underlying binder from exposure to solar radiation.

Operational characteristics: The geometry of the road alignment in terms of gradient and curvature can have an adverse impact on seal performance. On steep grades or tight curves, the seals are subjected to significant tyre-induced horizontal stresses for which seals with adequate shear strength are required. In these circumstances, the use of asphaltic concrete might be appropriate and, to a lesser extent, double chip, Cape or Otta seals would be much preferred to sand, slurry or single chip seals.

Safety: In areas such as intersections, sharp bends and steep grades, adequate surface texture may be required for safety reasons, particularly in high rainfall situations. In such situations, certain seals, such as chip seals and coarsely graded Otta seals, due to their better skid resistance properties, would be preferred over sand or slurry seals.

Construction: The construction technique employed will usually influence the selection of seal type. The plant available, use of labour-based techniques or small contractors will result in the selection of seal types suited to these conditions. Similarly, the experience of the contractor with specific seal types can influence the quality of some seals (e.g. chip seals) to a considerably greater degree than sand or Otta seals.

Maintenance: Where maintenance capacity is high, raveling, potholes and cracks can be rapidly and effectively repaired using sand, slurry and Otta seals. However, where a time lapse between the development of defects and maintenance is likely, more resistant/thicker seals such as double Otta seals, double chip seals, Cape seals or even asphaltic concrete are recommended.

Special conditions: Where specific problem conditions occur, the seal selection must take this into account. For example, where there is a saline subgrade or saline construction materials are involved, then a highly impermeable seal is required, such as a bitumen-rich double chip seal or a Cape Seal.

Costs: The cost of constructing bituminous seals can be a significant proportion of the overall cost of a pavement, particularly in remote areas where traffic is light and aggregate may have to be hauled over long distances.

In very broad terms, for a typical LVSR project with no unusual circumstances in terms of excessive hauls or very remote areas, coupled with competitive tendering, the cost of priming, aggregate, binder and construction together make up between 10 and 20 per cent of the total road construction cost. Relative costs for various seals compared with a double chip seal (1.0) are given in Table 5.18.

Table 5.18. - Relative construction costs of LVSR surfacings

Type of seal	Relative cost	
	With prime	Without prime
Sand seal	0.56	N/A
Slurry seal	0.85	N/A
Single chip seal	0.56	0.58
Double chip seal	1.0	N/A
Single Otta seal plus sand seal	1.0	0.75
Cape seal (13mm + single slurry)	1.2	0.60
Cape seal (19mm + double slurry)	1.6	0.90
Double Otta seal	1.0	0.90

The final selection of the type of surfacing would depend on the outcome of a life cycle cost analysis which combines the discounted unit costs of the following items during service life of the seals under consideration:

- construction
- maintenance
- road user costs
- fog spray
- reseals
- repainting of road markings
- cleaning/repair of reflectors

Suitability for use on LVSRs

The suitability of various types of surfacings for use on LVSRs, in terms of their efficiency and effectiveness in relation to the operational factors outlined above is summarized in Table 5.19.

Table 5.19 – Suitability of various surfacings for use on LVSRs

(Key: SS = sand seal, SIS = Slurry Seal, SCS = single chip seal, DCS = double chip seal, CS = Cape seal, SOS+SS = Single Otta seal + sand seal, DOS = double Otta seal, AC =asphaltic concrete)

Parameter	Degree	Type of surfacing							
		SS	SIS	SCS	DCS	CS	SOS+SS	DOS	AC
Service life required	Short	■	■	■	■	■	■	■	■
	Medium	■	■	■	■	■	■	■	■
	Long	■	■	■	■	■	■	■	■
Traffic level	Light	■	■	■	■	■	■	■	■
	Medium	■	■	■	■	■	■	■	■
	Heavy	■	■	■	■	■	■	■	■
Impact of traffic turning action	Low	■	■	■	■	■	■	■	■
	Medium	■	■	■	■	■	■	■	■
	High	■	■	■	■	■	■	■	■
Gradient	Mild	■	■	■	■	■	■	■	■
	Moderate	■	■	■	■	■	■	■	■
	Steep	■	■	■	■	■	■	■	■
Material quality	Poor	■	■	■	■	■	■	■	■
	Moderate	■	■	■	■	■	■	■	■
	Good	■	■	■	■	■	■	■	■
Pavement and base quality	Poor	■	■	■	■	■	■	■	■
	Moderate	■	■	■	■	■	■	■	■
	Good	■	■	■	■	■	■	■	■
Suitability for labour-based methods		■	■	■	■	■	■	■	
Contractor experience/capability	Low	■	■	■	■	■	■	■	
	Moderate	■	■	■	■	■	■	■	
	High	■	■	■	■	■	■	■	
Maintenance capability	Low	■	■	■	■	■	■	■	
	Moderate	■	■	■	■	■	■	■	
	High	■	■	■	■	■	■	■	

Key	■ Suitable/ Preferred	■ Less suitable/ not preferred	■ Not suitable/ not applicable
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Whilst not exhaustive, the factors listed in Table 5.19 provide a basic format which can be adapted or developed to suit local conditions and subsequently used to assist in making a choice of surfacing options. These options can then be subjected to a life-cycle cost analysis and a final decision made with due regard to prevailing economic factors and the overall financial situation.



An example of a single Otta seal with a sand cover performing very satisfactorily after more than 13 years in service and without any surfacing maintenance in a harsh environment.

Box 5.10 – Merits and de-merits of the Otta seal

Although the choice of surfacing will depend on the particular conditions prevailing on any particular project and, ultimately, a life cycle cost analysis, the Otta seal merits particular mention. This relatively new type of seal has been found to be particularly advantageous in situations where the following factors play an important role:

- road construction in remote areas where, for example, only natural gravels occur and where it may be prohibitively expensive to set up crushing facilities
- contractor capacity may be low and workmanship may be of indifferent quality
- flexibility and durability of the surfacing is required to tolerate, for example, comparatively low-quality, low bearing capacity bases with relatively high deflections
- low maintenance capability
- high solar radiation resulting in an increased rate of weathering of the binder.

The disadvantages of using the Otta Seal include the following:

- need to cater contractually for the post-construction “after care” of the seal.
- blending of hot bitumen and cutting agents on site.

5.5.7 Surfacing Design

The complexity of surfacing design depends very much on the type of seal involved. Some seal types, such as the chip seals and Cape seal, entail a fairly complex, rational design process which involves selection of the appropriate aggregate size and calculation of the aggregate and bitumen spray rates, taking into account such factors as embedment of stone into the base or existing surface, gradient, climate, traffic speed, etc. Formulae and figures are available in the design manuals that allow these factors to be determined, fairly easily.

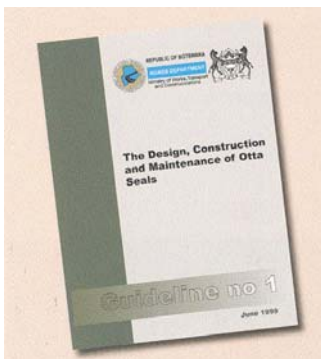
In contrast to chip and Cape seals, Otta, sand and slurry seals are designed on the basis of broad guidelines and constructed by “feel” with the required ability of site personnel to adjust or correct the aggregate and binder application rates as a project proceeds or the material quality varies.

The general aspects of seal design for the various surfacing types discussed above, except for the Otta seal, have all evolved from extensive South African and British practice as contained in the following documents:

- Draft TRH 3 (1996)⁴⁷.
- TRL – Overseas Road Note 3⁴⁸.
- SABITA Manual 10⁴⁹.

Until relatively recently, no formal guideline or manual existed for the design of Otta Seal. However, this short-coming has been rectified by the production of the following documents:

- Ministry of Works, Roads Department, Botswana: guideline No. 1 – The Design, Construction and Maintenance of Otta Seals.
- Norwegian Public Roads Administration: Publication No. 93 – A Guide to the Use of Otta Seals.
- Pavement and Materials Design Manual, Ministry of Works, Tanzania.



The Otta Seal guideline contains detailed information on the design, construction, maintenance, specification and contractual aspects of Otta seals.

5.6 Summary

1. The main factors affecting the performance of low-volume roads are traffic and environment, with the latter being more significant at low levels of traffic. Drainage in terms of the crown height is particularly influential. Thus, measures that improve the pavement environment will significantly improve the performance of low-volume roads.
2. Examination of the origins of testing procedures and specifications for road-building materials often reveal that they emanated from very different environments and for different levels of traffic than those that prevail on low-volume roads in the SADC region. It is on the basis of these tests and specifications that many local materials are classified as “sub-standard” or “marginal” but often perform much better than expected.
3. Measures that provide an improved (drier) road environment, such as sealing shoulders and deepening side drains, also enable locally available materials, previously considered unsuitable for road construction purposes to be used with greater confidence.
4. The materials available for road construction in much of the region are weaker than those generally found in Europe or the USA but subgrade soils tend to be stronger. Thus, strong subgrades and the generally drier prevailing environment facilitate the use of these “sub-standard” local materials in the upper pavement layers.
5. Pavement designs are now available, which are based on research in the region and include local environmental factors. These designs are intended to make the best use of locally available materials without incurring unacceptable risk of failure. Familiarisation with local conditions and advice from local professionals will help to ensure that more appropriate designs can be implemented with confidence.
6. The traditional surfacing for sealing low-volume roads was a chip seal using a single sized stone with a high strength specification. Other options are now available that enable lower strength locally-available aggregates to be used in designs that produce durable road surfacings.
7. Forecasts of vehicle loading and predicted damage to road pavements are usually based on the 4th power law. In dry environments, road pavements can be stiffer than usual and there is evidence to suggest that a lower exponent might be more applicable, thus reducing the effect of heavy vehicles in comparison with lighter ones.

This chapter has covered aspects of pavement design, materials and surfacing of LVSRs, which are subject areas in which substantial advances in knowledge has been made through research in the region. The judicious use of the recommended designs together with the appropriate construction methods covered in the following Chapter 6, will reduce sealed road construction costs and increase the provision of rural road infrastructure.

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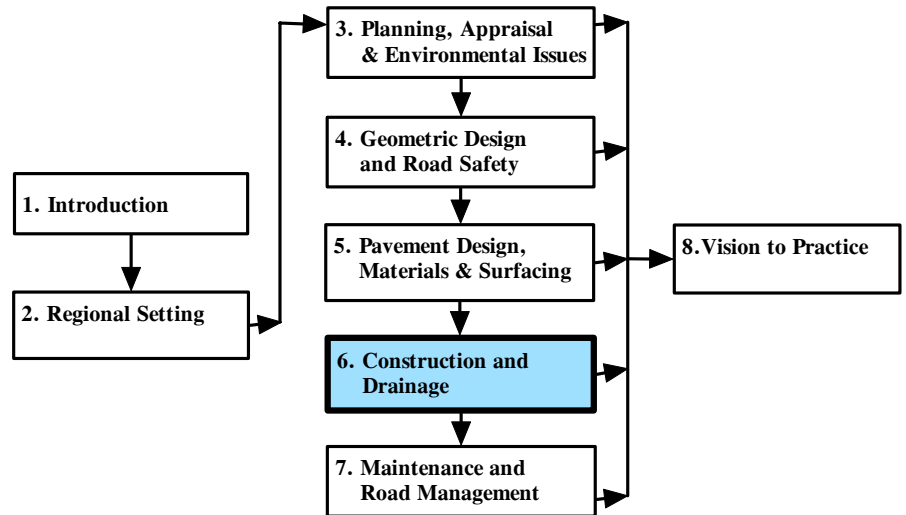
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Chapter 6



Construction and Drainage

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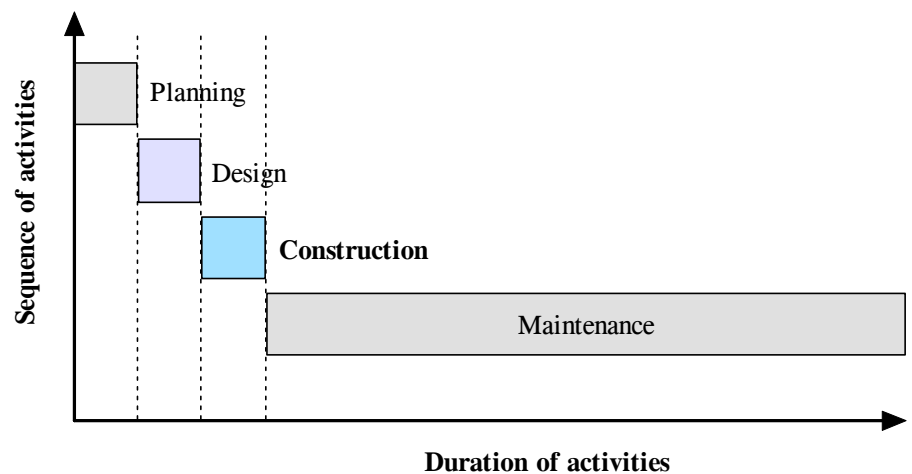
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Construction and Drainage

6

6.1 Introduction

6.1.1 Construction



Construction is a practical manifestation of the planning and design phases of LVSR provision in which the constructor faces the challenge of adopting a *construction strategy* that is appropriate to the prevailing social, economic, cultural and other needs of a particular country. In the SADC region, such a strategy should be aimed at optimising the use of limited funding by making maximum use of the relatively abundant resource of labour, indigenous materials and construction skills.

A secondary objective and consequence of adopting an appropriate construction strategy is that it should reduce the demand for scarce foreign exchange, principally by reducing the need for plant intensive operations, where feasible. This often requires modification of the conventional construction management techniques, contract conditions, tender evaluation procedures, and the administration and financing procedures normally used for the construction of major, high-volume roads.

Whatever construction strategy is adopted, the quality of the construction process is critical as it can impact significantly on the subsequent costs of maintaining the road. For example, *any initial savings made during construction through inadequate provision of drainage or lax quality control are likely to be paid for, many times over, during the life of the road through additional maintenance and road user costs.*

6.1.2 Drainage

Drainage is widely recognised as the single, most important factor that controls the performance of any road, more so a LVSR in which naturally occurring, often moisture sensitive, materials are used. The lack of good drainage can lead to ingress of water into the road structure leading to structural damage and costly repairs, whilst surface water can form a road safety hazard, especially on high speed roads when it can result in aquaplaning. For these reasons, adequate attention to drainage is not only an important aspect of the preceding design process, but also the construction and maintenance phases of road provision.

A clear distinction should be made between internal drainage and external drainage. Internal drainage is concerned with controlling the movement of water within the road pavement or embankment while external drainage is concerned with the control of surface water by various measures in the design and construction. In the final analysis, a balance has to be struck between the cost of the drainage measures and the function of the road as perceived by road users.

6.1.3 Purpose and Scope of Chapter

The main purpose of this chapter is to highlight the significant differences in approach to the construction of LVSRs as compared to high volume, major highways. In view of the importance of utilising the most abundant resource in the region – labour – the chapter also seeks to raise awareness of the scope for utilising labour-based construction and the type of equipment that is best suited to complement this approach. The importance of appropriate internal and external drainage is also highlighted as being of crucial importance in the performance of LVSRs.



Disruption of traffic and pedestrian movements due to flooding of rivers is a common problem in many rural areas.

In view of the significance of labour-based methods in the construction of LVSRs, wherever this issue arises, it is indicated as follows:

LBM

6.2 Construction Issues

6.2.1 LVSR Characteristics

The construction *process* for LVSRs does not, in principle, differ from that of other road types. However, LVSRs are much more sensitive to the social, economic and technical context in which they are built. Variations can be considerable with regard to the choice of construction method, type of resources available and type of construction materials being used. Moreover, aspects regarding social and environmental impacts, including the need for any resettlement action plan, require particular attention prior to the start of construction.

One aspect of the provision of LVSRs that is receiving increased attention is the use of labour-based construction. All governments in the region recognise that economic growth and redistribution of wealth rely upon increased employment opportunities. Continuous efforts are therefore being made to create productive employment through the use of labour-based construction (and maintenance), where technically and economically feasible.

6.2.2 Labour-Based Construction

The objective of labour-based construction is to maximise the number of job opportunities per unit of expenditure. This approach involves using a combination of labour and light equipment instead of heavy plant, without compromising the quality of the end product. It optimises the use of labour, and employs equipment only for those activities which are difficult for a labour force alone to undertake efficiently and cost-effectively. Unfortunately, despite the well-publicised and substantial potential benefits offered by labour-based construction, a number of myths and problems relating to this technology still persist in the minds of some practitioners.

Box 6.1 – Common misconceptions about the use of labour-based methods and small scale labour-based contractors¹.

Myths:

- standards should be lowered to allow for labour-based methods
- labour-based construction is out-of-date and incompatible with the modern world
- labour-based methods can be used for any construction activity
- labour-based construction is only for welfare relief schemes
- ill-educated contractors will never understand tender procedures
- voluntary labour can be used to keep costs down

Problems:

- lack of suitable documentation for the management of labour-based contracts
- many clients are still not open to even considering a labour-based approach to new projects
- inability of many clients to expedite payment for labour and materials fast enough to keep a labour-based contract operating smoothly.

In order to overcome these problems, suitable forms of contract need to be more widely used, clients need to gain experience in awarding and managing labour-based contracts and small-scale contractors also need to gain experience in managing such contracts efficiently. Government ministries also need to develop strategies that facilitate the implementation of pro-employment policies.



The development of a White Paper on Labour-based Works Policy is an example of a pro-active strategy by a SADC government to achieve increased utilization of abundant human resources in the roads sector².

Examples of appropriate choice of technology



Screening of aggregate for road surfacing.

Before construction starts, all relevant environmental assessments should be completed to ensure that the project does not achieve its own goal at the expense of loss or inconvenience to non-beneficiaries or future generations³.

Suitability of Construction Activities for Labour-Based Works

A number of activities are well suited to labour-based methods such as site clearance/bush clearing and ditch excavation while other activities, such as compaction of pavement layers or haulage of materials over long distances (typically > 5 km) are not. Quite apart from economic considerations, some construction activities (e.g manipulating heavy precast sections) are just not possible without the help of the right machinery. However, this kind of problem can be avoided if emphasis is given to those activities that can be undertaken effectively by labour-based methods, and design options selected that minimise the requirements for plant.

Labour-based projects usually employ a relatively large number of labourers. In such a situation, the site management staff need to be particularly good “man-managers” with a strong managerial as well as technical background. They will need to be familiar with local traditions and social structures in order to avoid serious disputes on site that could threaten the progress of construction and, ultimately, the sustainability of the project.

6.2.3 Environmental Considerations

Road construction can adversely affect the environment in a variety of ways. Assuming that the necessary mitigating measures have been incorporated in the contract documents, then it is important that the contractor is made fully aware of the environmental responsibilities as part of the contractual obligations. Moreover, compliance with the project’s environmental requirements should be monitored throughout the construction process in order to correct problems before they occur. (Section 3.4)

Box 6.2 – Typical best practice guidelines for environmental mitigation³.

- **Construction process:** Ensure the existence of an Environmental Management Plan which sets out the specific undertakings for the necessary environmental protection responsibilities, measures, monitoring and auditing to be undertaken during construction in order to achieve the environmental requirements set out in the contract.
- **Construction procedures:** Ensure that procedures are adopted that:
 - minimise disturbance to flora and fauna
 - minimise sedimentation and erosion by implementing effective drainage/stormwater control measures
 - minimise generation of dust and noise
 - progressively revegetate disturbed areas during road construction
 - minimise visual impacts and environmental disturbance at site camps
 - minimise environmental impacts of stockpiles and storage of materials
 - minimise construction wastes and dispose at an approved environmentally sustainable location
 - provide environmentally sound management for the handling, storage and disposal, if necessary, of fuel, oil, lubricants, bitumen and chemicals used in the road construction process
- **Auditing:** Ensure the existence of a documented environmental due-diligence system to measure compliance with environmental management requirements throughout the construction process with the objective of correcting problems before adverse environmental impacts occur.

6.2.4 Mobilisation

Preliminary and General Items

LVSRS are often constructed in remote areas and mobilization costs normally make up a substantial part of the total project cost. The cost of preliminary and general items, where mobilisation is included, is a larger proportion of total construction cost for LVSRS than on more heavily trafficked roads.

However, where labour-based methods are utilised, one can expect mobilisation costs to be considerably lower than for large machine based units. This favours the use of labour-based methods in remote locations, in circumstances where projects are relatively small or where larger projects can be unbundled into smaller contracts.

Health and Safety on Site

Road construction is amongst the most hazardous occupations in all countries of the world, particularly on projects where a large amount of labour is involved. The following typical LVSR site situations require that particular attention is paid to health and safety precautions on site:

- LVSRS are often constructed in remote areas where access to emergency medical care is limited, thereby worsening the consequences in the case of accidents on site. Under these circumstances, greater awareness is needed of the risks attached to certain especially hazardous operations, and appropriate measures should be established to minimise these risks. For example, trained First Aid staff should be employed on site and an adequate stock of First Aid equipment and medicines should be kept in a secure clean place. This may, in any case, be a requirement under national employment law.
- Handling of hot bitumen is potentially hazardous due to the risk of burns and inhalation of fumes. The use of bitumen emulsion, which can be manufactured on site, is to be preferred⁴.
- Traffic safety measures in remote areas with low traffic density are often given less attention than they deserve. However, the hazards of traffic moving through construction sites at high speed always pose a severe danger to the construction staff.



Handling of bitumen is a hazard and requires suitable locations for storage, heating or blending.

Counselling ahead of project commencement is an important measure to combat the spread of HIV/AIDS as a result of construction activities.

HIV/Aids

All governments in the SADC region are committed to combating HIV/AIDS. Construction operations are relevant in this regard on account of the following:

- Construction of roads requires the services of skilled personnel, depending on the type of operation and project. This leads to migration of labour and sometimes division of families, a situation that is widely considered to be a contributory factor in the spread of HIV/AIDS.
- LVSRS are often constructed in sparsely populated areas where the local communities are vulnerable to the transient effects from the influx of large numbers of workers. The establishment of a road camp may cause a rapid change in the local economy, which further exacerbates these effects.

Awareness and active involvement in taking measures to combat HIV/AIDS has become a necessary requirement for sustainable operations and affects all responsible parties involved in road construction.

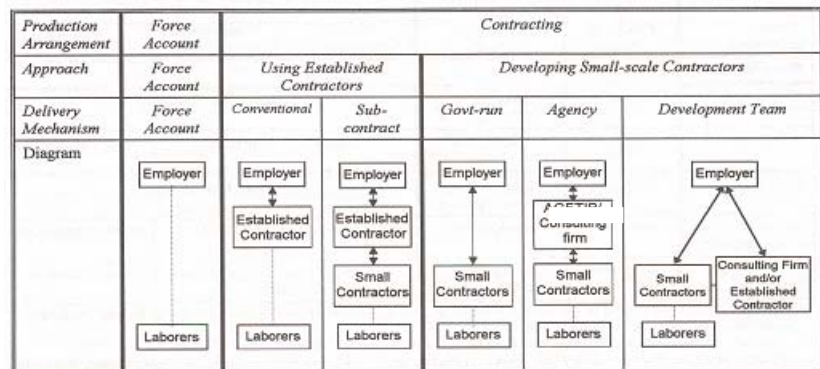
6.2.5 Contracts

Labour-Based works

The three main delivery mechanisms that may be adopted for expanding labour-based methods of construction and maintenance amongst small-scale contractors are shown in Figure 6.1 but can be briefly described as follows⁵:

- *The Government-run Model* whereby the responsibility for all aspects of contractor development (including small contract administration and payment) lies with the government roads agency.
- *The Agency Mode*, whereby responsibility for all aspects of contractor development lies with an independent non-profit management agency or with a for-profit consulting firm.
- *The Development Team Model* whereby the responsibility is divided among the employer, a construction manager and a materials manager.

Figure 6.1 – Alternative arrangements for undertaking labour-based works



The type of model to be adopted will depend primarily on the country's contracting environment and the extent to which the institutional reforms mentioned in Chapter 2 have been embraced. For example, if the roads agency is functioning well and reform can be facilitated, the Government-run model may be most suitable. Conversely, if the roads agency is unable to undergo the required reforms within a reasonable time, or would prefer to pass a portion of the risk of contractor development to the private sector, a Development Team Model may be the most suitable.

Risk Aspects

Wherever roads are constructed with innovative methods or marginal quality of materials, the aspect of risk inevitably plays a role in the process (Pavement Design Chapter-Section 5.4.6). Risk needs to be carefully considered and managed in relation to the potential benefits offered. The roads agency is often in the best position to allocate risk as it sees fit because it is generally in control of the conditions that control the project.

The construction of LVSRs offers much scope for innovation and cost-savings as highlighted in all chapters of this Guideline. However, given the nature of the construction industry, the party most able to promote innovation is the roads agency. In so doing, *the agency cannot expect to reap the potential benefits of reduced construction cost that lie in the use of innovative methods unless it is also willing to carry a part of the any potential risks that may be perceived to be involved.*

A commercially operating contractor or consultant will have to price risk into a contract, involving insurance cost and potential losses in execution of the project if problems occur. This aspect is a common hindrance to innovations that would give considerable benefits to society by providing LVSRs in rural areas using more cost effective methods. It therefore appears reasonable that society, through the agency, also carries a larger part of the calculated risk, bearing in mind that society is also the potential beneficiary in the use of innovative methods. Thus, the roads agency should carefully consider the merits of sharing some of the risk that normally lies with the contractor when allowing, encouraging, or prescribing the use of methods or materials that are perceived to carry increased risk.

Planning and Design Stages

The key to ensuring optimal operations in construction with marginal materials, and in a variety of different climatic conditions, lies in the preparation and planning/design of the contracts. Deriving maximum benefit from the use of marginal materials relies on the contractor's use of appropriate methods of winning the materials and subsequently processing them to meet the prescribed specification. The aim is to utilise the full potential of the material sources found in the project area once the appropriate standard has been set for the project. As illustrated in Box 6.2, incentives can be included in the conditions of contract to ensure that the contractor strives for the same end result as the agency responsible for the project.



Use of rock materials in bulk earthworks can speed up construction by:

- Allowing thick layers to be constructed in a single lift.
- Eliminating the need for construction water and mixing in earthwork.
- Minimising the need for laboratory testing.

Box 6.3: Issues to consider during contract preparation

Contractors normally depend strongly on their cash flow to meet their financial obligations for the project, and the following aspects should therefore be given particular attention in preparation of contracts for construction of LVSRs:

- A contractor may be reluctant to stockpile materials well ahead of construction (an approach that improves the management of marginal materials), unless there is separate payment for borrow pit operations that secures his cash flow.
- A contractor is unlikely to select the better of two materials that both meet minimum quality requirements if he/she has to carry the entire amount of any additional cost incurred.
- The inclusion of haulage cost in the contract plays a key role in directing and creating incentives for the contractor to locate and use material sources of non-standard quality, the use of which are considered desirable and, ultimately, also of benefit to the roads agency.
- Although the specification should be written to cater for producing an acceptable end product with marginal, variable materials, there may be instances where exceeding the specification minimum may be beneficial to the project. However, a contractor is unlikely to use additional resources or time in the processing to achieve a better than specified end result unless there is an appropriate reward scheme in place.
- In the choice between use of machinery or manual labour, a contractor is likely to select the option that gives the best utilisation of *his own resources* and gives the better cash flow. This may not coincide with the optimal resources for the project from a national socio-economic perspective. Thus, where warranted, it may be necessary to specify certain operational methods in the conditions of the contract.

Construction Stage

The ultimate goal of all parties on a construction project is to achieve optimal use of the available resources to meet the prescribed standards in the most efficient manner. However, after the project has started, it may not always be possible to make changes in itemisation and payment schedules without incurring a claims situation. Nonetheless, the supervisory staff can facilitate the attainment of optimal solutions in a number of ways which avoid claims. The following are typical examples:

- if available, the use of better quality materials can be promoted by pointing out the potential for reduced time needed for processing of the layer, often less need for the addition of water and a greater likelihood of attaining the specifications more consistently
- consistently improving the workmanship/method can justify the increased use of method specifications, reduced frequency of control testing or use of simpler test methods. This will, in turn, benefit the contractor by increasing the speed of construction

6.2.6 Earthworks Quantities and ‘Design and Construct’ Methods

The cost of earthworks in LVSR construction comprises a larger proportion of total costs than is the case with major highways where more expensive options for pavement structures and other installations are often used. Thus, a key factor in reducing total road costs is to maximise the use of fill materials in the road alignment and minimise haul distance or, preferably, avoid it altogether i.e. cut to fill by machine or to borrow from within the road reserve/side drain. Fill is a key factor in reducing the cost of earthworks.

Box 6.4 - Field staff requirements when using “design and construct” methods

Where ‘design and construct’ methods are used, it is vital that field staff understand the consequences of the selection of alignment. This is important for:

- traffic safety
- internal and external drainage of the pavement
- measures required to deal with poor in-situ soils
- quantity measurement for payment

The amount of earth-works is decided by:

- *the designer where pre-made geometric designs are used*
- *the site staff where design by eye methods are used.*

‘Design and construct’ methods can provide benefits of increased speed of construction and, in some cases, reduced earthworks quantities with associated cost savings, but this approach is only viable where the field staff have the required skills and knowledge and the appropriate measurement-for-payment procedure is in place.

The horizontal alignment should always be given the highest priority when allocating resources for alignment selection. This is because of the benefits that accrue from not having to move the road alignment if the road is later upgraded. However, in fixing the alignment, careful attention must be given to a large variety of features within the road corridor including dwellings, fields, graves, community access, drainage and irrigation channels, catchment areas, proximity of in situ material, avoidance of rock and unsuitable materials, preservation of flora and fauna, etc.



Supply of construction water may involve establishing large temporary pipelines.

LBM



Stabilisation with lime or cement can be successfully applied with basic methods and use of manual labour.

6.2.7 Working With Nature

Cost savings can be made where timing of the construction operations can be programmed to suit favourable weather conditions. However, a flexible approach is required in such cases. In contract work, such an approach may be difficult to achieve due to contractual difficulties unless the contracts are tailored especially for the purpose. Force account construction offers more scope for flexibility to take advantage of local conditions that often change rapidly and are not easily foreseeable. They allow changes to be made and new procedures to be introduced on site without triggering contractual disputes.

An example of “working with nature” in a hot and dry climate is to minimise the use of water for compaction, thereby reducing associated cost and delays⁶. Such techniques may include:

- Removing overburden from borrow pits before the rainy season in order to allow water to penetrate deep into the gravel seam and thereby increasing the moisture content prior to stockpiling.
- Carrying out compaction of the subgrade during or just after the rainy season (i.e. in conditions nearer to the optimum for compaction).
- Adding and mixing-in water at night in order to minimise loss by evaporation

However, it is important to be aware that it can be more expensive to dry out gravel that is wetter than optimum than to import water for compaction.

6.2.8 Stabilisation

Not all natural gravels are suitable for use as road pavement materials in LVSRs and some form of improvement may be required to achieve adequate strength and to limit permeability. There are numerous types of stabilisers available for the purpose of achieving these improvements of which the conventional ones - cement and lime, have had considerable success in the past within the region. Stabilisation with pozzolan can be expected to be similarly effective if applied correctly. Bitumen has become a viable option in recent years by the development of emulsions and foaming technologies for use with natural materials.

In addition to the conventional and well proven stabilisers, the market now offers literally hundreds of brands of alternative chemical stabilisers. However, experience with the use of these stabilisers has generally been mixed and they should be used with extreme caution.

As a general rule, stabilisers of all kinds should only be used after careful consideration has been given to all other options including, in particular, screening of materials to improve their grading or mechanical stabilisation through blending of materials. Unless there is some previous experience of using the products, there is always an inherent risk in adding substances to natural materials that, potentially, may not work as expected and may result in increased construction costs. For example, there is the risk that failure of the stabilisation method can make reworking of the material difficult and costly because previously-stabilised gravel could require the addition of at least 40 per cent fresh gravel for the remedial works.

6.3 Construction Equipment

6.3.1 Introduction

Traffic loading on newly constructed pavements by construction equipment is a concern on long duration projects where very heavy loading takes place after completion of the surfacing. In such cases, construction traffic should be included as part of the design traffic. Otherwise, work sequence/planning will be needed and measures applied to minimise the effects of construction traffic.

The choice of the most appropriate type of equipment for a particular project is normally dependant on the following major factors:

- site conditions
- type of operations
- size of the project
- soil conditions and material types being used
- the degree to which manual labour is used in the operation

Equipment in current use for construction of LVSRs in the region varies from heavy equipment for major highways to the light plant used for labour-based methods. It will often not be appropriate to use high-capacity, heavy equipment on many LVSR sites because of the smaller quantities of materials and dimensions of the works. Such equipment is certainly not appropriate where labour-based methods are used to any significant degree. Use of manual labour for construction operations requires flexible solutions with many small units of equipment.

6.3.2 Equipment Used with Labour-Based Methods

Fully labour-based methods usually require, in addition to hand tools, the provision of simple equipment such as wheel barrows and perhaps animal drawn carts, often supported by some mechanical transport. In addition, hand-operated compactors may be used for compaction. These require the use of specific methods to be effective, such as construction with a maximum layer thickness of 75 mm, and are unlikely to be effective in operations where pavement materials require compaction on a large scale. Heavier compaction equipment than the light equipment normally used on labour-based unsealed roads may be required for compaction of the pavement layers for sealed roads. Penetration macadam, emulsion-treated base and thin reinforced concrete pavement, can all be constructed entirely by labour-based methods, whereas densely graded materials require the use of plant-based methods in order to be effective.

Labour-Adapted Equipment - Tractor Units

Construction units with agricultural tractors⁷ will provide flexibility in the use of the smaller items of equipment that suit operations where manual labour is a major component in carrying out the roadworks. The uses of agricultural tractors in key operations include:

Loading/transport: A small number of tractors can operate, intermittently, many small buckets or trailers, thereby giving labourers sufficient time to load the buckets and trailers, whilst maximising the utilisation of the tractors. Buckets and trailers should be of such a height that they can easily be loaded by hand or, if this is not possible, the bench method can be used to facilitate hand loading.

Spreading/shaping: Graders suitable to be towed with agricultural tractors are available in several sizes to undertake spreading and shaping operations. Alternatively, these operations can also be done by hand if some reduction in the regularity of the longitudinal profile is accepted.



Wheelbarrows constitute part of the equipment used in LBM.



Typical tractor-drawn equipment used in LBM.

For scarification and stockpiling in borrow pits there is little practical use for tractors. Bulldozers and excavators are normally required. Labour can also do this work under favourable site conditions.



A typical tractor unit used in labour-based construction.



Typical gravel loading operations.

Watering: Tractors can be used to tow water bowsers fitted with simple spray bars to spread the water evenly on sections prepared for compaction.

Mixing on the road: Agricultural disc harrows towed by large tractors are very effective for mixing, including mixing materials on the road with water and for stabilisation or blending.

Compaction: Towed vibrating, grid or tamping rollers. (For labour-based methods, rollers are often hand controlled).

Surface preparation: Towed mechanical brooms.

Bitumen operations: Towed bitumen sprayers can be used for priming and binder application in conjunction with suitable heating and pumping equipment. For labour-based methods, bitumen emulsions are generally preferred to avoid the need for heating to high temperatures.

Surfacing aggregate: Spreading aggregate by hand from towed trailers – also used for towing backchip units.

Box 6.5 - Advantages of using tractor units.

Operationally, the tractor-based units have the following advantages that are well suited for use by emerging contractors and for operations in remote areas:

- Plant operation: Fewer mechanical items are in use and units are simple to maintain with ordinary mechanical skills.
- Plant availability: Easy to find locally available plant hire outside the ploughing season, thereby offering flexibility in fleet management.
- Better utilisation of agricultural tractors.
- Spare parts for tractors are usually readily available: Agricultural tractors often have easy access to spare parts compared to heavy construction machinery.
- Income to the community

6.3.3 Heavy Equipment Units

Construction units of various sizes based on conventional equipment, as opposed to tractor based units, have been widespread in the region. The components in typical units of this kind have the following features in the context of constructing LVSRs in remote areas, often by an emerging contracting industry:

Bulldozers for stockpiling: These have generally been replaced with more economical Excavators. Cat D8 or larger bulldozers are difficult to utilise economically where material sources are small, scattered and of very variable quality within each borrow pit. Cat D7 or smaller models are normally better suited. Bulldozers require regular (every 250 hours) preventive maintenance.

Front-end loaders for loading: Front End Loaders are available in a variety of sizes. They are used mostly for loading gravel but use of this type of equipment is also dependent on the size of trucks available. For LBM, a Tractor Loader Backhoe is also suitable and can load a 6 cubic metre truck in 5 minutes.



Graders are versatile for processing materials on the road.



Excavators are convenient for various applications, including lifting.



will benefit the grading and quality of the available material.



Grid

Scraper-operations: These are effective where earthworks quantities are large and where material quality is not critical. (The control of material quality is very difficult when using scrapers). The advantage of scrapers is that they can be used for cutting the road way, excavation of drains, filling, spreading and, to some degree, compaction, all with the one machine. However, motor scrapers incur very high investment and operational costs and therefore require high utilisation and mechanical skills for their maintenance. Thus, they are expensive to operate and currently tend to be replaced using a combination of other plant.

Motor- graders are versatile and are typically used to level tipped heaps, spread gravel, break down oversize, mix in water, place gravel layers for compaction, cut levels, shape road prism, shape cut-off berms and cut mitres. Most operations carried out by the use of motor graders can be undertaken by labour-based methods. However, on higher trafficked roads, it may be preferable for good riding quality to cut the final levels with a motor grader. This can be carried out as a one-off operation whenever a sufficient length (say 20 km) of base has been placed by hand.

Excavators: Large excavators can carry out the operations of both a bulldozer and a front end loader for earthmoving in the road-way and in the borrow pits and is an economical option. Selection of material quality is very difficult and such operations can, therefore, be used only where material quality is uniform or can be mixed in situations where quality assurance is not critical (e.g. for bulk earthworks).

Articulated dump trucks: These incur high investment and operational costs with stringent requirements for mechanical skills in their maintenance. They can be efficient in high capacity operations and provide both an off-road and an on-road driving capability wherever the units can legally use public roads.

Tipper trucks: Ordinary tipper trucks are often favoured by emerging contractors because they can be used for other transport purposes and are readily available on the second-hand market, generally with readily available spare parts. The skills required for their mechanical maintenance are moderate.

6.3.4 Compaction Equipment

As well as conventional rollers for compaction there are examples of equipment that give particular benefits in the construction of earthworks and pavement layers for LVSRs. Some of these are:

Grid roller: This is a static roller towed at a relatively high speed of 15 km/hour for breaking down oversize and 8 km/hour for compaction. In this manner the material is better utilised and problems due to oversize particles are avoided. Good results are generally obtained with the use of this plant for compaction of pavements constructed with natural gravel and of fill layers with marginal quality materials, which can sometimes be difficult to compact to the full layer depth.

The roller allows compaction of the layer to take place in several smaller lifts at the same time as the graders spread the material. This is achieved without forming laminations and shear planes within the layer due to the pattern of the surface of the roller.



Pneumatic



3-sided Impact compactor

Very heavy towed pneumatic rollers: This type of roller can be up to 50 tonnes mass on one axle and has been used successfully for compaction and proof rolling of the roadbed, especially in thick layers of single-size sand. Its advantage is in the provision of a uniform and sound foundation for the pavement, achieved by collapsing and densifying any soft areas.

Impact compactors: These are non-circular, relatively high-energy ‘rollers’, typically three-, four- or five- sided. Large-wheeled tractors are used for pulling the compactors at operational speeds of 12 – 15 km/hr producing a series of high amplitude/high impact blows delivered to the soil at a relatively low frequency (90 – 130 blows per minute) with the energy per blow varying between 10 and 25 kilojoules, depending on the mass and amplitude of the compactor.

Due to their very high *energy density* per blow, their main advantage over conventional compaction plant is their depth-effectiveness, typically of the order of one metre of fill or in situ layers, thereby producing deep, well-balanced, relatively stiff pavement layers. These rollers are well suited for densifying collapsible soils. They have been successfully used in low-cost road systems and, when appropriately specified, offer a cost-effective option for LVSR construction⁸.

Selection of Compaction Plant

Figure 6.2 provides a broad guide to the selection of compaction equipment. Each roller has been positioned in its economic zone of application. However, it is not uncommon to find them working out of their zones. Moreover, the exact positioning of the zones can vary with differing material conditions.

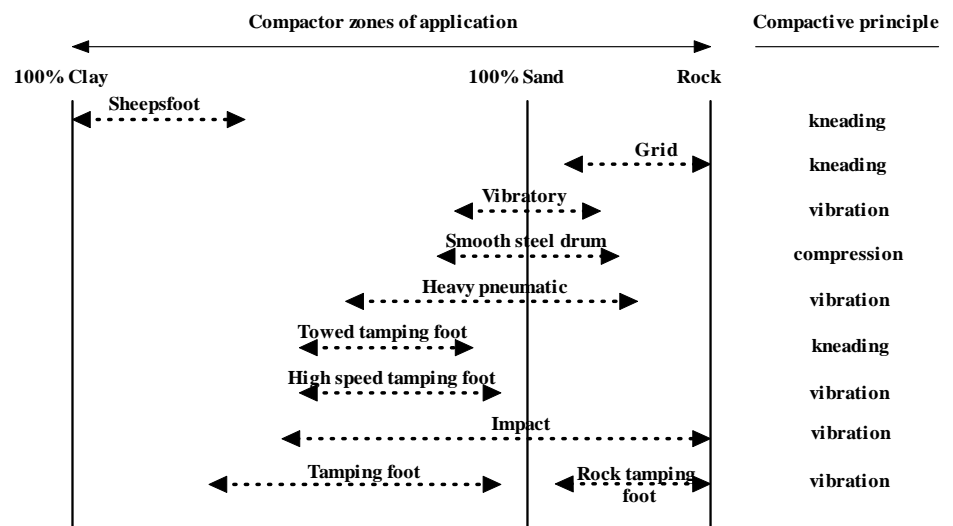


Figure 6.2 – Compaction equipment selection guide⁹

The degree to which soils and natural gravels can be utilized in LVSR construction, instead of more expensive processed materials, will determine the success of the project in terms of economy in both construction and maintenance.



Large thickness of overburden does sometimes exclude labour-based methods for winning gravel materials (the example shown in the picture is from construction of LVSRs where the thickness of the overburden is in excess of 2m).

6.3 Utilising Soils and Natural Gravels

6.4.1 General Considerations

Natural Gravel Resources

In areas where natural gravel and soils are available for road building purposes, these materials constitute the most valuable resource in the construction of LVSRs, hence, every effort must be made to use them in a creative manner – a challenge that has met with significant success in the SADC region. However, this has required that particular attention be paid to construction methods.

LBM

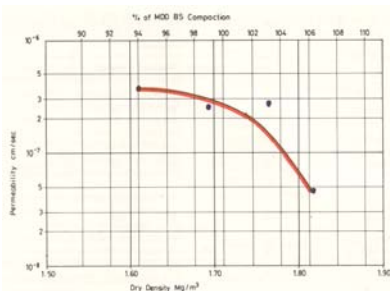
Box 6.6 - Labour-based methods in borrow pit operations

Labour-based methods in borrow pit operations may be utilised for combined stockpiling/loading in pits without overburden and where the ground does not require ripping. Labour-based operations may also be viable in combined operations where heavy plant is used for removal of overburden, while loading is carried out with manual labour. Where bulldozers have removed overburden, it is advantageous to let the same machines scarify the gravel and perhaps undertake stockpiling before manual loading.

Compaction

Compaction is a vital, integral aspect of LVSR construction which results in all-round improvements of soil properties and its performance as a pavement supporting layer. A well-compacted subgrade possesses enhanced strength, stiffness and bearing capacity, is more resistant to moisture penetration and less susceptible to differential settlement.

One of the critical aspects of using natural gravels is to maximise their strength and increase their stiffness and bearing capacity through effective compaction. This can be achieved, not necessarily by compacting to a pre-determined relative compaction level as is traditionally done, but by compacting to the highest uniform level of density possible without significant strength degradation of the particles (“compaction to refusal”). In so doing, there is a significant gain in density, strength and stiffness, the benefits of which generally outweigh the costs of the additional passes of the roller.



Permeability-dry density relationship for a lateritic gravel (Kenya).

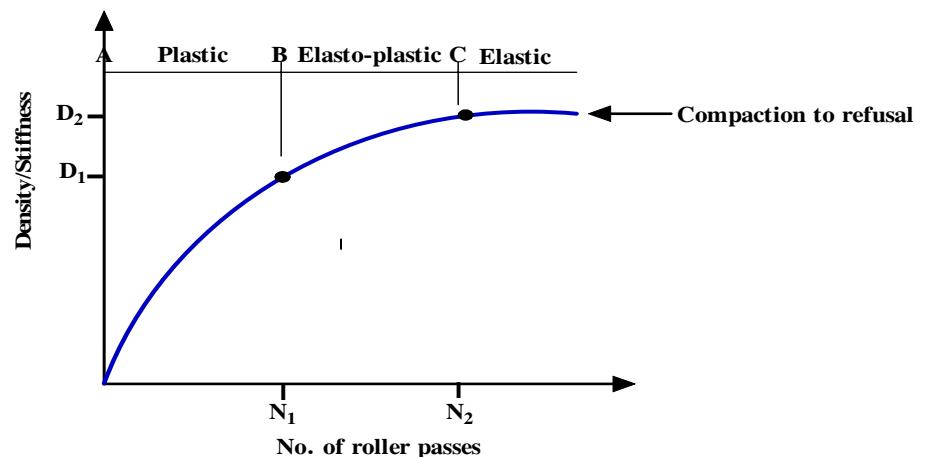


Figure 6.3 – Illustration of concept of “compaction to refusal”

Compaction to refusal ensures that the soil has been compacted to its near elastic state as shown in Figure 6.3 with the significant benefit of reduced permeability and, hence, susceptibility to moisture ingress.

In general, the effectiveness of the compaction process depends on three important, inter-related factors, namely:

- soil moisture content during compaction
- soil type
- type and level of compactive effort

A maximum allowable moisture content during construction should be specified and proper precautions for surface and sub-surface drainage (where required) should be taken on all roadbuilding projects to ensure optimal performance from the road.

Different types of soils respond to compactive effort in different ways. Thus, it is important to ensure that the compaction plant being used is appropriate for the type of soil being compacted and the purpose intended. For example, sand or sandy soils are most efficiently compacted with high frequency vibrating rollers whereas cohesive soils are most efficiently compacted by static pressure, high amplitude compaction plant. Further, if the requirement is to compact and to produce a good riding quality of base course, this is unlikely to be achieved with a very heavy roller that compacts to a great depth and, in the process, disturbs the surface.



Good management procedures that prevents rejection of material on the road creates confidence in the quality assurance system and greatly reduces the risk of shortcuts and poor practice.

It is important to ensure that rejection or acceptance of materials is carried out at the source and not after the material has been transported to the road.

6.4.2 Materials Management¹⁰

Proper management of the material sources, to ensure that the best qualities of available material are used in the top layers of the pavement structure, is essential. Efforts made in locating the best quality of locally available and often scarce materials for road base are of no avail if this material ends up in earthworks layers and good management of materials resources is, therefore, a critical operation in LVSR construction.

Box 6.7 - Procedure for materials management

Stockpiling forms an important part of materials management by promoting appropriate selection of materials as well as providing opportunities for blending materials and for testing materials before transportation to the road. The biggest threat to good materials management is when borrow pit operations are not kept sufficiently ahead of the construction.

There is considerable experience to show that the following sequence of procedures ensures good management of the material resources:

- Initial investigation of material sources by trial holes.
- Stockpiles to be clearly marked.
- Allocation of materials for specific layers on specific sections of the road after stockpiles are completed.
- Laboratory testing should be conducted if possible.
- Loading from stockpiles according to allocation for transportation to site.

The procedure set out in Box 6.7 requires sufficient plant for opening of borrow pits to avoid the construction demand exceeding the materials supply from the borrow pits. In cases where opening of borrow pits cannot keep ahead of construction, there is a considerable risk that materials selected for basecourse, for example, will end up in the lower layers of the pavement causing pressure on the material supply when base course materials are needed at a later time.

6.4.3 Borrow Pits and the Community

Operations in borrow pits will always put a strain on surrounding areas and the environment as a whole. Work in borrow pits has environmental disadvantages, such as temporary noise and dust pollution, and creates traffic safety problems and other hazards to livestock and humans. Some of the effects may remain after construction is completed, such as permanent changes of the topography and disturbance to the soil cover. The Environmental Management Plan, which should be developed in conjunction with the community, will indicate the agreed procedures for the opening and re-instatement of borrow pits.

Wishes of the Community

The wishes of the community will vary according to their needs in the particular area and may include one or more of the following:

- provision of future access to borrow materials for utilisation by the community
- use of the depression for water collection, sometimes requiring fencing or sloping of sides to at least 1:3 for the safety of people as well as to protect livestock from drowning
- levelling of the area in order to prevent collection of water that may lead to mosquito breeding and water born diseases
- use of the depression for landfill (rubbish) deposits, always requiring special precautions to prevent pollution
- re-instatement of the area for farming purposes, requiring fertile top-soil replacement, which must be self draining
- re-instatement and landscaping of the area for building or recreational purposes

It should be noted that the public perception of benefits in leaving borrow pits open is often exaggerated and, as a rule, borrow pits should be reinstated. Before decisions on future use of a borrow area are finalised, the community should be made aware of the disadvantages of leaving borrow pits open.

Re-instatement of Borrow Pits

The extent of the work required to comply with the wishes of the community will depend entirely on the requirements in each individual case. In the cases where no particular standard for re-instatement has been established, one should routinely carry out reinstatement as described in Box 6.8. The condition of all areas used for access roads should be assessed in the same manner as for the borrow areas.

Backfilling of borrow pits, i.e. replacement of the material from the pit, is only viable where the material for backfilling is either:

- *spoil material, or*
- *originates from a source where excavations give considerably less disadvantages than in the borrow area. The cost of this method is likely to be very high.*



Re-instatement operations in a borrow pit.



Burrowing animals such as termites can cause damage to pavement layers unless nests are removed properly and poisoned with an approved pesticide during clearing and grubbing.

Research has been carried out to establish whether it is possible to compact fills in dry regions without costly addition of water. Although possible, such practice could result in the compacted layer having a high void content and the risk of settlement at a later time if water enters the fill materials.

Box 6.8 - General procedure for borrow pit re-instatement.

The following simple procedure will minimise the limitations that the construction activity has placed on future use of the land.

- Shape mounds and steep banks down to a slope (steepest 1:3) that is naturally found in the landscape.
- Spread the topsoil evenly back into the pit in order to promote growth of vegetation.
- Ensure the area is self draining.

Before re-instating a borrow pit, one should assess the need for materials in future road maintenance and then stockpile appropriate quantities of gravel for this purpose.

6.4.4 Clearing, Grubbing and Removal of Topsoil

It is particularly important to take account of environmental aspects at the early stages of construction so that sensitive operations such as clearing and grubbing are conducted in the most careful manner possible. It is important that damage to the vegetation cover is minimized, shifting of soil and associated damage due to erosion is avoided and any mitigation measures set out in the Environmental Impact Assessment are observed, (Section 3.4). All topsoil that is stripped should be stockpiled for use in areas that are being reinstated for farming purposes or to promote vegetation. Any vegetation being removed should be disposed of in a manner that is to the benefit of the community, e.g. for fuel wood.

LBM

Box 6.9 - Clearing and grubbing using manual labour

Clearing and grubbing is eminently suitable for labour-based operations where the required speed of construction and availability of labour makes it possible. Labourers may experience problems in achieving the required result as described in specifications due to the need for ripping, depth of grubbing, size of roots, etc. In such cases it is advisable to review specifications in the light of the requirements of a low-volume road and to ascertain whether there is actually a realistic risk of damage to the pavement due to reduced standards of grubbing compared to current specifications.

6.4.5 Construction of Earthworks

The optimal techniques and methods for undertaking earthworks operations are largely dependant on available equipment in addition to the operational skills and experience by the field staff. Section 6.4 gives an indication of advantages and disadvantages of the various types of equipment available for earthworks operations.

When compacting earthworks it may be difficult to adjust in situ moisture content before compaction, especially when using clayey material types where a good distribution of water in the material is difficult to achieve. To mix water into such materials requires much effort and is not very effective. The possibility of adjusting moisture contents of earthworks is particularly difficult in wet climatic regions, whilst in dryer areas it is possible to dry out materials that are too wet. Careful timing of earthworks, where possible, can, to some extent, alleviate the problem.

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Box 6.10 Labour-based methods in earthworks

The use of labour-based methods in earthworks is only appropriate where the quantities are moderate or where there is a large source of labour available for the work.

There is experience to show that the performance of well-constructed base courses of natural gravel can be equal and or better than that of highly refined, but less well-constructed, crushed materials.

In the case of natural gravel with high fine contents, the required density to the full depth of the layer is often far more difficult to achieve compared to well graded granular pavement materials. This often requires special techniques, such as the use of grid rollers, to obtain a good result – see Section 6.3.4.



Mixing equipment such as ploughs or large disc harrows, greatly reduces the required time for mixing water into the material compared to blade mixing with grader but blade mixing is more effective.

6.4.6 Construction of Pavement Layers

Use of Natural Gravel Materials

Optimal use of natural materials is a constant challenge that is faced in the construction of pavement layers for LVSRs. However, depending on local conditions, it may sometimes be necessary to resort to processing of these natural gravels by crushing/ screening, or stabilisation. Natural gravel materials offer levels of performance that are directly related to successful construction methods and workmanship. Aspects of construction that require particular attention are as follows:

- Natural gravels with high contents of fines or clay particles gain their strength as a result of suction following drying back, rather than from friction between particles. This means that the in-service moisture regime of the pavement, achieved through appropriate internal drainage measures, is of vital importance for the performance of the layer.
- Correct moisture content (ranging between 1% above and 2% below optimum moisture) and achievement of the specified density for the different layers, is essential.
- Depending on the construction plant used, a good surface finish is sometimes difficult to attain. It is critical that the base has a smooth dense surface finish before sealing to ensure that a good bond is obtained between the base course and the bituminous seal and for subsequent good pavement performance.
- Natural materials often include some weak larger particles and, in compacting such materials, these larger particles may break down, hence changing the properties of the material as a whole. An assessment of the consequences of this processing action is therefore required in order to establish whether the material does meet the specification requirements following construction.

Moisture for Compaction of Pavement Layers

Experience with materials in the region has shown that thorough mixing of water with soil or gravel over the full width and depth of the layer at the optimum moisture content is essential for achieving the required density and an even surface finish. The optimum moisture content for the appropriate level of compaction determined in the laboratory is a good guide to the amount of water required in the field compaction process, although modern compaction plant normally requires a lower moisture content than the optimum indicated from laboratory compaction methods.

Box 6.11 - Effective mixing of water into the material

It is often far more difficult to achieve the required density to the full depth of the layer in natural gravels with a high fines content than in well-graded granular materials. Effective mixing with water is, therefore, of particular importance when utilising these materials.

Much as natural gravels may need to be brought near to saturation moisture content for efficient compaction, it is also good practice to allow a significant amount of drying back to occur before sealing takes place. This is particularly beneficial for fine-grained materials that rely on suction and cohesion as their predominant source of shear strength.

There is experience in the region of rapid premature failure of the uppermost layer of the base course, that can be linked to poor finishing of the base layer with subsequent loss of bond to the surfacing.

Finishing of Base Courses

If the operation of mixing, spreading and compaction is not completed before drying out of the surface takes place, then a loose upper layer (biscuit layer) will result. If this happens, the bituminous surfacing will not have a hard surface on which to bond resulting in base course failures due to shearing from wheel loads. Such failures may appear to be the result of insufficient material strength, but studies of construction records, and evidence of good performance under similar conditions in base course layers of poorer material qualities, indicate that finishing of the base course layers is vital and decisive for good performance of LVSRs.

Box 6.12 - Cutting final levels of natural gravel base courses

A critical operation affecting the future performance of LVSR pavements is the cutting of final base levels. Attempts to make minor adjustments to the surface should not be allowed. The cutting of final levels should be confined to the cutting off of high areas and not the filling in of low areas. Thus, it is much better to make corrections to geometric levels at subbase level where surface finish is not critical. Thereafter, construction of the base course can be carried out 'by eye' and with normal control of layer thickness. It is strongly advisable to *cut final levels of natural base courses by eye* rather than by following geometric levels set out in the field.

Figure 6.4 illustrates a recommended procedure for finishing off base courses made of natural gravel. The advantage of this method is the speeding up of the processing of the base course to prevent drying out of the surface whilst ensuring that full attention is given to surface finish instead of minor irregularities of geometric levels. Trimming of the surface should be confined to the action only of cutting off gravel to side spoil or off loaded for use in subsequent sections. Spreading loose material over the surface in a thin layer is unacceptable because this is likely to prevent a firm finish of the layer which will inhibit the bond with the bituminous surfacing.



In most cases, the removal of over-size material is best carried out by the use of manual labour.

Box 6.13 - Pavement construction with labour-based methods

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Labour-based methods for construction of pavement layers have varying potential depending on the type of layer being constructed. Certain types of road pavement and surfacing types are more "labour-friendly" than others as far as their construction is concerned.

- Penetration macadam may be constructed entirely by labour-based methods, including production of materials at hard rock sources.
- Granular materials, including natural gravel, may be spread, mixed and levelled by labour. Compaction can be done effectively by labour-based methods as long as the method is appropriate to meet the requirements of a sealed road.
- Improved riding quality is obtained if a motor grader is used to cut the final level.



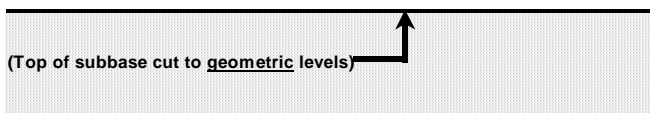
When trimming off the pattern from grid rollers in the surface of the base, it is important to ensure that any dragging marks from stones is filled in immediately and before smooth rollers are applied.

Step A:

Surface pattern of the base course after use of gridrollers for building up the full thickness of the base course in several thin layers.



(Base course dumped, mixed and compacted 'by eye' to an even final layer thickness made up of many thin layers by use of gridrollers)



(Top of subbase cut to geometric levels)

Step B:

Base course to be cut to final level by trimming off the pattern left by the grid roller "by eye" while still moist. No filling-in of depressions to be allowed. If the surface has dried out, apply a light spray of water and subsequently apply smooth vibrating rollers for some final compaction. Pneumatic rollers are recommended for achieving the best final dense surface.



(Base course)



(Top of subbase)

Figure 6.4 - Illustration of procedure to finish off base courses made of natural gravel

6.4.7 Dealing with Variability

Utilisation of Local Material Sources

The mixing of two different materials to achieve a quality that exceeds that of the two individual sources is the most common and probably one of the best methods of improving the engineering properties of natural gravels. Mixing fine-graded materials with sources that lack fines, such as some volcanic tuffs, can create a material with less potential for breaking down under compaction, having a higher density through improved grading and improved stability and workability.

Mixing of sand in proportions up to a third of the total material quantity has shown benefits without adverse effects. However, the optimal proportion varies depending on material properties. Simple laboratory investigations and field trials (test sections) are required in each individual case.

Box 6.14 - Optimal use of natural gravel

Optimal use of local materials requires innovative engineering solutions to obtain the best performance from available resources. Mechanical blending is often the best option for increasing the *quantity* of an acceptable material quality or improving the *quality* of the final material.



The proportions when mixing material in the borrow pit will normally be less accurate than when mixing on the road. This method of blending is not recommended.

Separate stockpiling in advance is necessary to control the properties of the individual materials being mixed and the quality of the final material mixture.



Mixing of different material types requires particular attention to bringing the full thickness of the dumped layer of material on to the road, mixing it properly and adding water at the same time.

Mixing by labour-based methods normally gives effective mixing. Where quantities are moderate this method may be a viable alternative.

Unsealed shoulders place particular demands on the type of gravel materials being used as they need to be durable when exposed. This design may therefore complicate operations by requiring separate construction of shoulders and carriageway.

Some mixing during stockpiling is a good option when this process can be carried out by digging through two gravel seams of the materials to be mixed. Bulldozers are not well suited for this purpose and neither will heaping the borrow materials in high cones give satisfactory results. Building up stockpiles in layers and subsequently loading from them in a special manner or sequence is feasible but requires very close control of borrow pit operations. Best results are obtained by mixing on the road.

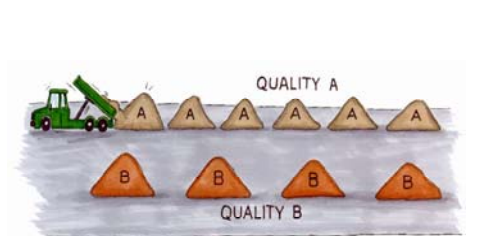
Mixing Technique on the Road

When mixing two types of gravel on the road, motor graders should be used in combination with disc harrows, if available, to achieve a homogeneous mix. The method should be to dump gravel A on the road in the required quantity, then to flatten the heaps and to spread over half the width of the base course. Then gravel B should be dumped on top of the spread material A and spread also over the same half width. Mixing should proceed as normal with the blading of both material A & B.

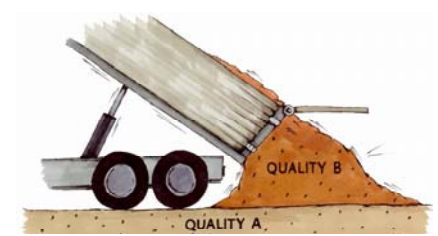
Step A: Separate stockpiling



Step B: Controlled dumping on the road



Step B (Alternative.) Controlled dumping on the road



6.4.8 Shoulder Construction

General

Besides the maintenance and traffic safety benefits gained by sealing of shoulders, there are benefits related to the load bearing strength of the pavement. Sealed shoulders reduce the risk of water penetrating into the pavement layers, resulting in a drier road environment, especially near and under the outer edge of the running surface.

Box 6.15 - Simplified construction with sealed shoulders

Sealed shoulders that use the same material as the base course is the preferred option. Generally there has to be a considerable difference in material cost for carriageway and shoulders to justify use of different materials in these two components. It may be justified where highly refined base course materials are being used but this is unlikely in LVSRs.

An increasing number of countries in the SADC region are embarking on the sealing of shoulders on roads that were originally constructed with gravel shoulders. This is operationally difficult and there are critical aspects with regards to construction technique that are likely to determine the success of such programmes. The following should be given particular attention:

- Materials in the paved shoulder should be at least as permeable as the materials in the adjacent base. If this is not possible to achieve, then suitable filters should be incorporated in the shoulder in order to prevent the collection of water in the base.
- A well-compacted joint can only be achieved if the joint between the surfacing and the new shoulder is initially cut straight and clean before shoulder materials are placed.
- The shoulders have to be at least 2.5 m wide to enable a motor grader to mix and place the shoulder gravel as well as to accommodate the width of water trucks and compaction equipment. Access width can, if required, be cut off on completion of shoulder layer works.
- Shoulders should be finished off and compacted at least 10mm higher than the adjacent base, and subsequently cut to level as shown in Figure 6.5. Proper compaction and a firm surface for shoulder surfacing is otherwise impossible to achieve.
- Where a widening of the road prism is necessary, earthwork fills should be benched and compacted in order to prevent pavement damage due to differential settlements.

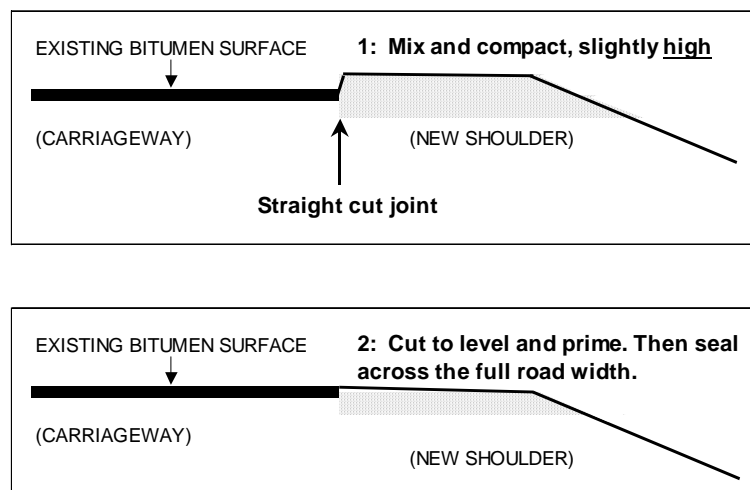


Figure 6.5 – Construction of sealed shoulders to existing bituminised roads initially having unsealed shoulders

Shoulder Seals

Seals on shoulders should have a higher bitumen content than seals in the carriageway unless the shoulders are expected to be regularly trafficked, e.g. in built up areas. This can be achieved without higher binder spray rates by using a smaller aggregate size than in the carriageway.

Blinding off shoulder seals with a bituminous sand seal is often an appropriate method to:

- arrest loss of aggregate
- provide a good surface for pedestrians and bicycles
- give a desired visual contrast to the carriageway
- edge marking of the running surface with a paint line is also desirable if resources to do this are available.

6.5 Construction of Seals

6.5.1 Selection of Seal Type and Materials

Design of seals and selection of appropriate type of seal is fully covered under Section 5 - Pavement Design and Surfacing.

Decisions on utilisation of aggregate sources for bituminous surfacing often require revision at the construction stage as a result of increased knowledge about available material sources as construction proceeds¹⁰. This is of particular relevance to LVSRs because:

- A wide range of aggregate types and qualities can be used for the bituminous surfacing.
- Site investigations at the design stage tend to be focussed on identifying bulk materials for the pavement layers. As construction proceeds and materials are excavated for the pavement layers, better quality sources of surfacing materials are sometimes revealed that were not discovered at the design stage.

Box 6.16 - Utilisation of local material sources for bituminous seals

Site staff must become familiar with the wide range of seal types and suitable aggregates for LVSRs and the scope for applying labour-based methods in the production of aggregate and construction of the seal. Inability to fully utilize locally available resources in the construction of low cost but durable seals results in lost opportunities for achieving construction cost savings.



Sand seals require lower levels of skill, material quality and equipment than chip seals or Cape seals. If applied over an Otta seal, locally available sand along the roadside may be of adequate quality for the sand seal.

6.5.2 Required Resources on Site

As indicated in Table 6.1, the various types of surfacing each have different requirements as regards the necessary resources on site to achieve a satisfactory end result. It is important to observe these requirements when deciding on an appropriate choice of seal for a LVSR.

Table 6.1 – Required input for achievement of a good bituminous seal

	Required input for achievement of a good result (Low - Moderate – High)				
	Surface dressing	Otta seal	Sand seal	Slurry	AC ⁴
Skills	Moderate	Moderate	Low	Moderate ³	Un-suitable
Equipment, Spreading	Moderate	Moderate	Low	Low	Un-suitable
Equipment, Bitumen Application¹	Moderate	Moderate	Low	Low	Un-suitable
Materials quality	High	Moderate	Low ²	Moderate/High	Un-suitable

- 1) A bitumen distributor is required for most sprayed seals. Hand sprayers are an alternative, especially when using emulsions, but spray rates need to be controlled. Mixing slurry in concrete mixers is preferred even when laying by hand. Self-propelled slurry machines increase efficiency but at much higher cost.
- 2) Coarse sand, sometimes available by screening, can increase the material quality to “moderate” where sand seals are used alone as permanent seals. Where sand seals are used as cover seals, the material quality requirements can be reduced to “low”.
- 3) The selection and handling of bitumen emulsions, including proportioning and adjustment of consistency, increases the need for handling skills. Training is usually required.
- 4) Although included for comparison with other seal types, surfacing with AC is usually confined to areas with wet climates and/or steep terrain.



A small, simple crushing/ screening plant can be combined with labour adapted tractor operations.



Applying aggregate for surface dressing using mechanical chip spreaders.



High contents of dust and fines in the aggregate is more critical for performance of a surface dressing than an Otta seal.



Drag brooming is sometimes applied in order to improve distribution of aggregate.



Rolling of sand seal.

6.5.3 Aggregate Production

Table 6.2 outlines the required operations to win and produce aggregate for each type of surfacing that may be used with a LVSR.

Table 6.2 Production of aggregate for bituminous surfacing

Type of seal	Type of aggregate	Winning and processing of materials
Surface dressing	Crushed stone or rock.	Crushing and screening.
Otta seal	Gravel, natural or crushed.	Stockpiling. Normally screening is also required.
Sand seal (used alone)	River sand (crusher dust may be used, but can be expensive).	Stockpiling (while river is dry). Screening out pebbles.
Sand cover seal (over Otta seals)	Any non-plastic sand.	Stockpiling if sand is not available along the roadside.
Slurry	Crusher dust.	Crushing and screening.

6.5.4 Construction Procedure

All types of sprayed surfacing, such as surface dressings, Otta seals and sand seals, follow a similar construction procedure:

1. Priming of the base, (may sometimes be omitted).
2. Base repair (chip and spray by hand using emulsion) to even out the occasional rut caused by a stone under the motor grader blade.
3. Spraying of bituminous binder.
4. Spreading of aggregate.
5. Chip spreading requires uniform aggregate cover and a drag broom can assist this process on large areas.
6. Rolling is preferably carried out with pneumatic rollers but can also be done by trafficking.
7. Repeat steps 2 to 6, if applying a double layer.
8. An emulsion “fog spray” is sometimes applied to chip seals after they have been laid to enhance adhesion of the chippings.

In slurry seals, crusher dust, bitumen emulsion, water and cement filler are premixed with either a specialised “mix and spread” machine or in a concrete mixer for spreading by hand with squeegees. Mixing by hand is possible but is not recommended.

6.5.5 Labour Friendliness

The various types of bituminous surfacing appropriate for LVSRs offer different degrees of suitability for labour-based application. Table 6.3 provides an assessment of the suitability of each surfacing type for the use of manual labour in production of aggregate and construction respectively.

Table 6.3 – Labour friendliness of various surfacing types

		'Friendliness' for labour-based methods (Good – Moderate – Poor)				
		Surface dressing ¹	Otta seal ²	Sand seal	Slurry ³	AC ⁴
Production of aggregate	Quality	Poor	Good	Good	Good	Poor
	Output	Poor	Good	Good	Poor	Poor
Construction of surfacing	Quality	Moderate	Good	Good	Good	Poor
	Output	Good	Good	Good	Moderate	Poor

1) Hand-cushing of aggregate for surface dressing tends to produce flaky chippings with some rock types.

2) Oversize and fines can be removed by hand screening of natural gravel aggregate for use with Otta seals.

3) Output of aggregate production for slurry (crusher dust) depends entirely on availability on the commercial market.

4) Although included for comparison with other seal types, AC would not normally be used on a LVSR.

LBM



LBM

Spreading aggregate by labour-based methods from tractor buckets (Otta seal).



LBM

Screening aggregate by labour-based methods into tractor buckets (Otta seal is shown, sand seals would be similar).

Box 6.17: Labour-based methods in surfacing operations

- The ease of application of labour-based methods for construction of seals varies with seal type. However, in general, all seal types offer good scope for labour-based operations, as regards production of aggregate as well as construction on site. However, the uniform binder spray rates required for chip seals are more difficult to achieve with labour-based methods.
- Where labour-based methods are desirable, seal types that are most suited for this type of construction should be given the preferential consideration. It may be necessary to provide training to ensure that the final product will be of the desired standard.
- All seals, except the slurry seal, need rolling and therefore require some form of machine-based equipment for this purpose. Where traffic volumes are sufficiently high, it may be possible to rely on traffic for rolling, but at the risk of an inferior result and speed will need to be strictly controlled.

6.6 Quality Assurance and Control

6.6.1 Introduction

Quality assurance in road construction includes the total system within the construction site that ensures correct quality of the final road and associated structures. Besides conventional site control, quality assurance also includes the measures that contractors apply themselves for this purpose during operations.

Quality control includes laboratory and field testing of materials and construction, and forms part of the overall quality assurance system. It is applied in various ways depending on the type of contract. Conventional contract relations with a supervising body - often a consultant - carrying out control of the works is a common system used in the region. Under these circumstances, end product quality control is routinely included in elaborate systems and is applied with great effort on projects where roads are constructed. It is commonly considered necessary to establish full laboratory services on site for control of workmanship and material quality. The resources one can afford for such control during the construction of LVSRs is often less, for the following reasons:

- Quality control measures that are applied to more highly trafficked roads would form a much larger proportion of the construction costs of LVSRs.
- Contractors and consultants involved in construction of LVSRs are often smaller and have less resources available than those routinely constructing larger projects.
- LVSRs are often executed as small projects where the establishment of full site-testing facilities is often not viable. Distances to central laboratory services may also render this option impractical.

This section sets out a conceptual approach to ensure the best possible quality assurance with a reasonable level of control in constructing LVSRs. The inherent compromise in this approach will often require innovative solutions and focus on the overall quality assurance system to achieve optimal results.

6.6.2 Methodology

General

Resources available for quality control in construction of LVSRs are often limited. Therefore it is important to utilise whatever means are available as efficiently as possible and to combine conventional control methods with other quality assurance methods.

Quality Assurance with Reduced Resources

Quality assurance procedures where control systems are applied at reduced levels include the following:

- **stockpiling** as a means of selecting qualities and ensuring known quality of the materials being used
- good **management** procedures to ensure that materials are used to their full potential and to prevent rejection of material after transportation to the road

Quality control does not in itself create higher quality, but is one of several tools that are used to ensure that a product of the desirable quality is produced.



Effective quality control for LVSRs does not necessarily require a full scale programme of laboratory testing.



Density control is important in 'calibration' of method specifications, but full scale test programmes are not always viable on LVSRs due to lack of resources.



Having spray cans with bitumen emulsion available at all times during surfacing operations for repairing minor faults is part of good quality assurance.



Direct strength measurement with e.g. DCP can assist in calibration of method specifications, but cannot replace material management and continuous and skilful observation of the work procedures as the most powerful means of quality assurance where variable and marginal materials are used.

- systematic use of **method specifications**
- control by **observation** of construction procedures by an experienced practitioner
- **proof rolling** (eg with loaded trucks) to test the stability of layers before proceeding with construction
- use of methods for **direct strength measurements** by correlation to known parameters (e.g. probing methods such as DCP and others)¹¹
- laboratory testing for '**calibration**' of method specifications
- laboratory testing of typical material sources for '**calibration**' of visual observations

Priority in Quality Control

Box 6.18 Optimum priority for quality control

The resources put into quality assurance should be applied where there is a maximum benefit from the efforts, i.e. where the benefits, in terms of structural life or surface life, are highest in relation to efforts made in the control.

LVSRs typically utilise natural gravel in the base course followed by a thin bituminous seal. This pavement structure is sensitive to any irregularities in the seal, in the interface between seal and base course and in the base course itself. Conceptually, the priority when allocating resources to quality assurance should therefore be as shown in Table 6.4. The table sets out the priority on the basis of what is possible from a technical point of view in relation to the input of resources for control. It does not take account of contractual and institutional issues. These aspects will vary considerably and require varying measures for optimal quality assurance.

Table 6.4 - Priority in Quality Control



Visual control of the bitumen distributor and continuous inspection of the work on site are important parts of the quality control procedures and can reduce flaws in thin seal that could lead to premature failure of the surfacing.



Continuous visual control by skilled staff through the entire operation when processing the base course for LVSRs is essential. Inadequate compaction of natural gravel is often caused by poor mixing, insufficient moisture content or poor final spreading and compaction of the layer.

Priority	Layer	Comments
1	Bituminous surfacing	<ul style="list-style-type: none"> Choice of equipment, choice of material type, visual assessment and measurement of application rates is of greatest importance. Only basic laboratory equipment is essential for effective control during operation.
2	Surface finish of the base course	<ul style="list-style-type: none"> Biscuit layers are the most common reason for an unacceptable product. A geological hammer/pick will identify such flaws. Visual assessment, plus choice of equipment and working method is of greatest importance. Laboratory equipment is not essential for effective control during operation.
3	Material quality of the base course	<ul style="list-style-type: none"> Laboratory tests in advance and after construction, combined with indicative tests or observations during construction are essential.
4	Compaction control of the base course	<ul style="list-style-type: none"> Method specifications, appropriate choice of method and equipment, visual assessment and proof rolling, in combination with regular testing for 'calibration'. The extent of testing required for 'calibration' purposes should be adapted to site conditions and available resources.
5	Subbase and earthworks	<ul style="list-style-type: none"> Visual assessment and laboratory tests ahead of construction give improved confidence in material quality. Method specifications, visual control, proof rolling and appropriate choice of method and equipment is sufficient for site control of workmanship.

6.7 Drainage

6.7.1 Introduction

Drainage is probably the most dominant factor affecting the performance of any LVSR. When such roads fail it is often because of inadequacies in drainage resulting in the ingress of water into the road structure, structural damage and costly repairs. In addition, surface water can form a road safety hazard by causing aquaplaning of vehicles.

Unfortunately, many LVSRs have evolved with inadequate initial engineering and drainage design. Even with properly engineered LVSRs, on-site inspection is often necessary to correct any unforeseen conditions during construction. Such an approach is more cost-effective than maintaining or correcting deficiencies after the road has been in service for several years.

Two inter-related aspects of drainage require careful consideration during construction, namely:

- *Internal drainage* of the pavement which seeks to avoid the entrapment of water by allowing it to permeate through and drain out of the pavement structure.
- *External drainage* which seeks to divert water away from, and prevent ingress into, the pavement structure through measures such as sealed shoulders, side drains, etc.

6.7.2 Internal Drainage

General

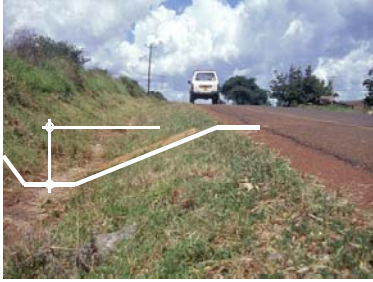
Internal drainage involves measures to minimise moisture contents in the embankment and pavement layers and importantly to prevent unwanted movement of water within the structure. Internal drainage is vital for the performance of earthworks and pavement layers made of natural soils and gravel, especially those that utilise fine grained and plastic materials such as those commonly used for LVSRs¹² (Refer to Chapter 5 for more details).

Permeability of pavement layers

Wherever possible, each layer in pavement and earthworks should be more permeable than the overlying layer in order to prevent any water entering the structure from being trapped. This requirement is often not possible to meet consistently and attention to the provision of cross-fall in all earthworks and layer works for water to escape from the pavement structure can alleviate the problem (see also Section 5.4.3 and Box 5.7). Under severe conditions, especially where there is risk of seepage water into the pavement structure, consideration should be given to installing subsurface drainage systems or, better still, to raise the height of the road over such areas.



It is important to create an awareness amongst the public so that actions that lead to impaired drainage of the pavement can be prevented.



Research in the region has shown that a minimum crown height is a critical parameter that correlates well with the actual service life of pavements made of fine grained and/or slightly plastic materials. A minimum crown height of 0.75m is recommended. See Chapter 5– Pavement Design and Surfacing, Section 5.3.4.

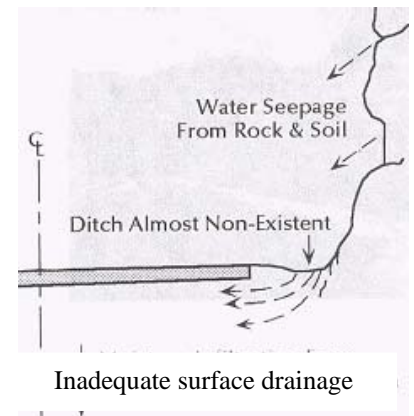
Crown Height

Crown height is the vertical distance from the bottom of the side drain to the finished road level at centre line and needs to be sufficiently large for proper internal drainage of the pavement layers. Economical ways to achieve sufficient crown height include use of material from the side drain and road reserve, a common procedure where scrapers/motor graders are used for construction. Maintaining sufficient crown height through cuttings is of particular importance due to the unfavourable drainage conditions in such areas. However, this may result in a considerable increase in the quantity of earthworks cut. Alternatives, such as subsurface filter drains, should be considered as a last resort because of cost and maintenance implications. The traffic safety aspects of large crown heights should be taken into account by moving the side drain further away from the shoulder break point.

In areas where in situ soils are considered to be self-draining, such as in sandy areas and desert-type areas, priority should be given to providing good side support within a low embankment profile and shallow side slopes (typically 1: 6 or 1:8) rather than a large crown height and relatively steep side slopes.

Seepage and subsurface drains

Unfortunately, inadequate surface and subsurface drainage are typical deficiencies associated with cut-and-fill pavements sections for LVSRs as shown in Figure 6.6. Such deficiencies can affect the pavement by erosion, decreasing soil support or initiating creep or failure of the downhill fill or slope. They should be addressed during construction rather than waiting until failures occur because it is much more expensive to undertake remedial works.



Road surfacing failures due to blocked side drains

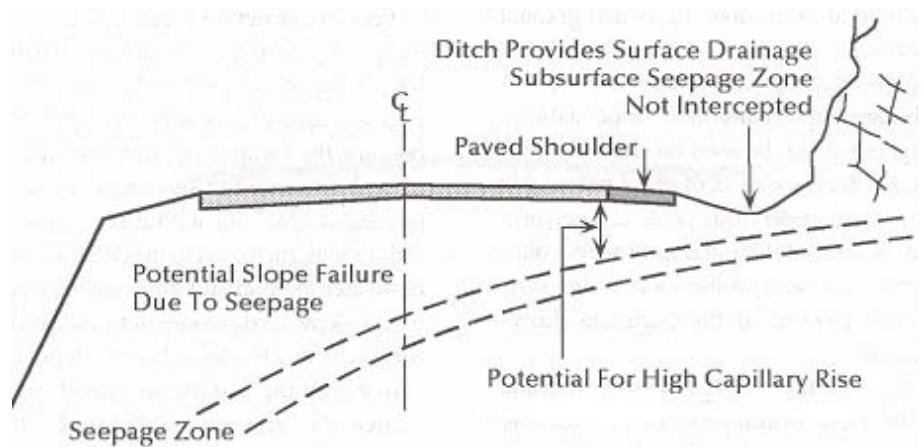


Figure 6.6 – Typical drainage deficiencies associated with cut-and-fill pavement sections¹³

In the design of the vertical alignment of LVSRs, it is advisable to try and avoid cutting into the ground to reduce the risk of encountering subsurface water. Thus, the “depressed pavement construction” shown in Figure 6.7 should be avoided except where soil moisture conditions are suitable or the drainage systems effectively eliminate water-related problems.

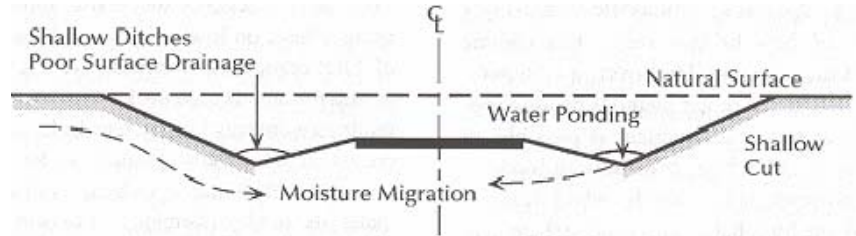


Figure 6.7 – Potential drainage problems associated with depressed pavement construction

Localised seepage can be corrected in various ways but seepage along pervious layers combined with changes in road elevation (grades) may require subsurface drains as well as ditches, as shown in Figure 6.8.

Subsurface drains can be made of geotextiles wrapped around aggregate, with or without pipes installed, but various specialised systems are also marketed. Such drains have commonly been made out of aggregate surrounded by filter sand instead of geotextiles, depending on the grading of the in-situ soils.

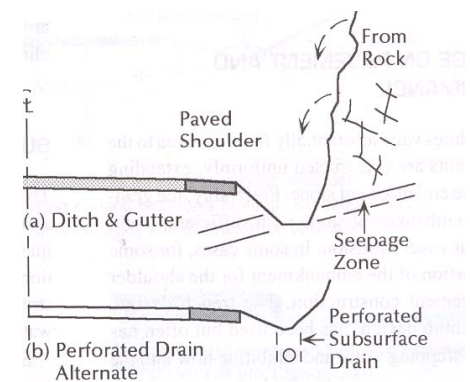


Figure 6.8 – Beneficial interception of surface runoff and subsurface seepage¹³.



Construction of filter drains is well suited for labour based methods. Geotextiles used for filter drains should be of a type that does not get blocked by fines from surrounding soils.

Subsurface drainage systems usually incur relatively high installation costs and there is the risk of blocking of buried systems, hence alternative options are preferred.

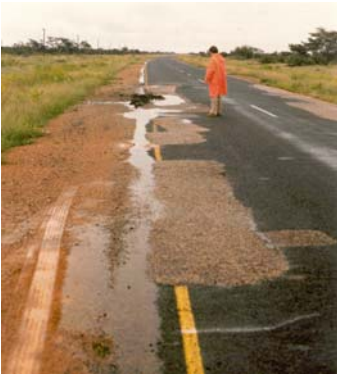
Shoulders

Construction of shoulders needs to be undertaken carefully if typical drainage problems are to be avoided. Preferably, the granular base should extend to the embankment slope with sufficient height above the ditch to prevent water intrusion. Trench, canal or “bathtub” construction, in which the pavement layers are confined between continuous impervious shoulders, should be avoided as this has the undesirable feature of trapping water at the pavement/shoulder interface and inhibiting flow into the drainage ditch.

Shoulder materials should be selected which have a similar permeability as the base course, so that water does not get trapped within the pavement. However, the material properties for unsealed shoulders may well be different from those required for base for reasons of durability. Unsealed shoulders are similar to a gravel wearing course and require material with plasticity, which is a property which might be considered less desirable for road base material.

A common problem is water infiltration into the base and subbase, which arises for a number of reasons illustrated in Figure 6.9. These include:

- rutting adjacent to the sealed surface
- build up of deposits of grass and debris
- poor joint between base and shoulder (more common when a paved shoulder has been added after initial construction)



Water infiltration in shoulder rut leading to edge failures.

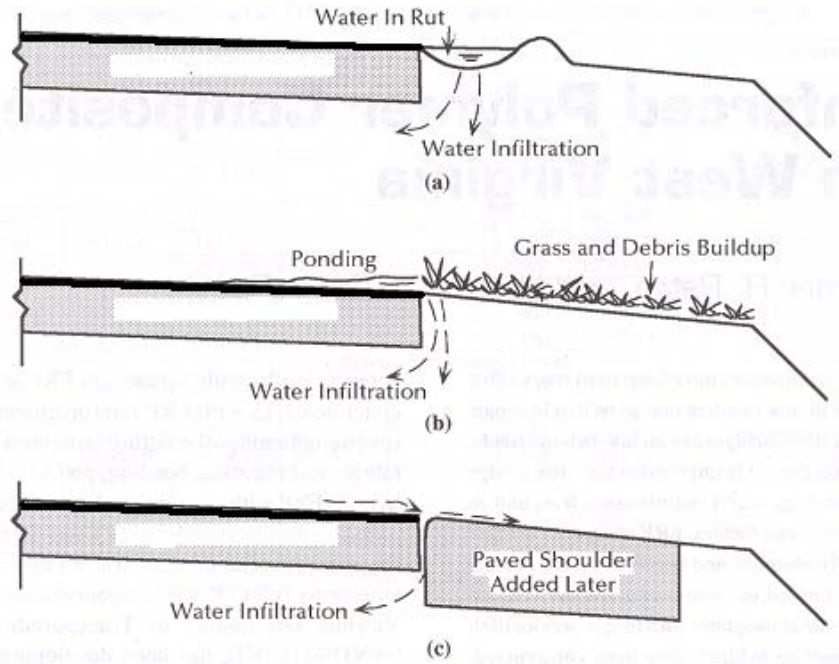


Figure 6.9 – Typical drainage deficiencies associated with pavement shoulder construction¹³

Ideally, as illustrated in Figure 6.10, the base and subbase layers should be extended outwards to form the shoulders which should desirably be sealed.

Use of different materials in the shoulder than the carriageway is often uneconomical because of disruption in the construction procedures. Use of the same material in the carriageway as the shoulder eliminates the risk of trapping water.

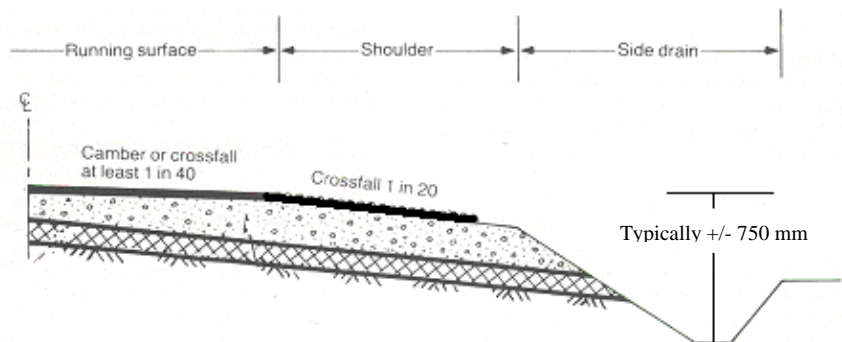


Figure 6.10 – Ideal shoulder construction/drainage arrangements



Caution is required in drainage work because small disruptions of the natural drainage pattern can, sometimes, lead to major environmental damage in sensitive areas.

6.7.3 External Drainage

Introduction

External drainage involves methods to enable crossing of watercourses, measures to divert water away from the road and prevention of damage caused by erosion. In the construction of LVSRs, there is often wide scope for the use of various measures to improve external drainage, such as low level structures, drifts etc. where 100% passability to traffic throughout the year may not be required.

It is not within the scope of this Section to provide a *detailed* description of all the various measures that make up a good drainage system. Conditions on site will vary tremendously in respect of in-situ soils, topography, vegetation, climate, human settlement patterns, environmental concerns, etc. The skills of site personnel and knowledge about local conditions are critical for successful installation of mitre drains, catch-water drains, side drains, berms, channels, cut-off drains and crossings along the road¹⁴

6.7.4 Hydrology and Hydraulic Calculations

Introduction

The use of sophisticated methods to estimate run-off and for the calculation of the size of waterway structures is not always appropriate for LVSR because either the data and/or resources required are unavailable. Thus, alternative methods, which also rely on visual observations and historical evidence from consultations with the local populations are often more appropriate. Furthermore, financial constraints also mean that a compromise is often required between structures that provide all weather access and those that can be constructed within the available resources.

Method

The capacity of drainage structures should ideally be calculated on the basis of local experience gathered over a long period of time, and updated to cater for any recent changes in rainfall pattern and climate. However, such information is often not readily available in many countries, prompting a need to develop standards for drainage design and calculations. In all cases it is advisable to combine calculations with observations on site, in addition to information from reliable local sources.

With the ever increasing cost of maintenance, it is desirable to increase the size of drainage structures to a minimum of a 600 mm opening so that they can be easily maintained.

Return Period

The return period for a given flow of water is related to the estimated statistical risk of overtopping of drainage structures. It is part of the hydraulic calculations required for each type of structure for each project on the basis of policy and anticipated consequences to the road or the public. The return period is therefore a critical parameter in the design of LVSRs because it controls the level of risk in relation to cost of construction and the type of structure that is appropriate. As a broad guide, the following return periods can be considered for LVSRs:

- Bridges: 10-50 years
- Culverts: 5-10 years
- Drifts or well-protected culverts: 0-5 years



Overtopping on LVSRs, although undesirable, has less impact on the economy than if it occurs on HVRs.



Inadequate culvert capacity, particularly in combination with high embankment, can result in severe damage and expensive remedial works.



Low-level drift.



Vented drift.



Banks of pipe profiles culverts are prone to blockage by trees even when large sizes are used.

6.7.5 Drainage Structures

Introduction

This chapter gives some examples of the range of solutions available to designers and constructors of LVSRs. The techniques shown are the results of innovative methods tried out and applied in many countries in the region over a number of years. A basic requirement in the construction of structures for crossing water courses is to assess the need for protection of the structure against erosion during the construction period as well as assessing the risk that structures that are not designed to withstand flooding will actually experience overtopping, so that additional protection measures can be taken. Construction of low, “sacrificial” points for overtopping should be considered where available resources do not allow for the provision of structures with adequate capacity ¹⁵.

Low level structures

A low level structure is designed to accept overtopping without damage, and is ideally suited for LVSRs in locations where less than full all-weather passability is acceptable to the community. The two basic types listed below have been used with success in the region. Various alternative names are sometimes used to describe these structures.

- **Drifts** are designed to provide a firm driving surface in the riverbed, where traffic can pass when water levels are moderate.
- **Vented drifts** (sometimes named fords, causeways or Irish bridges, larger structures called low level bridges) allow water to pass through openings, but can withstand overtopping without damage. Openings in vented drifts should, like culverts, be made large enough, preferably no less than 0.9 m so that cleaning during future maintenance is made easier and the risk of blockage is minimised.

A common feature of all low level structures is that they require proper foundations and anchoring, as well as scour protection to the road prism.

Culverts

Types: Culverts are constructed on LVSRs using a variety of methods and materials. Examples include corrugated plastic pipes, steel pipes or arches, pre-cast or fresh concrete pipes, boxes, arches or half arches (shelverts), reinforced concrete slabs resting on blockwork in a box culvert profile and wooden culverts in a box or circular profile.

As indicated in Box 6.19, there are many innovative ways of producing inexpensive culverts.



LBM

Inflatable rubber balloons have been used successfully as formwork for construction of concrete pipe culverts on site. Concrete is poured directly against the side of the trench, which is protected with plastic sheets.



Upstream protection against blockage by trees can be successfully constructed from old railway steel sleepers well-anchored into the riverbed.



LBM

Concrete culverts are only practical for use in labour-based methods if each section is not too heavy for handling by labour or by other mechanical equipment available on site.

Box 6.19 - Innovative construction of culverts

In the region there are innovative methods in use for simple and efficient construction of culverts that are particularly well suited for application in LVSRs, more so where labour-based methods are used. Examples of such techniques include:

- use of locally produced treated planks (pine) for yard production of pipe culverts, strapped with steel bands (Tanzania)
- use of inflatable rubber balloons as formwork for site casting of concrete pipe culverts in a large variety of dimensions (Tanzania) up to several metres in diameter
- use of drums as formwork for standardised yard production of concrete modules for pipe culverts (Zimbabwe)
- use of drums as formwork (left behind) for site casting of concrete pipe culverts (Tanzania)
- use of timber for site construction of square profile culverts
- use of blockwork for site construction of square profile culverts (Botswana)
- shelverts are pre-casts concrete half-arches that require less skill for construction than culverts
- masonry vertical brick walls with cast on site concrete slabs.

Location: Wherever possible, culverts should be located in the original stream bed with the invert following the grade of the natural channel. Stream bed realignment may be undertaken in exceptional cases.

Skew culverts: Water courses intercepting the road at an angle of skew less than 20 degrees can generally be accommodated by a culvert placed at right angles to the road centre line. In such cases, the culvert inlet should be positioned at the point where the channel meets the road, and any modification to the channel made downstream of the outlet. Water crossings with a skew angle greater than 20 degrees should be provided with a skew culvert.

Inlets: To avoid silting, culvert inverts should be placed at a grade of not less than 1.25 per cent for pipes, and 0.5 per cent for box culverts. Invert gradients should be increased by one per cent for culverts provided with drop inlets.

Outlets: The invert level at the outlet of a culvert should coincide with ground level. Where culverts are unavoidably constructed on a steep slope, the energy generated must be dissipated to avoid serious erosion at the discharge end of the culvert. A stilling box and widening at the outlet are effective methods of reducing the velocity.

Foundation: Ideally, culverts should be located on sound foundations such as rock. Soft, saturated and expansive clayey soils may cause settlements or seasonal movements of the culvert. Removal of poor soils or stabilisation of the foundation should be considered.

Use of Labour-Based Methods

Labour-based methods are very well suited for construction of drainage structures, excavation of drainage channels, construction of soil berms, stone pitching, scour protection, etc. Pre-cast concrete culverts are not well suited for LBM if the weight of each element is excessive for manual handling.

LBM



Blockwork has been used successfully for simplified construction of headwalls on small culverts and for the support of concrete slabs to make a box culvert.



Erosion in outlet channels can cause considerable environmental damage in sensitive areas.



Concrete scour checks in side drain.



When there is a risk of erosion at outlets, suitable aprons and other protective measures are required.

6.7.6 Erosion

Introduction

Any disruption to the natural flow of water carries a risk of erosion that may lead to environmental degradation, silting, damage to roads, damage to buildings and services, destruction of farming land and loss of fertile soil. Thus, there is a responsibility to ensure that the construction of the drainage system for a LVSR receives the same attention to good practice as the construction of other roads. Indeed, avoidance of erosion can be more critical in the case of LVSRs because of the greater challenges faced in maintaining the drainage system in remote areas where these roads are often located.

Scour Checks

There are many examples in the region of inexpensive and effective methods that are used to protect drainage channels and side drains by the use of scour checks that are easily constructed by labour based methods. The scour checks can be made of wooden sticks, rocks, concrete or other materials depending on the most economical source of materials. The frequency of scour checks needs to be properly adjusted according to slope gradient in order to prevent erosion between the checks causing damage to the system. The following can be used as guidance:

<u>Gradient of the ditch</u>	<u>Scour check spacing (m)</u>
4% or less	(not required)
5%	20 m
8%	10 m
10%	5 m

Erosion of Culverts

Short culverts requiring high headwalls and wingwalls are prone to erosion around both inlet and outlet, especially along the wingwalls. Constructing culverts that are sufficiently long to reach the toe of the embankment will minimise necessary protection measures, future maintenance and the risk of damage to the embankment around the openings. It is necessary to carefully assess the additional cost of lengthening culverts against these benefits, especially in the case of LVSRs that are often located in remote areas where regular maintenance is challenging.

Slope Protection

If required, the embankments slopes should receive topsoil and planting of vegetation in order to minimise erosion before indigenous vegetations can establish roots.

Box 6.20 - Planting of vegetation for protection of slopes against erosion.

Where grass or other vegetation is being planted for protection of slopes, it is absolutely vital that professional advice is obtained from a botanist. Failing this could lead to intrusion of non-indigenous species that may cause threats to the environment or damage to local farming.

6.8 Summary

The key points raised in this chapter are:

1. The characteristics of LVSRs are such that the methods employed for their construction may be different from more highly trafficked roads. In some circumstances labour-based methods can be effectively employed for many, if not all, of the construction activities.
2. Construction of LVSRs are often carried out in remote rural areas. These circumstances can give rise to special problems relating to health, safety and the environment and appropriate measures need to be taken to ameliorate any detrimental effects of the road construction processes on local populations and the environment.
3. A higher degree of awareness of the properties and use of materials is required in the construction of LVSRs so the use of the (often) scarce resources of good quality road-building material can be well-managed.
4. The nature of LVSRs construction provides a range of both technology choice and equipment use. The selection of equipment must be matched to the chosen technology in order that the highest quality of construction is attained with the available resources.
5. Compaction of natural gravels is an essential component for the good performance of LVSRs. Where the materials are suitable, compaction to the refusal during construction adds relatively little to construction costs but is likely to produce significant benefits from improved road performance. Conversely, poor compaction is likely to lead to lower density, moisture ingress, deformation and increased maintenance.
6. Good quality control during construction is important in the construction of all roads but it is particularly important on LVSRs, where greater use is made of locally available resources. It is important that these roads provide a good quality riding surface and pavement performance so that unexpected maintenance inputs do not occur.
7. Many natural gravels used in the construction of LVSRs provide high strengths when dry but they are also moisture sensitive. Keeping the pavement dry through good drainage is, therefore, a critical factor in the performance of LVSRs and it is important that measures that reduce moisture ingress are applied at the construction stage rather than later, when they are generally much more expensive to carry out.
8. Perceived risks associated with the use of unconventional approaches, technology and materials can be sensibly managed through relatively low-cost measures that ensure good performance.

Methods appropriate for the construction of LVSRs have been described in this chapter with particular reference to the application of labour-based technology. Drainage has also been covered as it is of particular importance to the subsequent performance and maintenance of these roads. a subject which is covered in Chapter 7.

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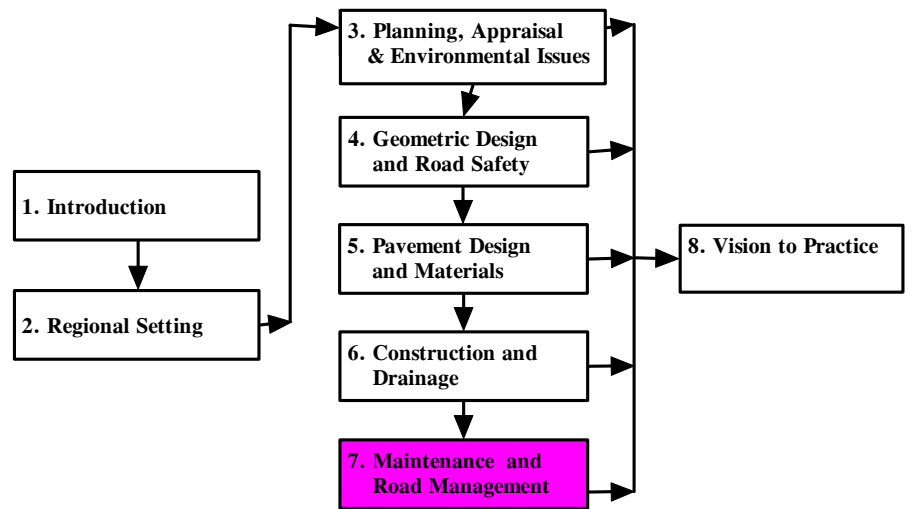
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Chapter 7



Maintenance and Road Management

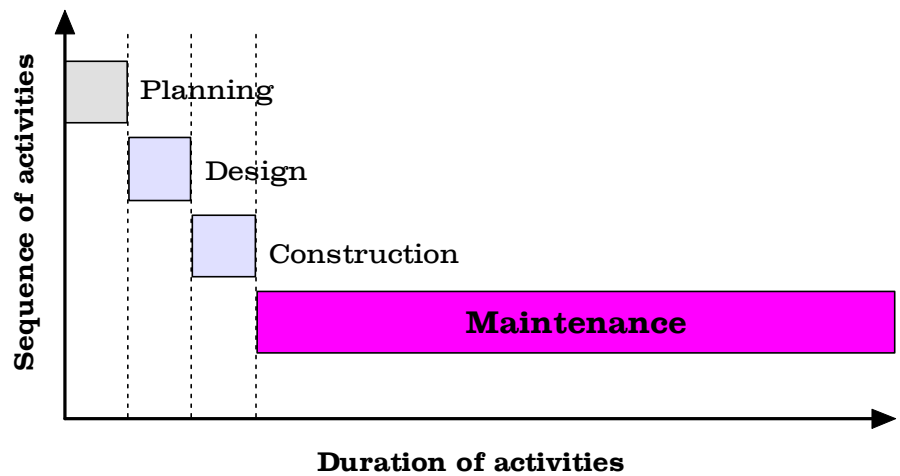
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Maintenance and Road Management

7

7.1 Introduction

7.1.1 Maintenance



Definition of road maintenance

“To conserve as nearly as possible, the original designed condition of paved and unpaved roadways, and of traffic signs, signals and markings, in a manner most likely to minimize the total cost to society of vehicle operation and accident cost, plus the cost of providing the maintenance itself, under the constraints of severe resource limitations, in respect of skilled manpower, equipment and money, both local and foreign.” (PIARC).

Road maintenance is an integral component of the LVSR provision process, the type and cost of which is influenced significantly by decisions made during the preceding planning, design and construction phases. Proper maintenance contributes to the preservation of the road asset and to prolonging the road’s life to its intended service duration. Without adequate maintenance, roads deteriorate rapidly, become dangerous and costly to use and, ultimately, the costs to the economy are substantial.

Whereas design and construction of LVSRs are dominated by engineering issues, maintenance is essentially a multi-dimensional issue in which the management and technical aspects are influenced by political, social and institutional issues. For example, the use of maintenance works as a poverty alleviation tool through appropriate community involvement is assuming increasing importance.

Maintenance currently constitutes one of the major preoccupations of roads agencies in the SADC region. In the early stages of road development, most of the road expenditure was spent on construction. However, as these networks have become more developed, the expenditure required for adequate maintenance and rehabilitation has increased relative to that required for new construction.

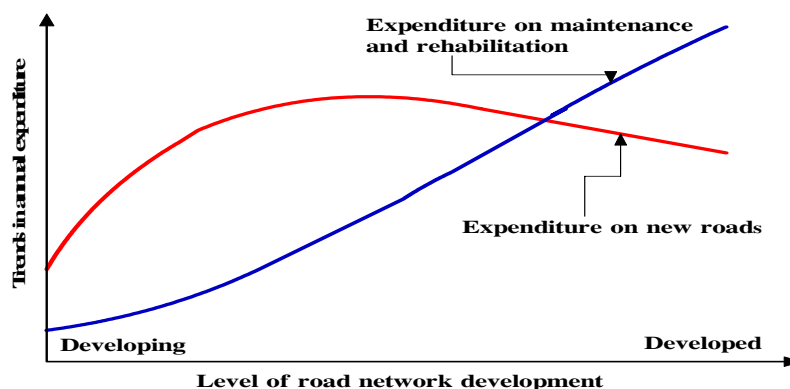


Figure 7.1 – Pattern of road expenditure in the SADC region



Unfortunately, for a variety of reasons, including lack of adequate funding, provision of satisfactory road maintenance still remains an elusive goal for a number of SADC countries. As a result, these countries, and the region as a whole, have paid a high price in terms of deteriorating road networks, very high transport costs and the reluctance of donors to assist with funding of new or rehabilitation projects. Fortunately, however, roads agencies are beginning to tackle the maintenance challenges in a more holistic manner to improve efficiency and effectiveness and to achieve sustainability.

7.1.2 Road Management

The SADC road system represent a major investment and is one of the region's largest public sector assets with the replacement cost amounting to more than \$50 billion (2000). Indeed, the asset value of the road system often exceeds the combined value of all the other surface transport systems. Therefore, it is extremely important that this asset is preserved through effective and efficient management. In the absence of this, the investment can quite quickly be eroded because roads that are not maintained deteriorate very rapidly.

Even for relatively low-trafficked road networks, reliable information has become essential for effective management. This has led to the development of management tools, including various types of road management systems, that assist roads agencies in allocating resources in a manner which achieves the best value for money. However, to be sustainable, such systems should be carefully chosen to match the available resources – both technical and financial – of the roads agency. Unfortunately, there are a number of examples of systems which have failed to work satisfactorily.

7.1.3 Purpose and Scope of Chapter

The main purpose of this chapter is to provide guidance on how to improve the maintenance and management of LVSRs, through adopting appropriate institutional arrangements, management strategies and technical standards. Guidance is also given on criteria for establishing road management systems to assist roads agencies in the overall management of their road networks. Aspects of maintenance operations are not covered in detail because sufficient reference texts on this topic already exist.

7.2 Maintenance Issues

7.2.1 Maintenance Setting

Why Maintenance?

The case for maintenance is compelling. Having spent time, effort and money in planning, designing and constructing a road, it is vital to ensure that the asset is preserved by timely and effective maintenance. Such maintenance has three principal purposes:

- it prolongs the life of the road and postpones the day when renewal will be required
- it reduces the cost of operating vehicles on the roads
- it helps to keep roads open and enables greater regularity, punctuality and safety of road transport services

The first purpose corresponds most directly to the interest of the roads agency, the second to that of operators of vehicles, and the third, more generally, to that of the inhabitants of the area traversed by the road.

Typical Maintenance Activities

Maintenance activities are either *cyclic* or *reactive* and can be of a *routine* or *periodic* nature. Cyclic activities are those that are carried out at regular intervals. Reactive activities are those that are carried out in response to an occurrence e.g. erosion, drainage repairs, or a condition defect exceeding values dictated by maintenance standards, e.g. rutting greater than a given value.

Table 7.1 - Maintenance activities

Works Category	Maintenance Activity	Type	
		Cyclic	Reactive
Routine Maintenance	<i>General:</i>		
	Grass cutting	X	
	Removal of obstacles		X
	Culvert clearing/repair		X
	Bridge clearing/repair	X	
	Drain clearing	X	
	Erosion control/repair		X
	Carriageway markings		X
	Repairing road signs		X
	<i>Pavement:</i>		
	Pothole repairs		X
	Surface patching (local sealing)		X
	Crack sealing		X
	Edge repairs		X
Periodic Maintenance	Rejuvenation seal		X
	Resealing		X
	Shoulder regravelling/reshaping		X

Routine maintenance: fixed cost activities that are carried out irrespective of the engineering characteristics of the road or the density of traffic (e.g. grass cutting).

Recurrent maintenance: activities required throughout the year but whose frequencies vary with traffic, topography and climate (e.g. road marking).

Periodic maintenance: those recurrent activities that are required at intervals of several years (e.g. re-sealing).

Lengthman: A man engaged on a contract basis responsible for routine maintenance on a fixed length of road adjacent to his own home. He is paid a fixed sum per day or month to keep drainage ditches clear, fill in potholes, cut grass, repair minor erosion to shoulders, etc.



Grass cutting – a typical, labour-based, routine maintenance activity.

Many of the activities in Table 7.1 can be carried out cost-effectively using labour-based methods. If some of the routine maintenance work is contracted on a “lengthman contract” basis, for example, there would be little or no requirement for maintenance labour camps for transport to and from

the work site, thereby saving money. Some periodic maintenance work may still require specialised equipment, e.g. bitumen sealing operations, but labour-based methods can be used for many activities.

Lack of attention to simple maintenance tasks can impose a multitude of problems for road users, society and the national economy as illustrated in Table 7.2.

Table 7.2 – Maintenance problems, effects and solutions

Road Safety		
Issue/Problem	Effect	Solution
Vegetation growth	Impairs driver visibility	Ensure safety standards are established and maintained.
Potholes	Danger to motorists	
Flooding (blocked culverts)	Reduces pavement strength	
Dirty, damaged or missing traffic signs	Increases likelihood of traffic accidents	Carry out routine inspections to identify deterioration likely to lead to a reduction in road safety.
Faint road markings		
Damaged bridges and guard-Rails		
Scoured highway shoulders	Impairs integrity of road pavement	Record and analyse accident data to provide clues to maintenance deficiencies .
↓	↓	↓
Increases safety hazards to road users	Causes more road traffic Accidents	Need for effective and timely road maintenance
Road User Costs		
Issue/Problem	Effect	Solution
Clear link established between pavement condition and vehicle operating costs and embodied in transport investment models (e.g. HDM-4.)	An increase in surface roughness causes vehicle operating costs to increase. Significant additional costs incurred by road users when maintenance requirements are overlooked.	Identify, programme and control maintenance operations.
↓	↓	↓
Rate of pavement deterioration is often not contained causing surface roughness to increase at an accelerating rate	Additional costs to high Way users	Use of an appropriate maintenance management system
Life-Cycle Costs		
Issue/Problem	Effect	Solution
Feasibility and design strategies assume: (a) regular pavement strengthening will be carried out to arrest deterioration, (b) care will be taken to deal with localised imperfections as they arise (e.g. crack sealing)	Failure to control deterioration results either in an earlier requirement for strengthening or a substantially increased cost for reconstruction.	Optimise investment by judiciously applying maintenance interventions to arrest rate of deterioration and to preserve structural integrity of each road link in the network.
↓	↓	↓
Assumptions often not realised in practice	Economic penalties incurred which result in a need for premature reconstruction	Use of an appropriate pavement management system

7.2.2 Deterioration Characteristics

Even with strict adherence to proper standards of construction, roads deteriorate with the passage of time. The rate of deterioration may vary widely depending on the climate, the strength of the pavement and underlying subgrade, and the traffic volume and axle weights. The wear and tear of road surfaces by traffic is aggravated by rainwater and by changes in temperature. Cracking occurs in the bituminous surfacing which, together with the ingress of rainwater.

Figure 7.2 illustrates how road condition deteriorates with time and how road life may be extended by controlled maintenance.

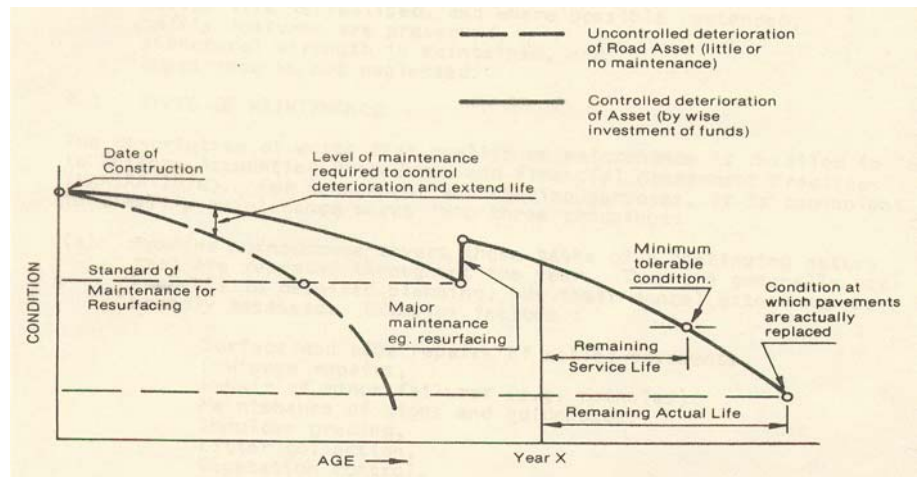


Figure 7.2 – Typical road condition deterioration with time

Of particular significance in responding to the maintenance requirements of LVSRs is the fact that, in contrast to higher trafficked roads, the proportion of total distress resulting from environmentally-related influences is very high, as illustrated in Figure 7.3¹.

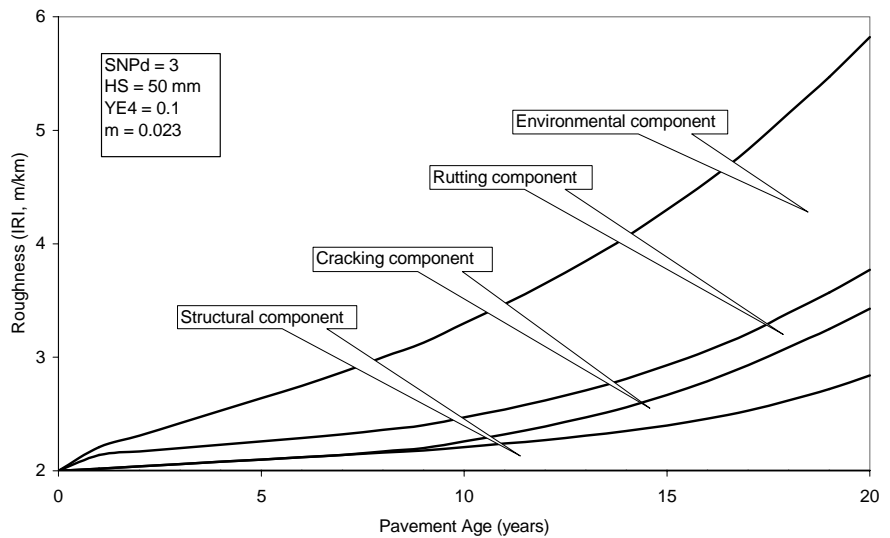


Figure 7.3 – Contribution to total predicted road roughness of different components for a low-medium volume paved road¹

All roads deteriorate with time. However, LVSRs are particularly sensitive to the vagaries of the physical environment so that timely and effective control of their deterioration becomes the key and the challenge to the management of road maintenance.

In Zimbabwe, the environmental component of roughness progression varied by a factor of almost 4, with low-volume roads built to lower cross sectional standards having the highest rate of progression and higher volume roads with standard designs having the lowest rate of progression. Corresponding crack initiation times and rates of crack progression were almost half and double those of standard designs respectively¹.

Whether the increased risk of deterioration is important in any locality will ultimately depend on local climatic, traffic, pavement design and maintenance factors, therefore knowledge of local rates of deterioration will be vital. On the other hand, higher levels of deterioration and consequent reduced service standards, can be tolerated from both an economic and user perspective. The lesson, therefore, is to appreciate the risks and manage these within the decision making framework for justifying investment levels (see Section 5.4.6).

7.2.3 Characteristics of LVSRs

As a general rule, LVSRs are built to lower geometric and pavement design standards than roads which carry higher traffic volumes. Thus they may be expected to have the following characteristics which have significant implications on maintenance operations:

- *A low cross section profile* – thus making them more susceptible to moisture ingress and general deterioration, i.e. deterioration of the cross section which has serious impacts on overall performance.
- *Measures to protect the drainage system are usually minimal* – which often leads to increased erosion.
- *Thin bituminous surfacings are commonplace* – consequently, progressive embrittlement, poor construction or other causes of damage to the surface can easily lead to moisture ingress and consequent accelerated deterioration of the pavement.
- *The upper pavement materials are usually plastic in nature* – this lead to a considerable loss in strength on wetting up, leading to accelerated deterioration under load.

7.2.4 The Maintenance Challenge

The provision of adequate maintenance for LVSRs becomes even more difficult in an environment of limited funds, where resources become stretched to the limit to contain road deterioration.

LVSRs present a more demanding challenge than more heavily trafficked HVSRs for their proper maintenance. Their characteristics, particularly greater sensitivity to the vagaries of the natural environment, often mean that, in order to avoid rapid deterioration, maintenance must be scheduled and carried out more frequently and expeditiously than for HVSRs.

Attitudes to Maintenance

Historically, maintenance has been viewed as being unattractive and mundane. As a result, it has not received the priority it deserves. This attitude has been strengthened by the preference of some aid agencies to finance capital rather than recurrent costs which has sometimes introduced a bias against maintenance (as recipient governments sought to use their limited funds in new construction where they would attract maximum foreign financial participation.)

With maintenance often being seen as a public responsibility, funds allocated for maintenance have, on occasions, been diverted to other sectors what may be considered more deserving causes in the eyes of those involved in high level decisions. Through the 1980's and early 1990's, problems of this kind led to the deterioration of extensive parts of the main road network in many countries in the SADC region. This has contributed to the high transport costs – some four to five times higher than in developed countries – thereby making the region globally uncompetitive. The cycle of the effects of inadequate maintenance is shown in Figure 7.4.

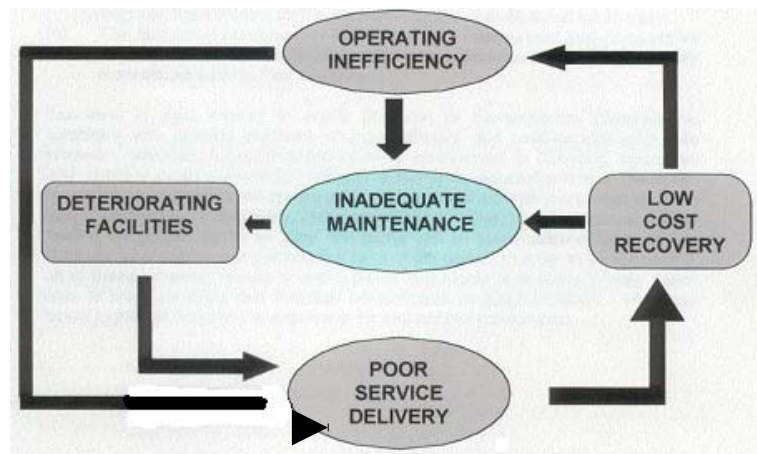


Figure 7.4 – The vicious cycle of inadequate maintenance

Funding of Maintenance

Although the concept of protecting the capital investment of road provision through timely financing of road maintenance is generally well understood, the application of this concept has presented formidable problems, primarily because of a lack of a sustainable source of funding.

In most SADC countries road maintenance expenditures are generally well below the levels needed to keep the road network in a stable long-term condition. Worse, budget allocations are often cut at short notice in response to difficult fiscal conditions, funds are rarely released on time and actual expenditures are often well below agreed budget allocations. This has led to a maintenance crisis in many countries where there is now a backlog of roads in poor condition. The net result is that the road transport sector is operating well below its optimum level and this has had an adverse impact on many other sectors of the national economy.

Box 7.1 – Maintenance backlog on the SADC main road network²

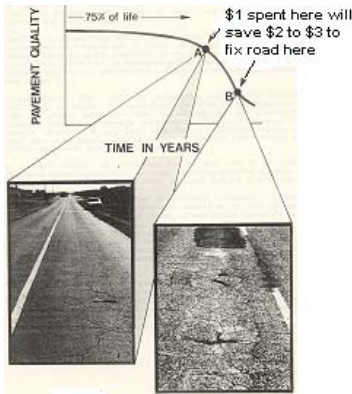
Recent studies indicate that about US\$ 1.7 billion per annum (about 1 per cent of regional GDP) needs to be spent on regular maintenance of the region's roads, including a cycle of reseals and rehabilitation of paved roads. However, little more than one half of this amount is allocated.

GDP (1995)	Actual Annual Expenditure	Estimated Annual Requirement	Annual Shortfall	Backlog Maintenance
165,000	960	1,760	800	6,400

Note: All figures in millions of US \$

It is also necessary to bring a significant kilometrage of main roads back to maintainable condition which is estimated to cost about US\$6.4 billion.

The impact of inadequate maintenance?



- Drains get blocked (leading to flooding), verges become overgrown and obscure the driver's view thereby increasing the incidence of road accidents.
- The surface deteriorates, develops potholes, gets rough and difficult to drive on and vehicle operating costs increase.
- Soon, stretches of the road become impassable for long periods of the year.
- Eventually, and usually more quickly than most people realise, the road needs reconstructing, often at three to four times the cost of effective and timely maintenance.
- Where maintenance funds are not available, the road becomes abandoned, commerce and business stagnates, rural areas become isolated and condemned to remain poor without adequate communications.

Inadequate Road Maintenance

New paved roads, if inadequately maintained, deteriorate slowly and almost imperceptibly during the first half to two-thirds of their service life, after which they deteriorate much more rapidly. Without timely maintenance, they simply break apart and, in so doing, the costs of operating vehicles – and of transporting goods – increase rapidly. Worse, vehicle operators who pay these costs, then pass them on to the general public and the cost of living increases.

In rural areas, where roads often become impassable during the rainy season, poor road maintenance has a profound effect on agricultural output. Poor roads and poor transport services also have adverse effects on the provision of health, education and social services; these effects are not easy to quantify but are of vital importance to the people living in rural areas and in helping to eliminate poverty in its widest sense.

Box 7.2 – The costs of poor road maintenance

A LVSR in good condition, carrying about 200 vpd, requires resealing, costing about \$10,000 per km, every seven years to keep it in good condition. This has a net present value (NPV) discounted at 12 per cent over twenty years, of \$7,000 per km. Without maintenance, the road will deteriorate from good to poor condition. This will increase vehicle operating costs by about \$2000 per km which has an NPV, when discounted over twenty years, of \$18,000 per km. The benefit cost ratio of a fully funded road maintenance programme is almost 3!

Poor road maintenance also raises the long-term costs of maintaining the road network. Maintaining a LVSR for fifteen years costs about \$60,000 per km. If the road is not maintained and allowed to deteriorate over the fifteen year period, it will then cost about \$200,000 per km to rehabilitate it. Thus, rehabilitating paved roads every ten to twenty years is more than three times as expensive, in cash terms, as maintaining them on a regular basis, and 35 per cent more expensive in terms of NPV, discounted at 12 per cent per year.

In quantitative terms, when a road is not maintained, and is allowed to deteriorate from good to poor condition, each dollar saved from not carrying out maintenance increases VOCs by \$2 to \$3. Thus, as illustrated in Figure 7.5, *far from saving money, cutting back on road maintenance increases the costs of road transport and raises the net cost to the economy as a whole. This fact is a powerful one and one which roads agencies can use to convince government of the high cost that countries pay for inadequate funding of road maintenance.*

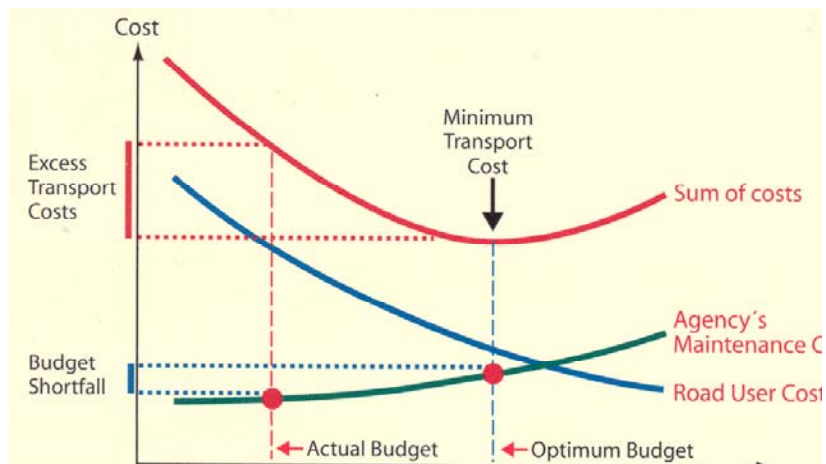


Figure 7.5 – Relationship between maintenance standard and transport cost



Vehicle overloading also has an adverse effect on road safety

Overload Control

To protect the huge investment in road infrastructure, all SADC countries have promulgated Road Traffic Acts that stipulate permissible axle load and gross vehicle mass limits. These limits are meant to ensure that roads last for their full design life with normal maintenance expenditures. Unfortunately, overloading is rife in most countries with rates of up to 50%. Such overloading causes not only a disproportionately high degree of road damage, because of the exponential relationship between axle load and road damage, but also contributes to the poor road safety record in many countries. Thus, overload control is particularly important on LVSRs.

Unfortunately, the current, traditional government driven approaches to overload control have been ineffective in many countries for the following reasons:

- current systems provide a criminal response with low conviction rates.
- in-house operation with low-paid staff is susceptible to corrupt practices.
- no link between level of fines and damage to the road.
- constraints in the criminal justice system result in a low priority given to overloading offences.
- road authorities often have a limited role in regulating overloading.
- current systems do not have the primary goal of preserving road infrastructure.

There is, therefore, a need for a new approach and a vehicle loading reform strategy has been developed for the region which will form annexes to the SADC Protocol on Transport, Communications and meteorology.

The main elements of this initiative are:

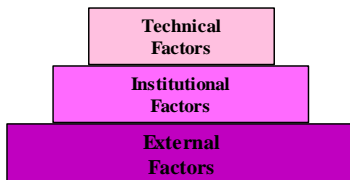
- introduction of a Regional Overloading Control Association
- introduction of a regional strategy for overload control
- operation of a self regulatory system by transport operators
- decriminalisation of offenders by administering an overloading fee
- linking the level of the imposed fees to the actual cost of road damage
- outsourcing weighbridge operations to the private sector

7.2.5 Lessons Learned

The ineffectiveness of maintenance operations, management and financing of LVSRs (and, indeed, all roads) in the SADC region has been the subject of much study and investigation by international and local organisations. The worst cases of maintenance ineffectiveness have been found to occur in countries where some or all of the following conditions occur, not necessarily in order of importance:

- a weak institutional framework which suffers from high vacancy rates and reliance on contract personnel
- a large amount of maintenance work carried out through “force account” operations with reliance on plant and equipment provided from government plant pools “free of cost”

Hierarchy of management issues
(Adapted from Brooks et al., 1989)



Until the external and institutional frameworks are improved, it is extremely difficult to overcome the numerous technical and human resource problems which hamper attainment of efficient and effective management of road networks in the SADC region.

- lack of basic management systems and procedures which has compromised the ability of roads agencies to manage their road networks in a satisfactory manner
- poor regulation of various aspects of road management including, control of overloading
- inadequate involvement of the community in maintenance

It is apparent that the key issues raised above are predominantly social and organisational rather than technical. They support the widely emerging view in the SADC region that many of the endemic problems associated with inefficient and ineffective management of road networks are symptoms of a deeper problem. The real causes are weak or unsuitable institutional arrangements for managing and financing roads.

New approaches

As indicated in Chapter 2, through the *SADC Protocol on Transport, Communications and Meteorology*³, the SADC region has embarked on a programme of road sector reform which has fundamentally changed the way in which road maintenance is undertaken and financed.

Box 7.3 – New Approaches to Road Maintenance Operations, Management and Financing in the SADC Region

A new approach to road maintenance in its various aspects is emerging in the SADC region. It is no longer being viewed as a mundane topic for second rate engineers. Today, it operates in a changed environment and with a changed approach. It now holds a key position in roads agencies as a concept that espouses the need to preserve the value of the road asset, to provide improved service to road users and to contribute to environmental quality. Sustainable sources of road maintenance financing are increasingly being provided by road users.

7.3 Maintenance Management

7.3.1 Main Purpose

Maintenance management is essentially a systematic means of efficiently planning, programming, budgeting, scheduling, controlling, data collection, monitoring, etc. In conjunction with the 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 challenge is to set policies which can contribute the greatest benefit to communities whilst supporting broad national goals.

The undertaking of the various inter-related activities associated with the management of maintenance can be facilitated by the use of an appropriate maintenance management system. Such a system must be well conceived and careful consideration must be given to pursuing a strategy for its development which should be based on methodologies, techniques and resources that are matched to local circumstances.

7.3.2 Inventory

A road inventory is necessary for any maintenance function. It is used as a basic reference for planning and carrying out inspections in relation to a location reference system. The essential elements include road nodes, route name and length, functional classification, pavement and surfacing type.

The inventory is a set of information about the basic engineering characteristics of the road network and is vital for any management function. It defines the key features of each section of road and is an essential reference source for inspection and analysis. The content of the inventory should be directly relevant to maintenance management. When it is first drawn up it should be as simple as possible and need only contain information on the following items.

- route name
- functional classification
- section length
- type of surface and construction
- cross section width

As the inventory is built up, further information can be added on all factors influencing the management activities. In addition, data about the distribution and engineering properties of soils will be useful in identifying possible sources of maintenance materials. Inventory data are expensive to collect and keep up-to-date. Generally, the inventory should be as simple as possible and not be overloaded with unnecessary information.

7.3.3 Components

There are four distinct and inter-related components of road maintenance which, together, comprise a management framework for successfully addressing the maintenance challenge⁴. As illustrated in Figure 7.6, these are: Planning, Programming, Preparations and Operations.

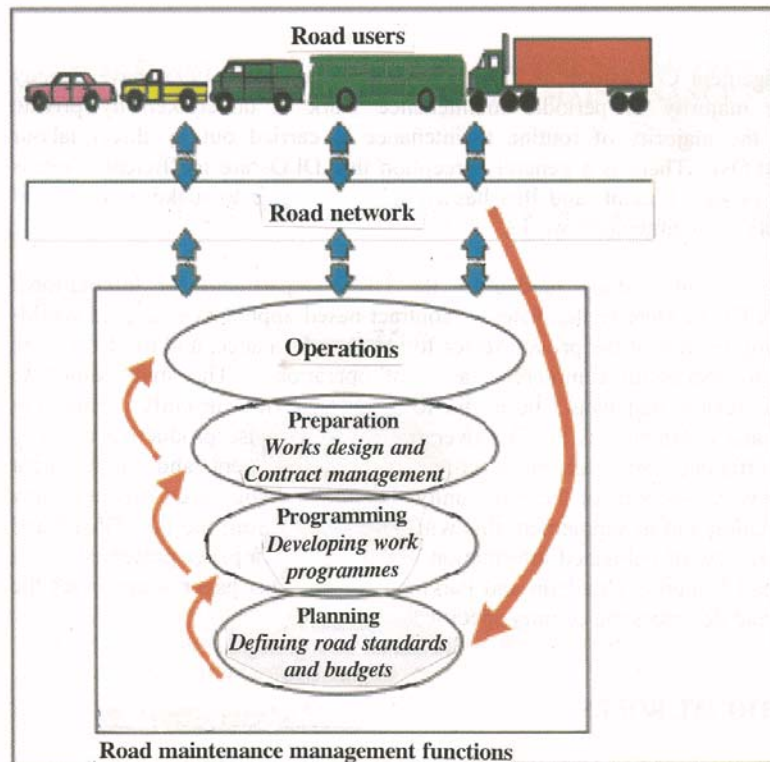


Figure 7.6 – Road maintenance management functions in relation to the road network and users⁵

An implication of Figure 7.6 is that, if road maintenance at the point of delivery is to be optimised, then there is also a need to *optimise* the higher level functions of planning, programming and preparation. However, the higher level functions will need to reflect the needs of road users on the network – an issue that has taken on added significance with the more commercialised approaches to road management currently being pursued in the SADC region in which road users have become “customers” of roads agencies as “service providers”. The challenge is to set policies which can contribute the greatest benefits to stakeholders whilst supporting broad national goals.

An important conclusion from the above is that any successful change to improve maintenance operations on SADC road networks should be driven from the needs and requirements of users and the network (“bottom-up”) whilst supporting broader national goals of economic development and poverty alleviation. The remainder of this chapter focuses on such issues in the context of the LVSR maintenance management cycle.

Road maintenance management

At a practical level, road maintenance management aims to ensure that the correct activities are performed on the network at the right time, and to the desired quality. The challenge is to set policies which can contribute the greatest benefit to communities whilst supporting broad national goals.

7.3.4 Management Cycle

Maintenance management strives to achieve maintenance policy objectives through a series of well defined, organised and executed functions. They relate to both long and short-term decisions, and concern the whole network, sub-networks and individual lengths of road. The sequence of activities moves in a cycle that begins with planning and moves through programming, preparation and then operations in the manner shown in Figure 7.7^{4,6}.

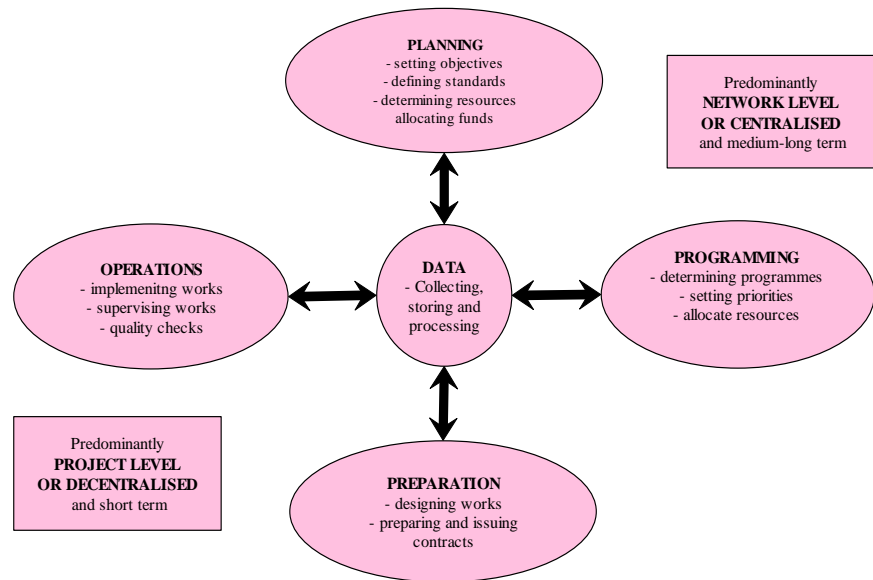


Figure 7.7– The cycle and scope of maintenance management functions

The following issues are important, though not exclusive, to LVSRs:

- Effective management depends on the availability of sufficiently comprehensive data on all assets, traffic and costs.
- Participation, or effective representation, at the highest level, i.e. network planning, is usually essential to ensure adequate resources are made available for maintenance.
- Whilst general programming and prioritisation might be done at a central level, more detailed programming will benefit from greater local knowledge and participation.

At each stage, procedures are required to guide staff in their duties, and should form the basis of more formal management systems which, for low-volume sealed roads, may comprise simple manual or spreadsheet-based systems.

Having defined in general terms the nature of maintenance, the following sections consider the operational environment within which maintenance resides with a view to offering solutions to its more effective delivery.

7.3.5 Maintenance Policy and Organisation

A policy framework is required to provide the context within which road maintenance is carried out in the SADC region. Maintenance policy would be expected to support Government policy in the roads sector. Increasingly, such policy is now focusing on broader national issues pertaining to the attainment of socio-economic goals, greater involvement of the private sector and more attention to fulfilling users' expectations.

Box 7.4 – Typical Maintenance Policy Objectives for LVSRs

The following are examples of typical policy objectives which are fundamental for ensuring that maintenance is carried out in a sustainable way:

- Poverty reduction through employment creation and the related use of labour based methods wherever feasible.
- Local community involvement in the planning and execution of maintenance of rural road facilities.
- Private sector involvement (local contractors) in road maintenance (rather than undertaking such maintenance by force account operations).
- The use of the most cost-effective rather than most technologically advanced approaches in carrying out road maintenance.
- Minimising the environmental impact of material resource developments by adopting Environmental Impact Assessments.
- The use of maintenance standards that balance life cycle costs (construction, maintenance and vehicle operating costs).
- The use of simple contract documents appropriate for use by small contractors.

The SADC protocol on Transport, Communications and Meteorology envisages an institutional framework which clearly differentiates between the roles played by road sector stakeholders in policy formulation, policy delivery and works execution. The arrangements were illustrated earlier in the General Introduction to this Guideline (Chapter 2, Figure 2.5 – SADC institutional framework). This is a significant change from the previous arrangements which led, in one way or another, to the maintenance crisis of the 80's and 90's.

Another significant change relates to the private sector, which is now involved as network maintenance contractors and network management consultants. The nature of the contracts may also be long-term and outcome-based, as opposed to the more traditional “schedule of rates” approaches.

Regional agencies, with a greater degree of autonomy than those previously working with community representatives, can be expected to be involved in priority setting, whereas communities might also deliver services at the operations level.

Table 7.3 - Functions of various road sector stakeholders

Function	Typical aims	Spatial coverage	Organisations concerned
Policy	Policy formulation Formulation of strategic objectives Defining standards	Network-wide	Ministry
Strategic Planning	Determining resources to support defined standards and objectives	Network-wide	Roads Agency (HQ) with approval by Ministry policy advisors
Program-ming	Determining the work programme that can be obtained within the budget period and resource constraints, including local priorities	Network-wide to Region or sub-network wide	Regional Agencies or Consultant and Contractors and Communities
Preparation	Design of works Preparation and issue of contracts and works instructions	Sub-network, Road-link, Section or project	Regional Agencies or Consultants and Contractors
Operations	Undertaking tasks as part of works activities	Sub-network, Road-link, Section or project	Contractors and Consultants and Communities
Monitoring and Evaluation	Measuring achievements against performance, end product and financial targets	Network-wide to project level.	Representatives of all functions, including Road Fund Board

7.3.6 Maintenance Standards

In the constrained budgetary situations that prevail in most SADC countries, maintenance standards and associated levels of user service should be set, wherever possible, on the basis of minimising total transport costs over the life cycle of the road link. If maintenance is carried out too frequently, or to too high a standard, the maintenance provided will be unnecessarily costly and resources will be wasted just as they will be if too little maintenance is carried out.



Badly potholed road.
Is this acceptable?
No



Road with occasional potholes which can be maintained through patching, but with a waterproof surface.
Is this appropriate?
Yes



Road in excellent condition.
Is this always affordable?
No

Figure 7. 8 – Choosing appropriate maintenance standards

For LVSRs, the range of choices is typically as illustrated in Figure 7.8. In many cases the middle example will often provide the most appropriate solution, but this will depend on local circumstances and the extent to which it fits with the current views of policy makers and user's, and those of engineers and planners.

The Engineer and the Planner will need to specify an appropriate standard for all types of maintenance and, importantly, to be able to justify this to policy makers and the paying public and they will need to be especially flexible according to local circumstances. Their responses may vary from a comprehensive, 'Full' maintenance strategy where the objective is to minimise life-cycle transport costs, to a minimum strategy which will help fulfil 'Basic' access standards. A strategy to minimize road user costs, which is the expensive extreme, is unlikely to be promoted by stakeholders.

Typical examples of routine maintenance standards, intervention levels and work procedures, in relation to road function, are given in Table 7.4. Similar standards and maintenance strategies can also be developed for periodic maintenance. Many models exist for such analyses (e.g. HDM 4, RED) but their applicability becomes more and more questionable when road user savings are small relative to the cost of the road. In such situations, cost-minimisation strategies become a prudent alternative, *without compromising road safety*.

Table 7.4 - Typical routine maintenance standards

Activity	Standard		
	A	B	C
	Strategic/primary roads AADT >150	Secondary/Tertiary roads AADT 150 < and > 50.	Secondary/Tertiary roads AADT <50
Grass cutting	Grass height not > 30 cm	Grass height not > 30 cm where sight distance must be maintained	As the need arises
Removal of obstacles	Clear carriageway immediately; Clear rest of road area and repairs within 5 days	Clear carriageway immediately; Clear rest of road area and repairs within 10 days	Clear carriageway immediately; Clear rest of road area and repairs within 60 days
Culvert clearing/repairs	Clearing and repairs before wet season; Clear once a week during wet season; Repairs within 20 days	Clearing and repairs before wet season; Clear once every 2 weeks during wet season; Repairs within 30 days.	Clearing and repairs before wet season and, when required, during wet season.
Bridge clearing/repairs	As above	As above	As above
Erosion control/repairs	As above	As above	As above
Drain clearing	Clean out within 5 days when drain depth is reduced by > 20 %	Clean out within 10 days when drain depth is reduced by > 30 %	Clean out within 20 days when drain depth is reduced by > 50 %
Pothole repairs	Repair potholes within 2 days	Repair potholes within 2 days if > 5 potholes/km or during wet season, otherwise repair within 10 days	Repair potholes within 5 days if > 10 potholes/ km or during wet season, otherwise repair within 20 days
Surface patching	Repair within 2 days	Repair within 5 days	Repair within 10 days
Crack sealing	Seal all cracks before wet season starts; Seal immediately during wet season; At other times seal within 5 days if affected road section is > 10m or if crack width is > 3mm	Seal all cracks before wet season starts; Seal immediately during wet season; At other times seal within 10 days if affected road section is > 50m or if crack width is > 3mm	Seal all cracks before wet season starts; Seal immediately during wet season; At other times seal within 20 days if affected road section is > 50m or if crack width is > 3mm
Edge repairs	Edge drop should not be > 15mm; Correct within 10 days.	Edge drop should not be > 25mm; Correct within 20 days.	Edge drop should not be > 25mm; Correct within 30 days.

Note: Adapted from TRL (1987)⁷

7.3.7 Assessing Needs

Road condition surveys are an important aspect of the maintenance process and are carried out to establish maintenance requirements and, subsequently, priorities. Such surveys are normally carried out in two stages:

- Network screening survey – in the first stage, an engineer or senior technician undertakes a drive-over survey of the network to identify those sections likely to need treatment.
- Detailed pavement testing – the second stage involves a small team, led by a technician, whose task is to determine the requirements for reactive and periodic works, and to identify those sections where detailed investigations are needed prior to carrying out renewal works.

Figure 7.9 gives a flow diagram of road condition surveys. Visual condition surveys, including a drive-over of the network, are normally adequate for LVSRs, with a detailed walk-over survey done selectively for sections appearing to need major works. Detailed pavement testing e.g. with an FWD or Benkelman Beam, is required for pavement rehabilitation design but this is not the main concern in this Guideline. The concept of Information Quality Levels (IQL)⁸ have been developed with a level of detail that is appropriate for LVSRs.

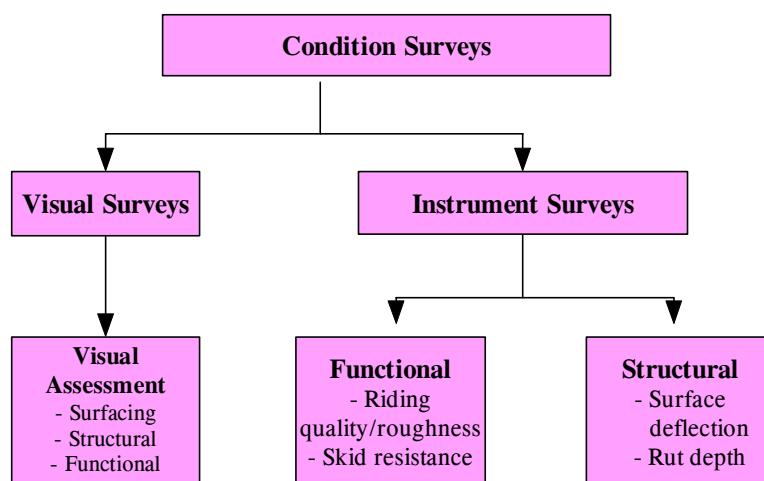


Figure 7.9 Flow diagram of road condition survey tasks

Common types of road condition data collected during surveys are given in Table 7.5.

Table 7.5 - Condition data elements

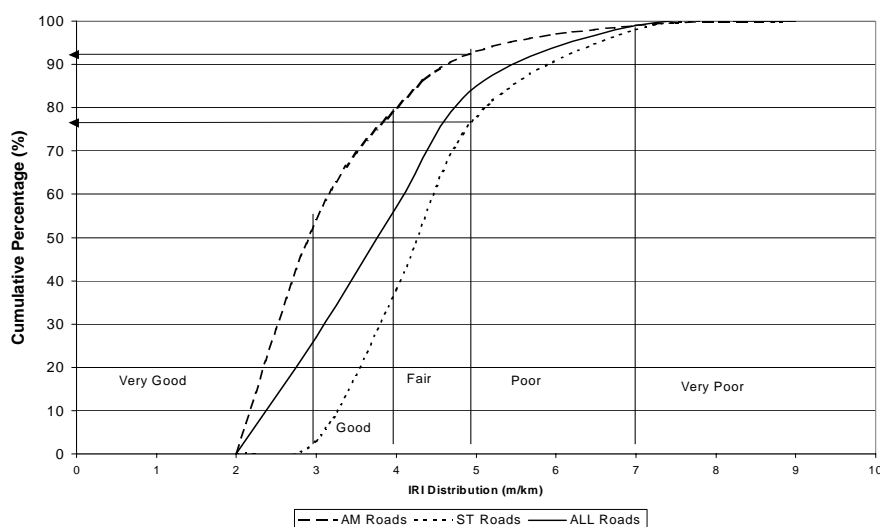
Data Category	Data Elements	
Visual (to be followed, if necessary, by more detailed inspection and measurement)	<ul style="list-style-type: none"> ● Texture ● Surfacing failure ● Surfacing cracks ● Block cracks ● Crocodile cracks ● Longitudinal cracks ● Transverse cracks ● Pumping 	<ul style="list-style-type: none"> ● Aggregate loss ● Binder condition ● Bleeding/Flushing ● Rutting ● Settlement ● Patching ● Potholes
Visual and/or instrument	<ul style="list-style-type: none"> ● Deflection (FWD or Benkelman Beam) ● Rut depth ● Riding quality/roughness ● Skid resistance ● Surface drainage ● Cross – section 	<ul style="list-style-type: none"> ● DCP ● Laboratory tests ● Side drainage ● Shoulder condition ● Edge break ● Passability

Note: Adapted from CSRA (1995)

It is preferable that direct measures of each distress are reported for maintenance management purposes rather than combining several distress parameters into a single index. This is because different types of distress often require different treatments. A combined index obscures the severity levels of the various distress types and therefore makes it difficult to identify optimum treatment. Nevertheless, a combined index, such as the Present Serviceability Index, can be useful for reporting the condition of roads to non-specialists, who are unlikely to understand the engineering importance of the different distresses that may occur.

Irrespective of the road class, measurement of distress should be undertaken at least annually with statistics presented in a cumulative frequency distribution for each road class, as illustrated in Figure 7.10. This can be used to illustrate the current condition of the asset in relation to target values and previous and current conditions.

Figure 7.10 – Example of roughness distribution for different road classes



7.3.8 Determining Priorities

Even when standards have been developed on an economic basis, or in support of policy objectives, the fact that budgets are invariably less than the desired level means that choices must be made. The types of choices include whether to:

- (a) delay investment until more funds are available
- (b) lower standards
- (c) perform certain activities in preference to others

Different approaches are available to prioritise works. Some depend on the type of road, works type and traffic levels, whilst others take account of issues such as population served, economic indices, social indices and strategic importance. They are often applied differently to paved or unpaved roads, and to high or low-volume roads.

Three approaches are introduced below which span the range of available techniques and may be used to complement each other. They address the range of issues and potential conflicts important to low-volume sealed roads. These are as follows:

- Treatment choice method (TRL, 1987)⁷
- Cost effectiveness methods
- Economic NPV and NPV/Cost methods

Treatment Choice Method: In this method, funds are earmarked for 'essential' maintenance activities such as addressing emergency works, access restoration (over short stretches), drainage maintenance and asset preservation. Remaining funds are distributed to more heavily trafficked roads justifying more expensive treatments, with unfunded works delayed or other budget sources sought. It is both simple and flexible, since the user can specify the order of importance based on local priorities. An economic underpinning does exist, in that it is widely recognised that routine maintenance provides a higher economic return than intervening only after significant distress has already occurred.

Table 7.6 – Example of “Treatment Choice Method”

Hierarchy of maintenance activity	Priority							
	Traffic hierarchy							
	1	2	3	4	5	6	7	8
Traffic range (vpd)	Strategic	> 1000	500-1000	200-500	> 200	< 200	50-200	< 50
Surface type	P	P	P	P	UP	P	UP	UP
Emergency	1	7	8	9	10	11	12	13
Cyclic drainage	2	14	15	16	17	18	19	20
Reactive pavement work	3	21	24	27	30	33	36	39
Periodic preventative	4	22	25	28	31	34	37	40
Other cyclic/reactive	5	23	26	29	32	33	34	35
Overlay/reconstruct	6	42	43	44	45	46	47	48

Note: P = paved, UP = unpaved

Cost effectiveness methods: These methods introduce other considerations into the prioritisation process which are not addressed by conventional transport economic approaches. These considerations include:

- magnitude of population served
- weighting for degree of poverty in the communities
- potential for agricultural or other development
- number of social and other services

The approach might best be applied to rural feeder or collector roads, where the geographical area which benefits from an improvement can be precisely defined. It also lends itself for application at a local level through the direct participation of representatives of various stakeholder groups. Reference should also be made to Chapter 3 on this.

Economic NPV and NPV/Cost methods: These methods are appropriate to relatively heavily trafficked roads relying on user benefits to economically justify maintenance interventions. They are employed in models such as HDM-4 or RED which have been described in Chapter 3.

7.3.9 Management Systems and Tools

In the SADC region, where allocations to the roads sector have generally not kept pace with requirements, it is vitally important that scarce funds are allocated to competing components of the road system in an optimal manner. However, with the best of intentions, the determination of such a balance cannot be competently assessed by traditional methods which have generally relied on fixed standards, subjective judgement and intuition; neither can the development of appropriate funding (cost recovery) and pricing strategies for promoting more efficient use of resources in the roads sector. To this end, the use of an appropriately structured Road management System can greatly assist roads agencies in managing and financing their road networks efficiently and effectively.

The main objectives of a Road Management System are to:

- Provide a systematic and structured means of developing annual work programmes, resource requirements and budgets based on *optimum economic standards*.
- Ensure an equitable distribution of funds over the country and enable priorities for allocations to be determined in a rational way when available funds are inadequate.
- Authorise and schedule work.
- Provide a system for monitoring the efficiency and effectiveness of maintenance works.

The potential benefits of efficient road management systems are well documented but few systems have been sustainable within developing environments. Current difficulties are partly a consequence of the substantial resources required to operate them effectively, particularly the basic data collection itself and the over ambitious expectations of users. Key elements, such as the importance of cost effective standards, proven treatment

selection and prioritisation methods and the quality of service delivery are often given insufficient attention.

Experience from the SADC region and elsewhere indicates that the 'institutional' dimension has often been sadly neglected and, if the foundations and commitment required for sustainability do not exist, then the systems will fall into disuse and become ineffective. This has been put into sharp focus throughout the region as a result of the road reform process, and the resulting changes in responsibilities which have clearer outcome-based objectives and require more transparency and accountability.

For a road management system to be sustainable, commitment from senior people is vital. However, complexity and excessive resource requirements, especially at the early stages, are serious risks. Sustainability is more assured if a step-wise approach is adopted for its introduction, starting with a simple system requiring modest data collection in keeping with the current institutional capacity of the roads agency. An integrated modular design should be employed to facilitate future expansion and improvements and these should be introduced gradually as the operation of the system becomes institutionalised.

Specification of Road Management Systems

The approach for developing a specification for a system for application to low-volume sealed roads, and most other categories of road infrastructure, should⁶:

- be simple, since this will ultimately retain a greater feel of transparency and comprehension by users
- specify the *scope* of the system and its component modules, or sub systems
- identify the prospective *users* of the system and their role in managing its various parts and the access they will require across the whole system
- confirm the *outputs* that its users will require
- select the categories of *data* and *models* required to produce the outputs, and how the data will be collected and processed.

An example of a simple, basic RMS is shown in Figure 7.11.

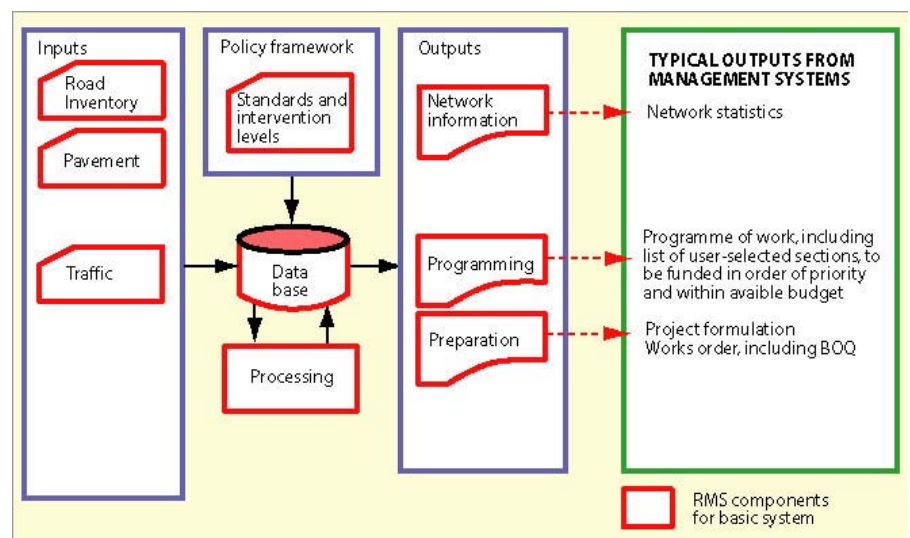


Figure 7.11 – Example of a simple, basic RMS

The scope and components (or sub systems) typically include:

- A Network Information System at the core, used to assemble, organise and store data about the network, including road inventory, pavement details, structures, traffic, finance (including budgets), on-going and planned activities, and resources.
- A number of Decision Support Systems to assist in the tasks that form the management cycle.

Decision Support Systems produce *outputs* which inform management of decisions whereas information systems simply list or present input data in tabular, graphical or map format.

The above approach tends to emphasise the overall purpose of the system, and de-emphasise the software and hardware considerations which, though important, are peripheral to the development of a system, at least in its early stages. This approach also emphasises user control, and places systems in their appropriate place.

Whether data is collected and presented in simple tables or spreadsheet formats, or manipulated in databases and processed through an analytical tool, the rules and processes employed should reflect the technical procedures described in the foregoing sections. More detailed guidance on system specification, and example outputs are given in various source documents^{5,6,7} and proprietary systems manuals.

Data Requirements

Probably the largest component of running costs for a Road Management System is that incurred in data collection. Thus, the type and quality of data to be collected will depend on what is actually needed and what can be realistically achieved. Only data which can be regularly updated and maintained should be collected and verified for consistency and completeness. To this end, the following criteria should be considered when selecting data items:

- (1) *relevance*: having a direct influence on the required output
- (2) *appropriateness*: both to the stage of planning and management process, and to the authority's capability to undertake the required data collection
- (3) *reliability*: in terms of accuracy, coverage, completeness and correctness
- (4) *affordability* : in both financial, and staff requirement terms

It is also important to select data acquisition technology that matches the requirements of the road agency. Choices to be made in the selection of data collection methods include:

- Mode of operation
 - manual, semi-automated or automated
 - pedestrian, slow or high-speed
 - independent or composite instrumentation
- Frequency, spatial coverage and spatial sampling of surveys

- Mode of administration
 - Centralisation
 - Audit process

The range of data quality and detail required, in terms of Information Quality Levels (IQL), depends on the management function, and must also be matched with resources available. Guidance on various aspects of data management for road management systems is provided in literature on this subject⁷.

7.4 Maintenance Operations

7.4.1 Organisational Roles and Models

Current and previous practice in many countries in the SADC region and, indeed, in most other countries in the world, has been to carry out maintenance (particularly routine maintenance) by direct labour i.e. labour permanently employed by roads agencies. However, this has proved to be inefficient in many countries and, in accordance with the SADC Protocol, there has been a gradual change in the execution of maintenance works towards the increased use of the private sector.

Roles

The terms used to describe the organisational roles which prevail in the SADC region are as follows⁴:

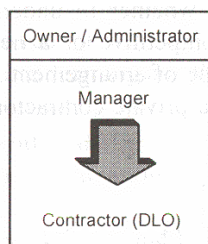
Owner: The organisation responsible for funding, establishing road policy and the legal and regulatory framework for management of the road network. Typically, this will be a ministry of transport or works acting as the *de facto* owner on behalf of the state.

Administrator: The organisation, responsible for implementing policy and ensuring that the performance of the road network meets the overall political and economic aims of the owner. In many countries, this is referred to as the road authority or agency.

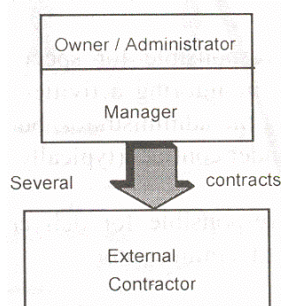
Manager: The role, or organisation, responsible for specifying activities to be carried out, supervising, controlling and monitoring activities. In most situations, the manager role is combined with that of the administrator, but increasingly worldwide there is a move to appoint managers under contract (typically, engineering consultants).

Contractor: The role, or organisation, responsible for delivery of operations by executing or undertaking works for the road administrator.

Model 1



Model 2



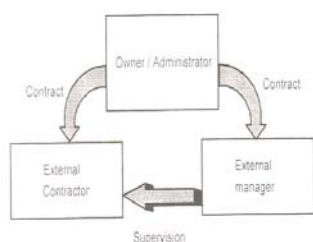
Models

Model 1 - In-house works unit (Direct Labour Organisation - DLO): This is the traditional model for undertaking routine and, sometimes, periodic maintenance works. In this case the administrator, manager and contractor are all part of the same organisation. In many cases, this will be the organisation of the owner, such as a ministry of public works.

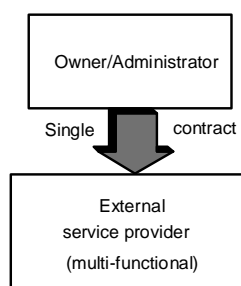
This traditional approach is gradually being phased out in the SADC region as more and more agencies are becoming autonomous or semi-autonomous organisations with a greater separation of “client” and “supplier” roles within organisations.

Model 2 - Conventional contractor: In this model, the road administrator, who lets conventional civil engineering contracts to an external contractor for carrying out the works, takes the manager role. The model has been widely used for carrying out development and periodic maintenance works but is less widely used for carrying out routine and special maintenance works.

Model 3



Model 4



Model 3 - Conventional contractor-consultant: In this model, the road administrator lets contracts for both the manager and contractor roles. Consultants typically undertake the role of the manager and have the task of supervising the work undertaken by contractors.

Many of the new Roads Agencies continue to employ this model, but with the Agency itself being bound by a “Performance Agreement” with the Owner Ministry. Their performance is monitored by a Road Board, or another independent body which essentially fulfils an audit role.

Model 4 - Total service provision: In this model, a single contract is let by the road administrator to the manager who is responsible for providing services to the administrator. The manager organisation may choose whether to undertake the contractor roles itself, or engage contractors. There are limited existing examples, although this type of arrangement is gaining favour.

7.4.2 Performance and Contractual Agreements

The change in circumstances requires a new set of agreements to be identified which are both legislative in nature, in that they transfer established responsibilities to a new organisation or responsible body, and contractual in nature. The changes also transfer a substantial amount of financial and technical risk to service providers, including road managers and contractors, and require new approaches for monitoring and evaluation. The appropriateness of the arrangements needs to be considered from the perspective of the supplier’s ability to accept risk and to provide the necessary quality management. This will ultimately decide the scope of works which various providers can deliver.

The characteristics of the various types of contract emphasising their relevance in rural situations, are indicated below:

Day labour: This type is purely a supply-only contract, and could be extended to include plant and materials. It continues to be appropriate where contractor development and the scale of operations is small, or uncertain. An appropriate example would be the supply of labour by ‘lengthmen’ contractors, perhaps organised through a community association, but with overall management vested in a local works department or managing agents.

Schedule of rates: This is the most common form of contract, Model 2 above, where the contractor is not subject to significant performance-based requirements, and undertakes a prescribed set of activities at specified intervals, or when conditions exceed ‘intervention standards’. Rates are negotiated, or in some cases stipulated by the purchaser; the reason for the latter is related to the stage of ‘commercialisation’ in the sector. The quality of workmanship will be specified, and *work planning and method guidelines* may be provided to ensure consistency in approach to each operation. Many road authorities in the region have adopted such guidelines.

Performance based, short-term: Performance based contracts require the contractor to accept the vast majority of the risk and to plan and specify the long-term maintenance needs to satisfy the outcome-based performance specification of the Client, and are usually lump sum. The scope of work includes routine and emergency works, and can extend to include periodic

works, the need for which requires approval processes to be actioned by the Client. In many cases, the contract incorporates provision for periodic works, thus reducing the need for new procurement processes within the contract term and therefore providing a greater guarantee of workload for the contractor. Such contracts are generally termed *Network Maintenance Contracts* (in Australia) or *Term Maintenance Contracts* (in the United Kingdom), and are usually managed according to Model 3 above.

Performance based, long-term: These extend the responsibilities to the service provider, who provides a ‘total service’ as illustrated in Model 3 above. The long-term nature of these contracts means that substantial planning and management capability must reside within the service provider. Works will include all maintenance activities and rehabilitation. Key Performance Indicators need to be set by the Client for long-term and short-term attributes. It is then the contractors who specify how the targets will be achieved and this will be incorporated into their tendered proposals.

Contracts of this kind are becoming common-place in Australia and New Zealand⁵, with entire rural road networks managed under such arrangements in Western Australia and parts of New Zealand (10% increasing to 30% in future). Independent auditing of achievement becomes a Client responsibility. These contracts allow considerable innovation on the part of the Contractors.

7.4.3 Acceptance of Risk

The form of contract defines each party’s responsibilities and allocates the various risks between them. Risks can be grouped according to those that affect:

- Quality - the possibility of the work not meeting the requirements of the client
- Cost - the possibility of the cost of work being different from that predicted
- Time - timely delivery is less of an issue for maintenance than for construction projects, and is closely related to cost

Political fashion in recent years has been to transfer as much risk as possible to the private sector, but experience has now shown it is best allocated to the party most suited to cope with that risk^{9,10}. In countries where maintenance has traditionally been carried out by in-house units, the private sector will often not be in a position to take on significant new risk, nor will the road administration be in a position to manage the private sector properly. Table 7.7 illustrates issues of risk allocation for road maintenance.

Table 7.7 – Contracting strategies and allocation of risk

Issue	Client to manage risk ←————→ Contractor to manage risk				
Type of contract	Hourly rates	Single activity	Grouped activity	Performance based (short)	Performance based (long)
Payment method	Cost reimbursable	Target cost	Schedule of rates		Lump sum
Term of contract	Short term	←————→			Long term
Packaging	Many small contracts	←————→			Few large contracts

7.4.4 Increasing the Use of Small-scale Contractors

A range of clients and contractors of differing capacity are usually present in all countries. Different sized contractors will respond to different types of client: for example, medium and large scale contractors will often have little interest in low-cost, dispersed rural routine maintenance contracts. In addition, many smaller local contractors might only be working currently in the building sector. A contractor development programme will enable them to compete for work in road maintenance and might achieve the objective of increased use of labour-based methods and increased local employment in such areas. This has been done in some countries. The use of local contractors and scope for labour-based maintenance, community involvement and responsibility has been dealt with in some detail in road maintenance policy seminars as part of the Road Maintenance Initiative (see Bibliography).

Community Contracting

Many maintenance works offer possibilities for community participation and contracting, which are often not fully exploited. However, this is only likely to happen if:

- the infrastructure concerned is of direct benefit to them
- a sustainable institutional framework exists
- initial external inputs are made available for system development, funding, demonstration and training.

Participation in community contracting initiatives implies stakeholder involvement in the planning, organising and implementation of the works. To this end, community bodies decide on local priorities and become responsible for managing the execution of the maintenance works by agreed means (e.g. through local contracts, paid labour/unpaid labour freely provided by the community with material support etc.)

Ultimately the successful involvement of small contractors or communities in carrying out maintenance works, by using labour-based methods where feasible, is important as a means of creating employment and helping to alleviate poverty. Fortunately, there are a number of manuals and guidelines available which deal with the development of small contractors employing labour-based techniques, including an introduction to business principles¹¹.

7.5 Summary

The key points arising in this chapter are:

1. Largely as a result of inadequate funding, provision of satisfactory road maintenance still remains an elusive goal in many countries. The net effect is poor road conditions, high operating costs and an adverse impact on national economies.
2. The key maintenance challenges are predominantly political, social and institutional rather than technical.
3. The road sector reform process currently being pursued in the region, including the establishment of dedicated road funds, is critically important for the sustainability of maintenance funding. In this regard, the recommendations of the SADC Protocol on Transport, Communications and Meteorology should be implemented.
4. The importance of pursuing sustainable maintenance policies through the use of labour-based methods, where cost-effective, as well as the involvement of local communities and small contractors, is crucially important as a means of employment creation with a direct link to poverty alleviation.
5. The absence of a systematic and structured approach to road maintenance results in inefficient and ineffective utilisation of scarce funds. However, the use of elaborate and complex management systems should be avoided and, instead, simple systems which are appropriate to local conditions should be introduced and implemented gradually.

The subject of road maintenance and its management; aspects that are essential for the preservation of the LVSR network as well as other influencing factors, such as vehicle overloading, have been covered in this chapter. The potential benefits from the recommendations contained in Chapter 7 and the earlier Chapters of this Guideline will only be realised through implementation, which is discussed in Chapter 8.

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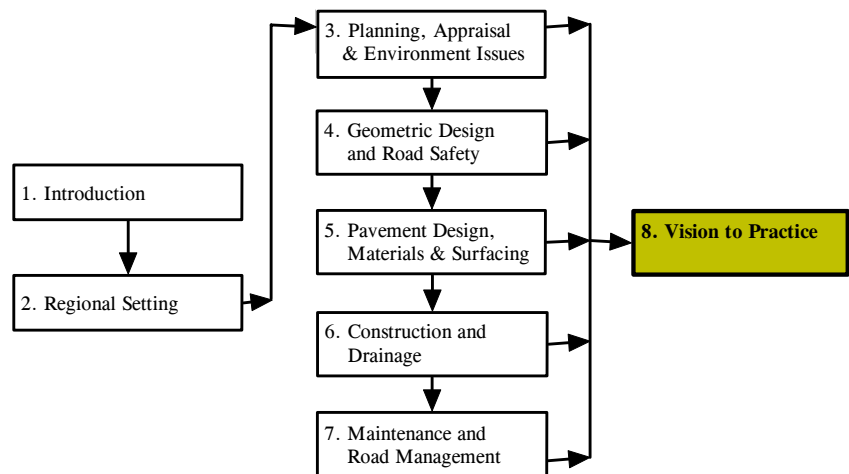
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Chapter 8



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Vision to Practice

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Vision to Practice

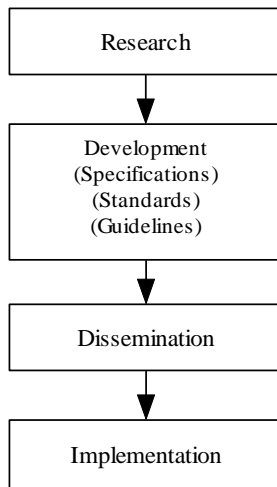
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8.1 Motivation

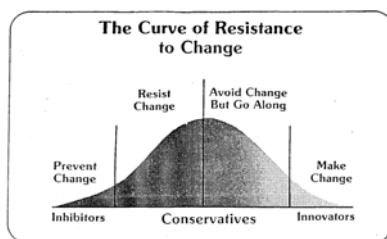
There has been a very strong motivation for preparing this Guideline on Low Volume Sealed Roads in the SADC region. In essence:

- Many aspects of LVSR provision have stemmed from technology and research in Europe and the USA in very different environments from that prevailing in the SADC region.
- Whilst changes have inevitably occurred in the region, much of the basic philosophy concerning LVSR provision remains unchanged, as have many of the norms and standards to be found in guidance documents which have not been revised for many years.
- A significant amount of research work spanning some 20 – 30 years has been carried out in the region by a number of specialist organisations, collaborating country agencies and, in some cases, by country agencies themselves.
- Much of the research has been aimed at low volume secondary and feeder roads including planning, appraisal, design, use of local materials, surfacing techniques, construction methods and finance for maintenance. Where implemented, the results of this research have invariably been highly beneficial and cost effective.
- Unfortunately, there is still a general tendency to use a conventional approach to provision of LVSRs which is often perceived to be “safe”. As a result, few of the results of relevant research have been put into practice and the potential benefits of so doing have not been gained.

8.2 Pathway to Implementation



Moving technology from the research environment to an operating environment will involve considerable technology transfer effort and resources to overcome various obstacles to implementation.



“There is nothing more difficult to take in hand, more perilous to conduct or more uncertain in its success, than to take the introduction of a new order of things, because the innovator makes enemies of all those who prospered under the old order, and only lukewarm support from those who would prosper under the new”.

Machiavelli, *The Prince* (1513).

The benefits of the Guideline will only be achieved if the approaches recommended are implemented. However, the path from research to implementation is a tortuous and time-consuming one. It has been estimated that in engineering, in each of the steps in the pathway which begins in attaining funding for research through to implementation, the magnitude of difficulty increases by a factor of between 2 and 8. These activities include carrying out the research, processing the recommendations, developing standards, disseminating the information right through to actual implementation. Thus, it can be quite difficult to get the results of engineering research put into practice, despite the evidence that very large savings can accrue where this has been done.

The implementation stage can be accelerated by understanding the process that is involved in technology transfer, identifying the likely obstacles and adopting a strategy that seeks to mitigate them. In broad terms there are five stages to the process of innovation¹:

Stage 1: Idea generator - the initial perceived need for developing the guideline.

Stage 2: Technology generation, adaptation and transfer – which has been achieved by raising awareness of the results of research carried out in the region, the adaptation of appropriate standards and the knowledge shared in the development of the Guideline.

Stage 3: State and local roads agencies – the importance of “buy-in”, which has been achieved through the process of stakeholder involvement in the compilation of the Guideline.

Stage 4: Specifications and contracts – the modification of conventional specifications and contract types to suit local conditions; the important role of contractors in embracing the new approaches as embodied in project applications.

Stage 5: Benefits – the substantial potential benefits of implementing the recommendations of the Guideline.

The production of this Guideline forms a major part of Step 3 as well as contributing to parts of Steps 2 and 4. This chapter is concerned with the pathway from here to full acceptance and implementation. The various obstacles, and associated problems, that remain and suggestions for overcoming them are discussed below.

8.2.1 Political

Government Policy: The road transport sector cannot be properly planned without reference to overall government transport policy. For effective planning, SADC governments need to take a comprehensive view of the whole transport sector, with road sector policy being designed to meet the wider social and economic goals of each country.

In one SADC country, the use of a slurry seal on a low-volume access road was politically over-ruled because in an adjacent constituency the more traditional chip seal had been used on a similar access road and was perceived as being of a "better" standard.

Accepting new techniques requires open mindedness and a willingness to learn from planners and engineers who must apply it. It also requires the political will to resist pressure from vested interests and make the best use of the resources that they have at their disposal.

Vehicle overloading is still rife in the SADC region with estimates ranging from 10 – 50%. The costs of such overloading has been estimated to run into millions of dollars.

A 22% overload from 82 to 100 kN will, in broad terms, increase the damaging effect on a pavement by a factor of 2.5 and reduce the pavement life by a factor of 0.6.

It is important that the key messages from this Guideline on the benefits to be derived from LVSRs are included in the debate leading to the development of a policy document. The policy should cover such issues as poverty alleviation, employment creation, technology choice, etc. The outcome of this process will dictate the type of planning system that is most appropriate.

Political and Public Perceptions: The intense competition for scarce public funds makes it imperative that appropriate, cost-effective standards are adopted at all times in the provision of LVSRs. This may well imply the use of lower, but nonetheless appropriate, standards on these roads. However, such standards can still provide a satisfactory level of service with no compromise on road safety.

It is important that the public and political authorities accept the standards adopted for LVSRs. However, their perceptions as to what is an appropriate standard of pavement or surfacing can adversely affect technical decisions. Very often, such perceptions are conditioned by standards adopted for high volume trunk roads; to accept a lower, albeit more appropriate, standard on a LVSR is often perceived to be "sub-standard" and, hence, unacceptable.

More effort needs to be expended on educating politicians and the general public as to the basis on which technical standards are determined so that they are more readily accepted. Ranking policy changes according to their political costs and benefits can help policy makers obtain support from politicians and the general public.

Axle Load Control: Inadequate axle load control remains arguably one of the most serious challenges faced by road authorities in the SADC region. As indicated in Chapter 5 of the Guideline, pavement performance is critically influenced by traffic loading which, in turn, controls the life of the pavement. LVSRs are normally constructed of lighter (thinner) pavements using naturally occurring materials which are often very sensitive to the impact of overloading. This makes them particularly susceptible to overloading which has an adverse and disproportionate effect on pavement life. Thus, overloading is not only an increased risk to the road, including bridges, it is also not justified on economic grounds. A more determined effort should be made to control overloading.

Effective control of overloading requires strong political will which is sometimes not forthcoming. The move towards new methods of overload control, as contained in the SADC Memorandum on Vehicle Loading, provides a strategy Control of Overloading, which should be implemented by all countries as soon as possible

Risk: The need to adopt more appropriate standards and specifications in the construction of low-volume road pavements has been clearly recognized in the SADC region for some time. However, whilst there are many examples of the successful adoption of such a strategy, few are well documented and, until relatively recently, the conditions necessary for successful performance have not been adequately defined. Thus, there has been an understandable reluctance, particularly by non-regional consultants and donors, to utilize non-standard materials because of an undoubtedly greater perceived risk of problems or even failure.

Fortunately, the results of research undertaken in the region over the past 20 years make it possible to utilize local resources with greater confidence. Moreover, risks can be mitigated by ensuring that standards/specifications apply to local environments.

The perceived risks associated with the use of non-standard materials and non-traditional designs can now be sensibly managed and a larger proportion of unsurfaced roads can be economically surfaced without additional risk.

8.2.2 Social

Employment creation: More and more governments in the SADC region are promoting the use of labour-based methods as an alternative to the more traditional plant-based operations as a means of combating high unemployment levels. In this regard, road programmes that maximize the use of surplus manpower that might exist in a rural community are more likely to engender a positive attitude to the future maintenance of the road than programmes that are plant-based requiring the import of a limited amount of skilled manpower.

Despite the above, negative perceptions still persist in some SADC countries whereby such approaches are considered to be uneconomic, time-consuming and sub-standard.

Where labour-based operations are indicated, government will need to make a clear policy commitment for change. This will call for special institutional arrangements, comprehensive planning as well as effective managerial and administrative systems and procedures.

8.2.3 Institutional

The institutional framework of roads sector organisations in the SADC region critically affects all aspects of LVSR provision. Historically, traditional approaches to the management and financing of road infrastructure have proved to be unsuccessful. Fortunately, the agreed SADC institutional framework for management and financing of roads offers a promising alternative to traditional approaches and, where implemented, has begun to show positive results.

Where the recommendations of the SADC Protocol on Transport, Communications and Meteorology that deal specifically with road management and financing have not yet been implemented, Governments in the SADC region should accelerate the reform process.

8.2.4 Technical

Technical Standards: The consistent application of appropriate technical standards and design methods is critical if cost-effective, sustainable solutions are to be obtained. In the past, there was an understandable tendency in the SADC region to rigidly apply imported standards, specifications and geometric and pavement design methods as “best practice” simply because there was little alternative other than taking an unquantified risk in using untried materials and design methods.

Appropriate labour-based strategies utilise the dual output of infrastructure provision whilst creating employment. Labour-based methods do not imply the elimination of plant but rather selective replacement. Nonetheless, such methods have a relatively higher potential for employment creation (typically up to four times more than equipment-based methods). Road infrastructure provision offers one of the highest employment potentials compared to other sectors. In the process, there is NO compromise on infrastructure specifications such as fitness for use and purpose.

ASIST Bulletin No. 11 2000.

Use of inconsistent, inappropriate standards should be avoided and, instead, regional standards promoted by governments and donors.

With the wealth of research and development work undertaken in the region during the past three decades, new, “indigenous” standards, specifications and pavement design methods have now emerged in a number of innovative ways on the basis of quantified evidence. Nonetheless, due sometimes to donor insistence or lack of awareness of the existence of regional standards, the tendency still exists in some countries to use imported standards.

The time has come for government policy to stipulate that where regional standards, including specifications and design methods exist, they should be used in preference to imported standards.

8.2.5 Economic

The results of research have shown, quite unequivocally, that adoption of the methods described in this Guideline result in low-volume roads that are less expensive to build, are no more expensive to maintain and reduce the costs of operating both motorised and non-motorised transport during their service lives. Thus both agency costs and costs and total (life-cycle) costs are reduced. Furthermore, although economic assessments cannot readily take into account social benefits, if these are included, the benefits of following the principles advocated in the Guideline should be obvious. Nevertheless it is necessary to demonstrate this repeatedly and as clearly as possible for the benefit of administrators, economists and others in authority who cannot be expected to be conversant with the engineering principles involved in road building and maintenance.

Research to improve appraisal methodologies which take better account of non-economic factors should be supported for the benefit of all.

8.2.6 Financial

The financing of road building and maintenance has been mentioned frequently in the Guideline. The main challenge is to secure sufficient funding both to maintain the existing network and to accommodate the extensions to the network that are deemed to be necessary for rural development and for the attainment of poverty reduction goals.

The SADC Protocol on Transport Communications and Meteorology has addressed comprehensively the issue of road financing and the associated institutional arrangements necessary to secure sustainable funding to maintain road networks in the region. The measures recommended in the Guideline support the goals set out in the protocol.

8.2.7 Environmental

One of the cornerstones of the Guideline has been the need to improve the “environmental” performance of the transport sector. This has been promoted in many ways throughout the Guideline, for example, through the use of local materials, preservation of resources of high quality stone, reduced haul distances, road surfaces that do not generate dust, cost and safety conscious design, consideration of non-motorised traffic, community participation and many more. The establishment of a government body or department to address environmental issues is becoming more common in the region and it anticipated that community participation will further encourage desirable practices and discourage those that are undesirable.

8.4 Vision to Practice

The technology transfer effort, which is so essential for the successful implementation of the Guideline, has encompassed the following activities leading to the production of the Guideline:

- Early involvement of stakeholders in the research planning phase to ensure that the Guideline responds to user needs.
- Continuous involvement of stakeholders in the compilation of the Guideline through their participation in a number of regional workshops.

Other aspects of the technology transfer process that will require consideration and possible external support to ensure successful implementation include:

- Technical assistance to support the implementation of the Guideline.
- Technical staff training, where in-house staff do not have the required expertise, and training to address internal resistance to change.
- Changes to country standards, design manuals and specifications needed to accelerate the implementation of the Guideline.
- Monitoring of acceptance, adoption, refinement and satisfaction amongst users of the Guideline.

By its very nature, the Guideline is aimed at all stakeholders in the rural transport system but the primary target audience are those who are in a position to foster change and to implement the ideas presented in the document.

For more information on the topics herein, the reader is encouraged to refer to the bibliographies in each chapter. Additional references can also be obtained by contacting the organisations listed in Appendix 9.

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Bibliography

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List of Useful Organisations

American Association of State Highway & Transportation Officials (AASHTO)

AASHTO is a not-for-profit, nonpartisan association representing highway and transportation departments in the USA and Puerto Rico. It represents the five transportation modes of air, highways, public transportation, rail and water. Its goal is to foster the development, operation and maintenance of an integrated national transportation system by advocating transportation policies, providing technical services, demonstrating the contributions of transportation and facilitating institutional change.

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www.transportation.org/aaashto/home.nsf/FrontPage

ASTM International

ASTM International is a not-for-profit organisation that provides a forum for the development and publication of voluntary consensus standards for materials, products, systems, and services. These standards are an important part of the information infrastructure that guides design, manufacturing, and trade in the global economy. ASTM International has more than 20,000 members from over 100 countries representing producers, users, consumers, government, and academia.

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Australian Road Research Board (ARRB) Transport Research

ARRB is the leading Australian provider of transport related research and technical services. It has a pool of experienced researchers, engineers, laboratory technicians and support staff and has particular expertise in infrastructure asset surveying and management, road safety and traffic engineering and transport policy and management. ARRB works in many countries throughout Asia, Europe and the Americas with a variety of customers including international aid agencies, national and local governments, state road authorities, and construction, transport and mining companies.

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Austrroads

Austrroads is the association of Australian and New Zealand road transport and traffic authorities. Its purpose is to contribute to improved Australian and New Zealand transport by developing and promoting best practice for the safe and effective management of the road system, providing professional support and advice to members, assessing and developing Australian and New Zealand standards and managing the National Strategic Research Programme.

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Council for Scientific and Industrial Research (CSIR)

CSIR is a scientific and technological research, development and implementation organization and plays a part in the development of South Africa as a nation and in the Southern African Development Community. One of eight operational divisions, Transportek offers specialist expertise in the fields of transportation research, traffic management, transport infrastructure and technology and information management, contractor development and rural and accessibility planning.

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Department for International Development (DFID)

DFID has a large programme of development assistance and also commissions research and dissemination projects with a transport theme. DFID also has a website whose purpose is to raise awareness of the importance of transport for development, within the context of developing countries. Many documents can be downloaded from this website. The address is www.transport-links.org

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ILO – Advisory Support, Information Services and Training (ILO/ASIST)

The International Labour Organisation (ILO) is the UN agency which seeks the promotion of social justice and internationally recognised human and labour rights. The ILO has a unique tripartite structure with workers and employers participating as equal partners with governments. ILO/ASIST, part of the ILO's Employment-Intensive Investment Programme, seeks to contribute towards the alleviation of poverty through the use of local-level planning methodologies and employment-intensive strategies in the provision of rural and urban infrastructure. ILO/ASIST has two Regional Programmes, run by the following offices, and publishes a regular *Bulletin*.

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Institution of Civil Engineers (ICE)

ICE is an independent engineering institution representing almost 80,000 professionally qualified civil engineers in the UK and worldwide. The objectives of ICE are to promote learning and training, provide professional status, act as a voice of the profession and facilitate best practice. ICE also publishes standard forms of contract, including the NEC series of contracts, suitable for international use.

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International Forum for Rural Transport and Development (IFRTD)

IFRTD is a global network of individuals and organisations encompassing community organisations, national and international NGOs, academia, governments, donor agencies, consultants, and technical institutions. Its mission is to promote policies and practices that address access and mobility as a means to eradicating rural poverty. IFRTD has a decentralised Secretariat based in the UK, Kenya, Peru and Senegal. IFRTD publishes *Forum News* quarterly. The UK address is given above.

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International Federation of Consulting Engineers (FIDIC)

FIDIC is an international federation of national associations of consulting engineers. FIDIC acts as a forum for the exchange of views and information and actively encourages the discussion of matters of mutual concern among member associations. More information, including order forms for contracts and other publications, is available on the website.

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www.fidic.org

International Road Federation (IRF)

The IRF is a non-governmental, not-for-profit international organization with public sector, private sector and institutional members in approximately 70 countries. Established in 1948 by business and industry leaders, its mission is to encourage and promote the development and maintenance of better and safer roads and road networks. Today the IRF continues to provide the lead in international road infrastructure and management development through its two programme centres listed below.

Geneva Programme Centre

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Washington Programme Centre

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Norwegian Public Roads Administration (NPRA)

NPRA is the national road authority in Norway. It is responsible for national and county roads, totaling approximately 54,000 km and its duties comprise strategic planning of the network and other modes of transport, contracting of construction and maintenance, traffic management, technical standards, registering and inspecting vehicles and licensing drivers. The Office for International Affairs coordinates Institutional Cooperation with a number of European and African countries.

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Southern African Bitumen Association (Sabita)

Sabita leads the bituminous products industry's contribution to development in southern Africa. Funded by its members, Sabita's threefold mission is to promote social and economic development through its road provision programmes, educate and train employees within the industry through formally sanctioned schemes and advance best practice to give competitive delivery of bituminous products and cost-effective construction and maintenance of roads.

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Southern Africa Transport and Communications Commission (SATCC)

The main function of the SATCC Technical Unit (SATCC-TU) is to provide administrative and technical support to the implementation agencies and monitor compliance by member states of their obligations in terms of the implementation of the SADC Protocol on Transport, Communications and Meteorology.

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Transportation Research Board (TRB)

TRB is a unit of the National Research Council, a private, nonprofit institution that is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering. TRB's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. TRB hosts an annual meeting which attracts a large number of transport professionals from around the world.

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TRL Limited

TRL Limited is one of the largest and most comprehensive international independent research centres working in land transport. The international staff work on projects for a range of clients including DFID, the World Bank and the African and Asian Development Banks.

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World Bank

The World Bank finances many rural transport projects in developing countries and coordinates the Rural Travel and Transport Programme and the Road Maintenance Initiative of the Sub-Saharan African Transport Program (SSATP). Its Rural Transport Thematic Group has produced important knowledge products on rural transport. A large amount of material is available at www.worldbank.org/transport/rt_over.htm

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World Road Association (PIARC)

PIARC is a non-political and non-commercial association with a main objective of becoming the world leader in providing information on roads and road transport policy and practices within an integrated sustainable transport context. It co-ordinates international technical committees, organises international seminars and publishes documents.

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