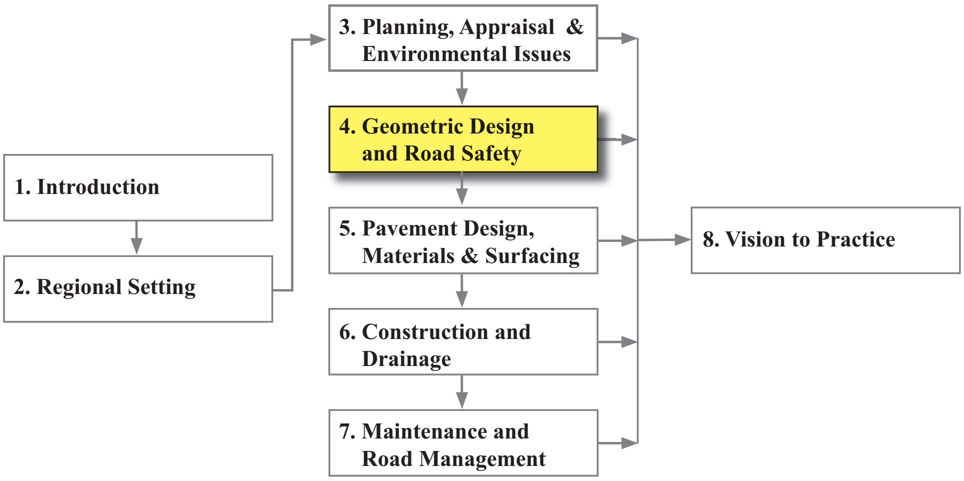
Chapter 4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Geometric Design and Road Safety

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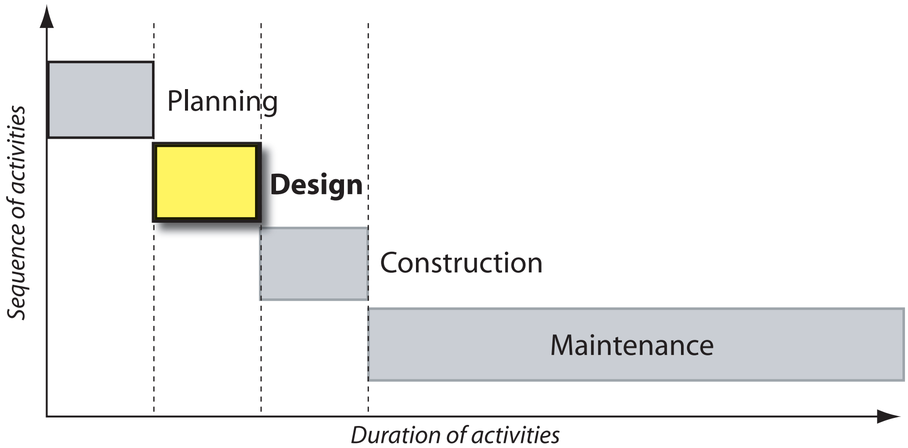
4.1 Introduction

4.1.1 Background



Geometric design is one of the first stages of the LVSR design process that is normally carried out after the planning and appraisal stages. The outcome determines the construction requirements and influences the maintenance requirements. In the design process, the layout of the road in the terrain is designed to meet the specific needs of road users. This involves the selection of suitable road widths and horizontal and vertical alignments in accordance with appropriately prescribed standards which provide the following:

- minimum levels of safety and comfort for drivers
- a framework for economic design
- consistency of alignment

The design standards should take into account the road environment, road conditions, traffic characteristics and driver behaviour. In so doing, the design aims to provide a road with an alignment and cross-section that are not only the best compromise between operational efficiency, safety and economy but also minimises any adverse environmental and social/cultural impacts. This requires a thorough knowledge of the local road environment which affects every aspect of the design process.

It was only in 2001 that, AASHTO produced its "Guidelines for Geometric Design of Very Low-volume Local Roads (ADT ≤ 400)". This was in recognition of the fact that " …very low traffic volumes make designs normally applied on higher volume roads less cost effective." Prior to this, its "Policy on Geometric Design of Rural Highways - 1965 edition", which did not cater specifcally for low-volume roads, was the de facto standard adopted in most SADC countries!

Geometric Design

The geometric design of LVSRs presents a unique challenge because the relatively low traffic levels make designs normally applied on higher volume roads less cost effective. Unfortunately, design standards for LVSRs have never been specifically developed for the SADC region. In the absence of such standards, there has been a tendency to use national standards that are based on those developed in industrialised countries, such as the traditionally used AASHTO *Policy on Geometric Design of Rural Highways*[1].

Imported standards tend to cater for relatively high levels of traffic and embody relatively high levels of service, as a result of which they are often inappropriate for application to LVSRs. Moreover, they give little, if any, consideration to the use of labour-based methods of construction which can influence the design process (ref. Box 4.1). This results in LVSRs often being designed in a manner that does not take account of the socio-economic and other characteristics of the local road environment.

Accident rates in the SADC region are of the order of 30 - 50 times higher than in Europe or the USA.

Road Safety

Many aspects of the geometric design process are affected by the road environment which, in turn, can influence the level of road safety provided to road users. Experience has shown that simply adopting "international" design standards from developed countries will not necessarily result in levels of safety that are achieved in those countries as these are generally accompanied by effective enforcement, driver training and publicity - influences that are often not operating as efficiently in the SADC region.

Road traffic operations also tend to be complex and often involve a mixture of motor vehicles, bicycles, animal drawn vehicles and pedestrians. A large proportion of the traffic composition is dominated by relatively old, overloaded and slow-moving vehicles and there are often low levels of driver training and control of road users. In such an environment, traffic safety assumes paramount importance, an aspect of geometric design which is often inadequately addressed at the various stages of planning, designing and constructing LVSRs.

Severe erosion of side slopes that can lead to siltation of streams and rivers.

Environmental Issues

Many aspects of the geometric design process also have a potential impact on the physical and social/cultural environments, especially where the alignment traverses built-up areas and where there is a high potential for severe erosion. Unfortunately, various practical measures that can be undertaken during the geometric planning process to minimise environmental impacts are often not adequately understood and addressed.

From the above, it is apparent that existing design standards and practice are generally not appropriate for application in the SADC region. A need therefore exists to adapt these standards in order to provide acceptable levels of service, safety and uniformity consistent with the types of traffic generally experienced on LVSRs. Such adaptation needs to be based on local knowledge, experience, socio-economic conditions and established criteria within a design process that needs to be flexible and multi-faceted, from feasibility to the end-of-life cycle.

4.1.2 Basic Terminology

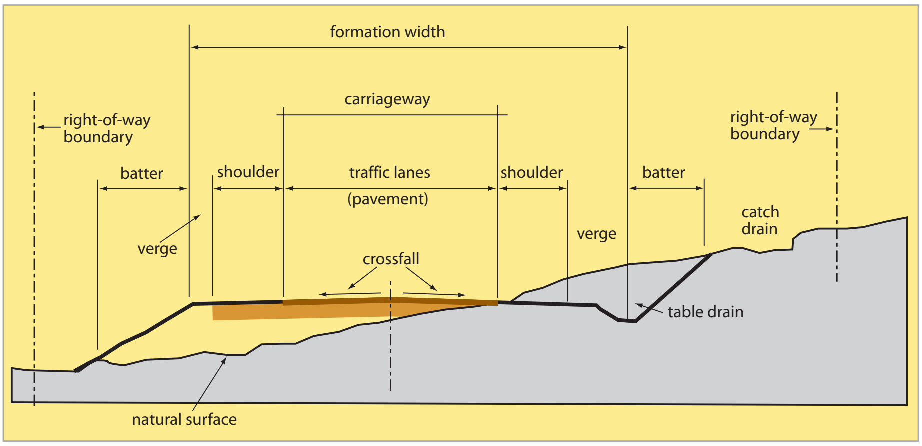


Figure 4.1 - Typical road cross section elements (after Austroads[2])

4.1.3 Purpose and Scope of Chapter

The main purpose of this chapter is to raise awareness of the widely differing recommendations made by various design guides or manuals pertaining to LVSRs. It highlights the many shortcomings that are inherent in those traditional approaches to geometric design that have been imported and used without appropriate adaptation to the specific characteristics of the LVSR environment. Particular emphasis is placed on the need to incorporate appropriate road safety features in the design process.

The approach adopted is not prescriptive; nor is it intended to be a detailed design manual that could supersede the need for application of sound principles by the knowledgeable design professional. Rather, it emphasises the need to consider the basis on which various design parameters are chosen in relation to the specifics of the SADC region's road environment.

4.2 Design Philosophy, Standards and Approach

4.2.1 Philosophy

The philosophy embodied in the geometric design of a road is linked to such factors as a country's economic prosperity, the state of development of the road network and the unique characteristics of the road environment within which the road functions. It would normally evolve from analytical evaluation and experience of local conditions and often reflect the physical and economic environment of the road project itself. Thus, geometric design philosophy would be expected to vary between industrialised and developing countries.

Flat terrain with little constraint on geometric standards.

The functionality and characteristics of the road network in the SADC region are quite different from those in industrialised countries. Not only are traffic levels relatively low, but the traffic mix is complex, consisting of a mixture of motorised and non-motorised traffic. The proportion of commercial vehicles and levels of pedestrianisation near peri-urban areas are also relatively high. This clearly dictates a need to develop a design philosophy and related standards that are suited to the socio-economic environment of the region. Such a philosophy would be expected to be quite different from that embodied in geometric design manuals developed in industrialised countries that often form the basis of geometric design in the region. Such manuals generally cater to higher traffic volumes, greater need for all-weather accessibility and provide for operational efficiency of the traffic using the network - requirements that are clearly less appropriate for the region.

Hilly terrain with constraints on geometric standards.

4.2.2 Standards

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

Unfortunately, there are no existing standards in any SADC country that are based on in-country research into economic and safety factors. Those standards that do exist vary tremendously, reflecting either the practice of the developed countries with which SADC countries have had previous ties or the preferences of international consultants who have worked in these countries. Many of them are a direct translation from overseas practice, sometimes with some modification to compensate for local operational differences and deficiencies, often without full evaluation of the consequences.

LVSRs, more than any others, call for a detailed examination of design options on the basis of sufficient data to allow an appropriate choice of geometric standards and should not be designed according to rigid guidelines and standards established a priori, often in environments very different from those prevailing in the SADC region.

In view of the above, until standards for LVSRs are developed, the challenge is to apply existing designs and standards in a flexible manner to fit the parameters pertaining to the local environment and to achieve safe economic design.

Choice of Standards

The choice of geometric design standards is related to the function of a road. In a developing region, such as the SADC, three stages of road network development usually occur, as follows:

- Stage 1 - provision of access
- Stage 2 - improvement in existing capacity
- Stage 3 - increase in operational efficiency

LVSRs generally fulfil a function within road networks at Stages 1 or 2 of the above sequence. Thus, the road design philosophy and standards should reflect the particular requirements of such roads and their particular characteristics. In this regard, a case may be made for a "relaxation" of traditional standards as, when sensibly applied, they can result in substantial construction cost savings, with little additional risk of increased accidents. Such relaxations, or local reductions in standards, can be undertaken in the context of the "Design Domain", a relatively new concept in geometric design which is described in Section 4.3.2.

4.2.3 Approach

Investment in road infrastructure represents a large part of investment in national development programmes. It is therefore even more important to ensure that scarce funds are deployed to best advantage. There is a tendency for the construction cost per kilometre to increase as each road design criterion is considered. As a matter of policy, therefore, it is necessary to ensure that an approach to geometric design is adopted which is appropriate to the prevailing socio-economic conditions. This may mean considering design approaches that favour labour exclusive rather than plant exclusive construction technology.

Box 4.1 - Labour-based methods and geometric design[3]

In a labour-abundant economy, it is often beneficial to employ labour-based rather than equipment-based methods of road construction. In such a situation, the choice of technology can be a major constraint or facilitator affecting design. Where labour-based technology is being contemplated at the geometric planning stage, it could have the following implications:

- the geometric standards that are achievable will be seriously affected, especially in rolling, hilly or mountainous terrain
- economic haul distances will be limited to those achievable using wheel barrows
- mass balancing will need to be achieved by transverse rather than longitudinal earthwork distribution
- maximum gradients will need to follow the natural terrain gradients
- horizontal alignments will need to be less direct
- maximum cuts and fills will need to be low

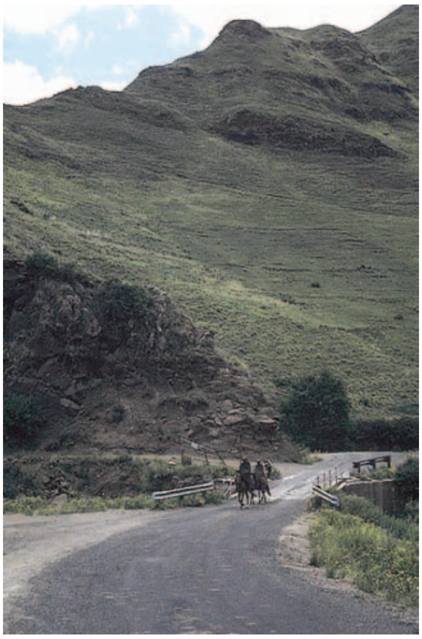
The reverse of the above is true for equipment intensive technology. Thus, at the geometric planning stage, consideration must be given to the type of technology to be employed in road construction and to the influence that this will have on the approach to geometric design.

The following aspects of geometric design require particular consideration from a policy perspective as they have a crucial bearing on the life-cycle costs of LVSR provision:

- Design standards
  - design speed
  - cross-sectional dimensions
  - safety measures
  - maximum gradient
  - horizontal curvature

In the final analysis, the wide variety of topographic, climatic, economic and social conditions will dictate the road geometry appropriate to a specific situation. The aim should be to establish a basic network of LVSRs by spreading limited resources to cover several road projects rather than building a smaller number of roads to a higher standard. In this way, funds saved by using cost-effective design standards can be used for other projects which would bring the best economic return on the investment.

Cost-effective geometric design can be achieved by identifying areas where road standards could be made more flexible and more responsive to environmental changes consonant with local knowledge, experience, socio-economic conditions and established criteria.



Physical obstacles in the terrain can constrain design options.

4.3 Design Framework and Process

4.3.1 Framework

LVSRs fulfil a variety of functions within diverse operational environments. Thus, designs need to cater for an array of different situations in which consideration must be given to all the inter-acting elements that affect the design process.

In order to help define the situations which are appropriate for a specific design application, it is useful to group them within a design framework as shown in Table 4.1.

Table 4.1 - Design Framework

Element	Range	Influence on design
Project type	▪ New ▪ Existing	▪ greater flexibility of choice but there are few new "greenfield" projects ▪ focus on upgrading/reconstruction projects which places constraints on designer's choice ▪ designer's choice often restricted by nature of existing developments and roadside environment
Area type	▪ Urban ▪ Peri-urban ▪ Rural	▪ wide range of operating characteristics, constraints and configurations which vary widely in terms of - range of uses - traffic volumes, speeds and mix - pedestrian activity ▪ need for producing appropriate matching designs
Functional classification	▪ Primary ▪ Secondary ▪ Tertiary/access	▪ identifies relative importance of mobility and access functions for road ▪ prescribes related minimum standards
Terrain type	▪ Flat ▪ Rolling ▪ Mountainous	▪ influences choice of alignment, design/operating speeds and standards ▪ impacts on drainage and maintenance requirements and also on environment
Design/ operating speed	▪ Low ▪ Medium ▪ High	▪ used to correlate various features of design ▪ ultimately determines construction, maintenance and road user costs
Traffic volumes, type and mix	▪ Low ▪ Medium ▪ High	▪ provides fundamental basis of design ▪ includes both motorised and non-motorised traffic

LVSR projects will be, predominantly, the upgrading of existing gravel roads to a bituminous standard. The designer's freedom of choice will often be restricted by developments, including ribbon development, surrounding the road to be upgraded. Thus, rigid adherence to standards may not be possible and flexibility must be built into the process through the adoption of flexible design techniques.

4.3.2 Process

The process of geometric design contains various stages within which the final product is gradually developed. The process is iterative. A number of investigations and evaluations have to be undertaken, questions asked, and decisions taken in preparatory phases that may have to be re-evaluated later, until the process has provided satisfactory results. An outline of the design process is presented in Figure 4.2.

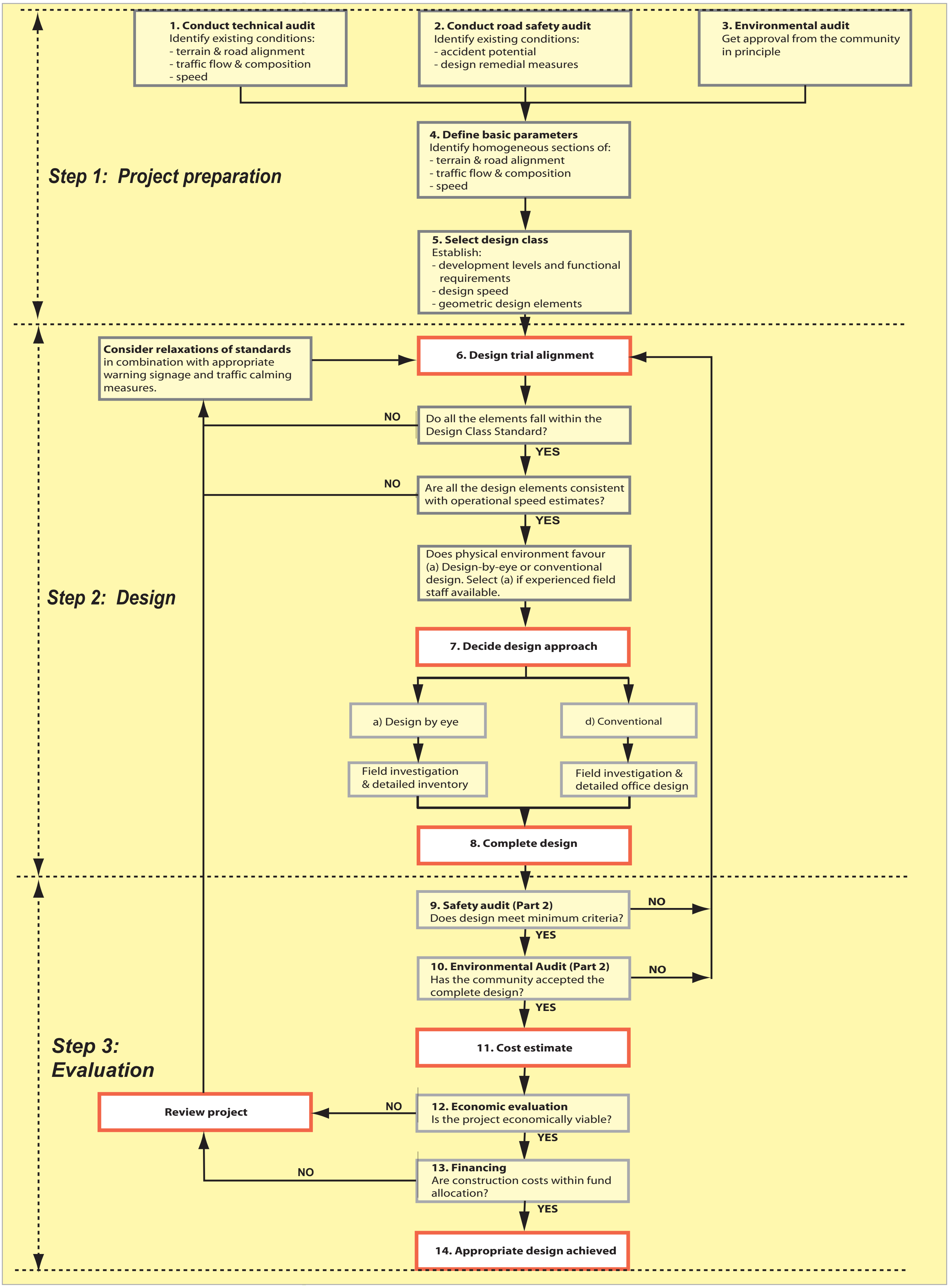


Figure 4.2 - The geometric design process

The design process may be broken down into three phases as follows:

- project preparation
- design
- evaluation

A. Step 1 – Project Preparation

The project preparation phase embodies a number of concepts that are not normally considered in conventional design manuals. These include a focus on the planning aspects of the geometric design process in which there is:

- a primary, over-riding focus on road safety
- continuous public involvement in all stages of the design process

The main activities undertaken in the project preparation phase include:

(1) ***Technical Audit:*** One of the first tasks to be carried out is a technical audit of the project. This entails information gathering on such factors as terrain and road alignment, traffic flows and composition, overall speed and speed over individual sections, land use and settlements including schools and hospitals. Traffic counts and traffic forecasts also need to be conducted. The results of the technical audit provide an input into the next step - the definition of basic parameters.

(2) ***Road Safety Audit (1):*** The preliminary design stage of the audit entails investigation of all factors that could have an adverse impact on the safety of the design, including such factors as accident "black spots" and the accident potential related to the improvement/upgrading of the road assessed, so that the information can be included in the subsequent design.

(3) ***Environmental Audit (1):*** The community should be consulted and involved at an early stage of the design process. This is necessary to ensure that their views are accommodated where appropriate and their priorities taken into account in the final design.

(4) ***Define Basic Parameters:*** The main task is to identify and group the project into homogenous sections with similar conditions and characteristics such as terrain, alignment, traffic, speed, land use and development. The information will form the basis for selection of the design class.

(5) ***Select Design Class:*** The selection of design speed and geometric elements is based on the developmental potential and functional requirements of the road. The design class for each homogenous section of road, in terms of terrain, road alignment, traffic and speed, can then be determined as a basis for selecting the various design elements.

B. Step 2 – Design

(6) ***Design Trial Alignment:*** The trial alignments will confirm if the intended standard can be introduced, for instance, if the design elements fall within the standard and are consistent with the expected operational speed. Failure to comply with set conditions will require new trials with modified inputs. Such trials may include relaxation of standards consisting of measures such as a lower design speed in combination with appropriate signage or traffic calming measures.

(7) Decide on design approach: The design approach will be dependent on topography, institutional arrangements, availability of suitable skilled and experienced field staff, etc. The selection of the design approach is also influenced by the type of project in terms of whether it involves rehabilitation of an existing facility or provision of a new one. The requirements for the field surveys and investigations will also depend on the type of project.

(8) Complete Design: The completion of the design concludes Stage 2 - Design, and is followed by the next Stage 3 - Evaluation. This stage includes the follow-up of a number of audits and evaluations related to safety, social considerations, costs, along with economics and financing which received preliminary consideration in the project preparation phase.

Step 3 - Evaluation

(9) Road Safety Audit (2): The design features are examined from a safety point of view. Remedial measures are proposed for possible weaknesses in the design. If the design is such that simple remedial measures are not adequate to rectify the shortcomings, the design will need to be reviewed and new trial alignments be carried out. This iterative procedure will be repeated until the design is acceptable from a road safety perspective.

(10) Environmental Audit (2): Public participation should continue after the detailed design is completed. If necessary, modifications or adjustments to the design, as a result of community consultations, will have to be undertaken to ensure that the final project accords with local requirements.

(11) Cost Estimate: Cost estimates should be conducted at various steps of the design process as they may influence the scope of the project and decisions made concerning the design controls and elements. A detailed cost estimate will be required at final design stage to allow an economic evaluation of the project to be carried out.

(12) Economic Evaluation: Cost-benefit analyses, as described in Chapter 3, need to be undertaken to allow the viability of the project to be assessed. If the project turns out to be not viable in terms of the criteria prescribed, modifications to the project may need to be undertaken. Such modifications may include relaxations of design standards, stage construction, or other factors that reduce cost or increase benefits.

(13) Financing: Adequate financing for the project, in terms of both construction and future maintenance costs, needs to be secured before implementation begins, otherwise the sustainability of the project could be jeopardised. Should such funding not be available, it may be preferable to defer implementation until it can be obtained.

(14) Appropriate Design Achieved: If the tasks outlined in the flow chart and in the discussion above have been methodically carried out, the final result should be an appropriate geometric design.

In 1990 road traffic accidents were rated ninth in the top ten causes of death and disability in the world. By 2020 it is predicted that it will be rated third.

Harvard School of Public Health Projections.

Unconventional signs are sometimes used to warn of the dangers of overloading and speeding.

A poorly-maintained road sign can be the cause of road accidents.

4.3.3 Safety Issues

Importance of Safety

Studies carried out by international organisations reveal that the road safety situation throughout the African continent, including the SADC region, is one of the worst in the world[4]. Fatality rates, in relation to vehicle fleets, are 30 - 40 times higher than those of industrialised countries. Indeed, in several countries a motor vehicle is over one hundred times more likely to be involved in a fatal crash than in Europe or the USA.

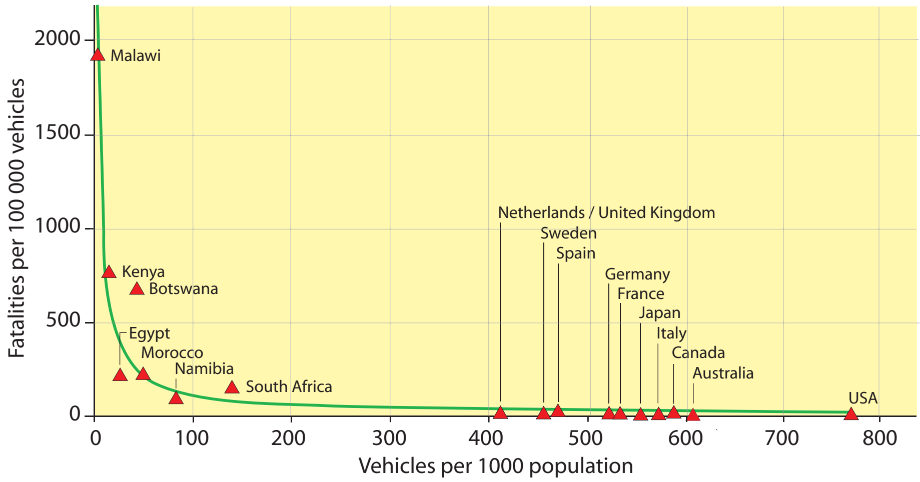


Figure 4.3 - International comparison of fatalities in selected countries[4]

Because of the substantial cost implications on the economies of these countries - of the order of one to two per cent of gross national product (GNP) - road safety has become of paramount importance in all aspects of road provision.

Road safety is multi-dimensional in nature and cannot be discussed in isolation from geometric design. As illustrated in Figure 4.4, the various elements of the road system, such as geometry and pavement condition and operational conditions, such as operating speed, influence road safety.

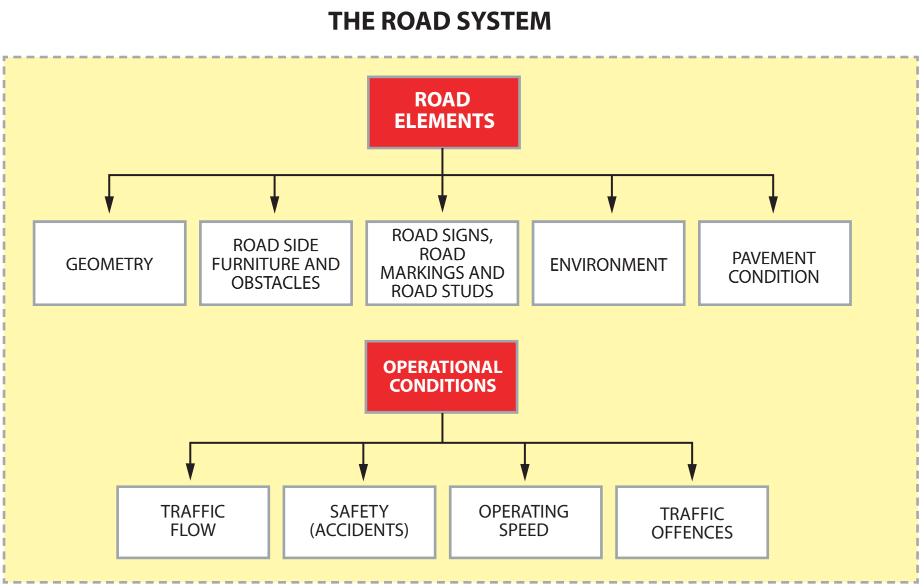


Figure 4.4 - Elements of the road system and operational conditions

For example, as illustrated in Figure 4.5, overloading has an important influence on pavement condition and deterioration and is influenced by police surveillance, while speeding is also influenced by the road geometry and police surveillance. Both overloading and speeding, in turn, have an influence on safety in terms of accidents.

Speed limit painted on the road.

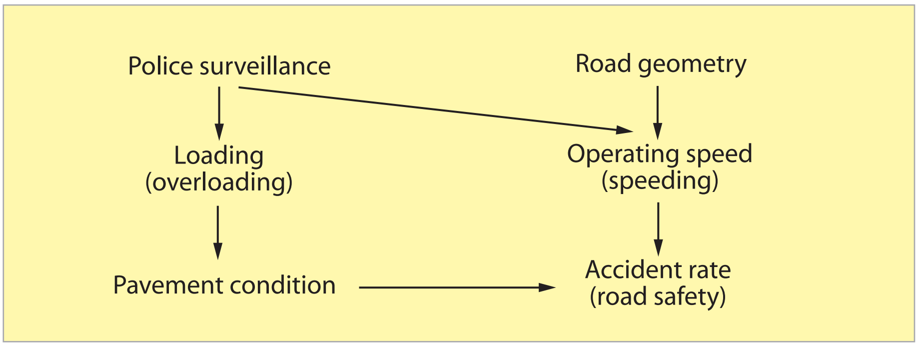
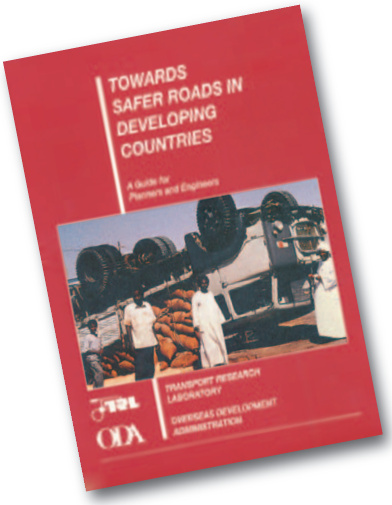


Figure 4.5 - An example of the interrelationship between road elements and operational conditions

Thus, although the importance of designing for safety is now widely recognised, the actual process of identifying key design features and resolving the conflict of safety and other considerations is complex and requires tackling in a holistic manner.

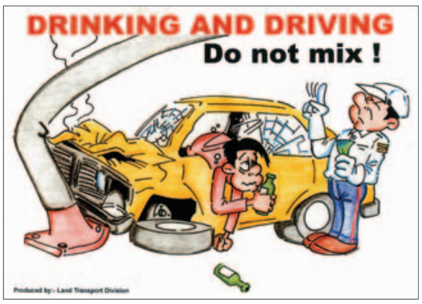


The above document provides practical guidance on how to make roads safer by highlighting the key, safety-related factors which need to be incorporated when planning, designing and operating road networks.

The Nature of Accidents

Confronting the challenge of safety requires proactive strategies that treat the root causes of accidents and levels of severity before they occur. To this end, valuable guidance on accident prevention is given in a number of documents including, particularly, the TRL guide entitled *Towards Safer Roads in Developing Countries*[5].

As illustrated in Figure 4.6, accidents are multi-causal in nature, involving human factors, the road environment and vehicle factors. They are more often caused by a *combination* of these factors, with human factors contributing to an estimated 95 per cent of all accidents, the road environment 28 per cent and vehicles ‘only’ 8 per cent. Thus, although not the dominant cause of road accidents, it is important that features are not introduced in the geometric design which could result in additional negative impacts on road safety.



Drinking and driving are a common cause of accidents in the SADC region.

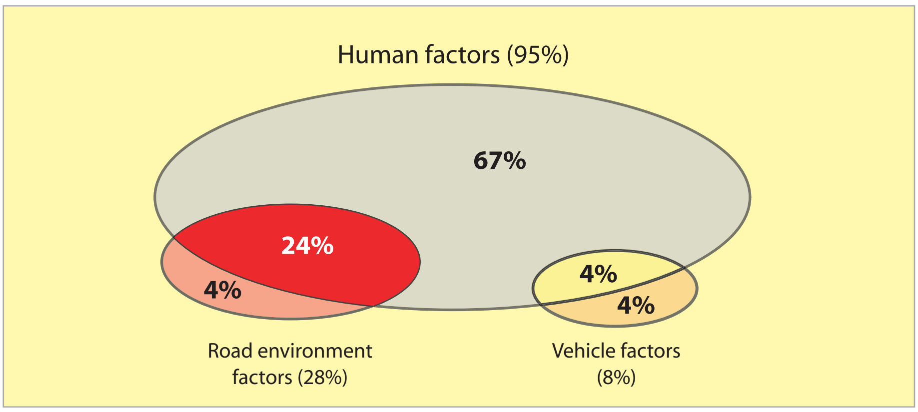


Figure 4.6 - Factors contributing to road accidents[6]

The Influence of Design

Almost all geometric design elements affect road safety by:

- influencing the ability of the driver to control his/her vehicle
- influencing the opportunities that exist for conflict (and accidents) with other road users
- influencing the outcome of an out-of-control vehicle
- affecting the behaviour and attentiveness of a driver

Reviews of road projects in many developing countries reveal a depressing catalogue of unsafe and inconsiderate road designs which though compliant with highway design standards, remain unsafe because of the particular characteristics of the traffic using the road and the "operating environment" in which the road will function[4].

Thus, by incorporating good design principles from the start of the design process, it is possible to avoid many problems simply by planning and designing new roads or upgrading existing ones in a safety conscious manner. *Moreover, it is often possible to improve road safety characteristics markedly at little or no extra cost, provided the road safety implications of design features are considered at the design stage. Unfortunately, road design engineers are often part of the problem and their failure to take adequate account of operational use of roads often result in increased speeds and increased deaths when such roads pass through communities straddling the road.*

There are a number of tools to assist in this process, such as Road Safety Audits, which are considered below.

Designs need to cater for different types of road users.

Box 4.2 - Key principles for designing safer roads

Adherence to various key principles of design can considerably improve the safety of LVSRs. These key principles are summarised below:

- *Designing for all road users.*
  - includes non-motorised vehicles, pedestrians, etc.
  - has implications for almost all aspects of road design, including carriageway width, shoulder design, side slopes and side drains
- *Providing a clear and consistent message to the driver.*
  - roads should be easily "read" and understood by drivers and should not present them with any sudden surprises
- *Encouraging appropriate speeds and behaviour by design.*
  - traffic speed can be influenced by altering the "look" of the road, for example by providing clear visual clues such as changing the shoulder treatment or installing prominent signing
- *Reducing conflicts.*
  - cannot be avoided entirely but can be reduced by design, e.g. by staggering junctions or by using guard rails to channel pedestrians to safer crossing points
- *Creating a forgiving road environment.*
  - forgives a driver's mistakes or vehicle failure, to the extent that this is possible, without significantly increasing costs
  - ensures that demands are not placed upon the driver which are beyond his or her ability to manage

Despite adherence to various key principles for designing safer roads, very few engineering measures, on their own, are totally self-enforcing. They normally require other measures of external control and facilitation such as enforcement and education, to be fully effective (ref. Section 4.5).

Road safety audits help to produce designs that reduce risks to road users.

Road Safety Audits

Safety should be given special attention at all stages of the design process. One effective means of achieving that goal is by the use of a road safety audit. This may be defined as "*…a formalised examination of an existing or future road or traffic project or any project which interacts with road users, in which independent, qualified examiner reports on the project's accident potential and safety performance*"[6].

The objectives of a road safety audit are essentially to:

- identify and report on the accident potential and safety problems of a road project
- ensure that road elements with an accident potential are removed or improved
- ensure that measures are implemented to reduce accident risks

As illustrated in Figure 4.7, road safety auditing is an iterative process and should be carried out at all stages of a road project from preliminary design, through detailed design to pre-opening. It provides an opportunity, especially during the preliminary design stages of the project, to eliminate, as far as possible, road safety problems in the provision of both new roads as well as those being upgraded.

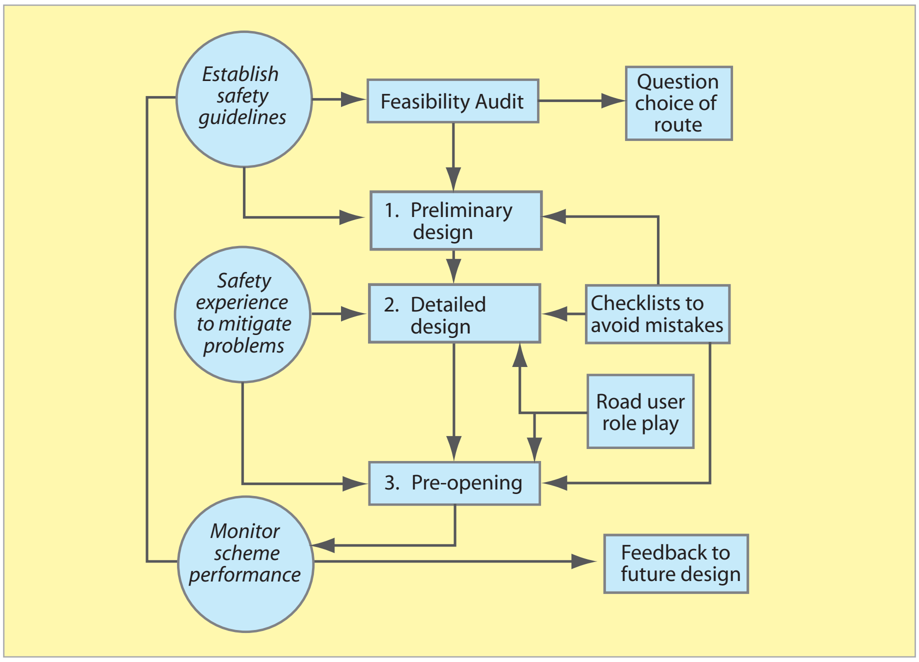


Figure 4.7 - Road safety audit flow-chart

The major benefits of such audits include:

- a reduction in the likelihood of accidents on the road network
- a reduction in the severity of accidents on the road network
- an increased awareness of safe design practices among traffic engineers and road designers
- a reduction in expenditure on remedial measures
- a reduction in the life-cycle cost of a road

The resources required for carrying out a road safety audit are usually quite small and could add about 4 per cent to the road design costs. However, the benefits can be very marked with an estimated potential benefit-cost ratio of 20:1[7].

By conducting road safety audits, a road authority is showing that it has the intention to improve the safety on its roads, and consequently has a stronger defence against tort liability claims.

Box 4.3 - Road Safety Audits in SADC

Road safety audits have not yet become a formalized, mandatory aspect of the road design process in many SADC countries. At present, road safety is assumed to be addressed through adherence to geometric design standards. However, this is neither adequate nor sufficient. It has been shown that *"roads designed to standards are neither necessarily safe nor unsafe and that the linkage between standards and safety is largely unpremeditated"* [8]. As a result:

- there is a need to accelerate the rate of adoption of a more formalized road safety audit procedure appropriate to all roads in any country
- road safety audit procedures should be introduced as part of a comprehensive road safety programme in all countries
- lessons learned from safety audits should be centrally coordinated and shared amongst all countries in the region

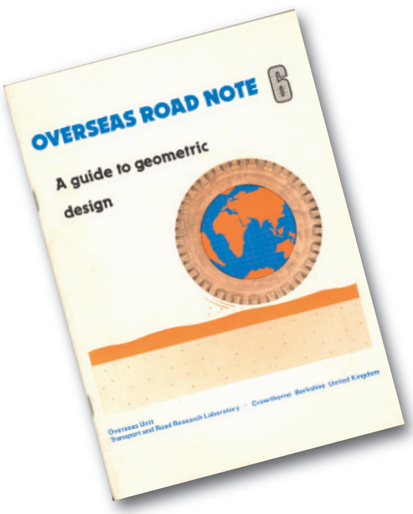
4.3.4 Design Guides/Manuals

Designs should cater for pedestrians as well as vehicular traffic.

In recognition of the shortcomings of the use of guides from developed countries for LVSRs, attempts have been made to develop more appropriate guides for developing countries (e.g. TRL's ORN 6[9]). Recourse has also been made to the use of more appropriate standards emanating from other countries such as Australia (e.g. NAASRA[10], Austroads[11] and ARRB[12] guidelines). Most recently, guidelines have been developed in the region for use either nationally (e.g. South Africa's G2 Manual[8]) or regionally (e.g. SATCC's Geometric Design of Rural Roads[13]). However, neither of these guidelines apply to LVSRs. Table 4.2 provides a listing of the various design guides and the extent of their use in the region.

Table 4.2 - Design guides/manuals used in SADC region

Design Guide/Manual	Degree of Use		
	High	Med	Low
USA			
• AASHO:			
- A Policy on Geometric Design of Rural Highways (1965).	X		
• AASHTO:			
- A policy on Geometric Design of Highways and Streets (1984).	X		
- Guidelines for Geometric Design of Very Low-volume Local Roads (ADT ≤ 400) (2001).			X*
Australia			
• NAASRA:			
- Interim Guide to the geometric design of rural roads. (1980).		X	
• Austroads:			
- Rural Road Design: Guide to the design of Rural Roads (1989).		X	
• ARRB:			
- Road classifications, geometric designs and maintenance standards for low-volume roads (2001).			X*
United Kingdom			
• TRL:			
- Overseas Road Note 6: A guide to geometric design (1988).		X	



Southern Africa			
• SATCC: - Recommendations on Road Design Standards: Geometric Design of Rural Roads (1987).		X	
• South Africa: - G2 - Geometric Design Manual (South Africa, 2003).			X
• Member states: Country manuals based essentially on one or other of the guides listed above.	X		

* These guidelines have very recently been developed and knowledge of their existence and use is still very limited.

All the guidelines/manuals listed above are based on different philosophies and make different assumptions or use different criteria for developing design values for the various design elements. For example, some guides give emphasis to safety considerations while others may place emphasis on service level, capacity, comfort or aesthetic values. Not surprisingly, the resulting design values recommended, and their related cost implications, all differ, sometimes quite significantly. Thus, it is essential for the designer to have a thorough understanding of the origin, background and basis of development of the design guides or manuals and related design criteria as a basis for adaptation, where necessary, and subsequent judicious application to LVSR situations.

In the next section, a comparison is made of design values obtained from the application of some of the design guides considered most appropriate for use in the SADC region.

4.4 Design Controls and Elements

4.4.1 Techniques

There are a number of techniques that have been developed in recent years which offer a considerable degree of *flexibility* to the LVSR designer in the design process as well as improve the quality of the design. These are described briefly below:

Context Sensitive Design

Context Sensitive Design[14] is responsive to, or consistent with, the road's natural characteristics and human behaviour, i.e. the design can deviate when necessary from accepted design criteria. Consideration is given to the desires and needs of the community by inviting the appropriate stakeholders to participate in identifying solutions so that they are acceptable to the community.

Context Sensitive Design recognises that exceptions may be required in some cases in applying standards. For example, where provision of an engineered alignment results in excessive earthworks, it may be preferable to lower the design speed in order to minimise social or environmental impacts.

Design Domain Concept

The 'design domain' concept[8], shown in Figure 4.8, recognizes that there is a range of values which could be adopted for a particular design parameter within absolute upper and lower limits. Values adopted for a particular design parameter within the design domain would achieve an acceptable, though varying, level of service in average conditions in terms of safety, operational, economic and environmental consequences.

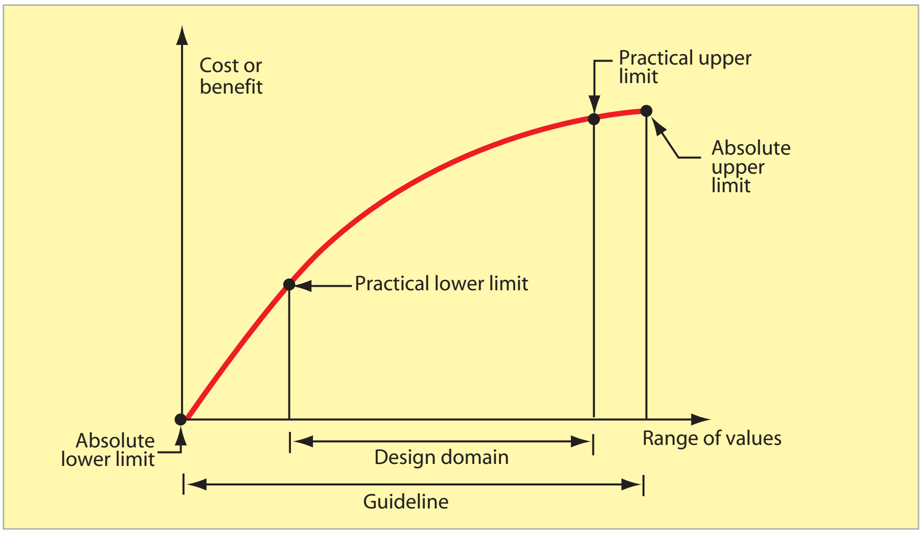


Figure 4.8 - The design domain concept

While values within the lower region of the design domain are generally less safe and less operationally efficient, they are normally less costly than those in the upper region. In the upper region of the domain, resulting designs are generally safer and more efficient in operation, but may cost more to construct. The design domain sets the limit within which parameters should be selected for consideration within the value-engineering concept.

The design domain concept provides the following benefits to the designer:

- It is directly related to the true nature of the road design function and process, since it places emphasis on developing appropriate and cost-effective designs, rather than simply meeting standards.
- It directly reflects the continuous nature of the relationship between service, cost and safety and changes in design dimensions. It thus reinforces the need to consider the impacts of 'trade-offs' throughout the domain and not just when a "standards" threshold has been crossed.
- It provides an implicit link to the concept of 'Factor of Safety' - a concept that is used in other civil engineering design processes where risk and safety are important.

An example of the design domain concept for shoulder width is shown in Figure 4.9

The flexibility offered by the Design Domain concept

For many elements, a range of dimesions is given and the designer has the responsibility of choosing the appropriate value for a particular application. If a design involves compromise, it may be more appropriate to compromise several elements by a small amount than to compromise one element excessively. It is important that a design should be balanced.

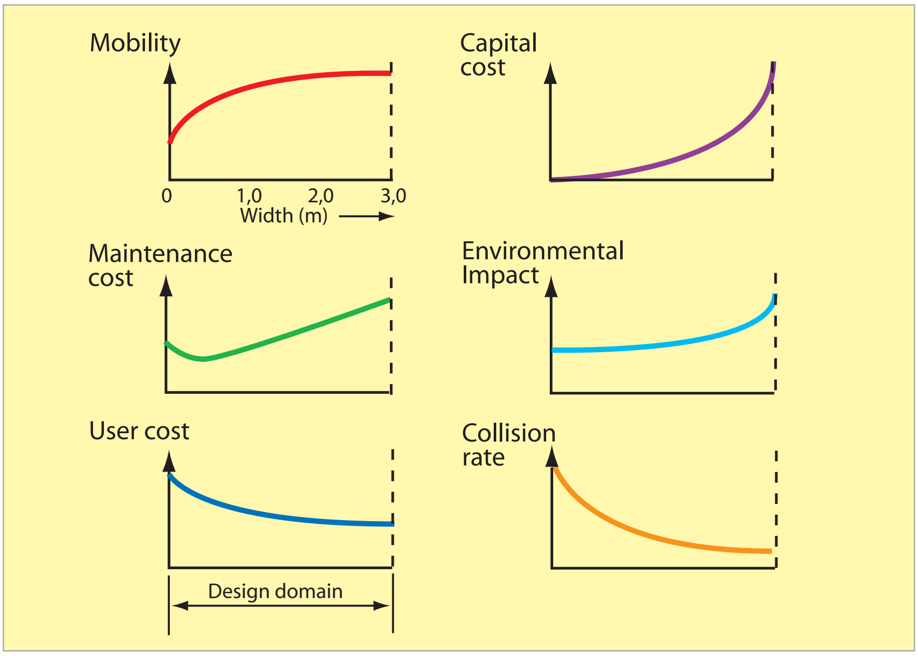


Figure 4.9 - Example of design domain application - shoulder width[14]

Design-By-Eye

Conventional approaches to design involve precise engineering surveys over the total length of the road as a basis for producing horizontal and vertical alignments and cross-sections on working drawings from which quantities are normally calculated. The cost of this approach, which is normally justified for relatively high-volume/standard roads, can hardly be justified for relatively low-volume/standard roads.

Design-by-eye is a relatively simple approach to design which is intended primarily for the upgrading of existing LVRs where the geometry is adequate. In this approach, the route alignment is chosen "by eye" at the time of construction by experienced site staff who are aware of the economic, operational and safety consequences of geometric design.

Box 4.4 - Advantages of the Design-by-eye approach

- Enables the engineer to fit the alignment to the terrain so that it causes minimum disturbance to any existing facilities and the adjacent physical environment.
- Obviates the need for a conventional topographic survey of the existing road and normal plan and profile drawings do not need to be prepared.
- Allows the geometry of the road to be described on a simple road location straight-line plan showing roughly the horizontal alignment with kilometre-stationing and possible improvements indicated, such as sight distances.
- Minimises earthworks, increases speed of construction and reduces preparatory costs and, ultimately, construction costs by 10 - 20 per cent.
- Can result in a finished product of at least similar quality to the conventional approach.

The design-by-eye approach is best suited to situations where detailed documentation in terms of drawings and quantities is not required. This includes situations where construction is undertaken by a management team or by in-house construction units rather than by a contractor governed by rigidly specified contractual and payment conditions of a contract.

The degree to which the design-by-eye approach is applied in relation to conventional approaches (full horizontal and vertical survey and control) can also vary widely depending on local circumstances and can include the following options:

- no survey, but brief indications of corridor, areas to avoid, required fill/cut heights for drainage, soils, or other information
- survey of the horizontal alignment and/or vertical alignment with spot surveys of alignment options at critical locations
- survey of the horizontal alignment and vertical alignment up to e.g. sub-base level only. Base course then to be placed within thickness tolerances

4.4.2 Controls

The need to relate the physical elements of a road with the requirements of the driver in an environmentally acceptable manner imposes a number of controls on the road designer. Many of these controls relate to the characteristics of the road environment; those that may be appropriate for one environment may well not be appropriate for another. The more important design controls include:

- driver characteristics
- design speed
- sight distances
- design traffic
- design vehicles
- environmental factors

Design parameters such as driver-eye-height and perception-reaction time vary considerably among drivers as well as vehicle type and driving conditions. Thus, in relation to the underlying assumptions made, guidance on various design parameters pertaining to driver characteristics vary quite significantly as illustrated in Table 4.3. As a result, the values derived for related design elements such as sight distance are affected. Such guidance should be carefully evaluated in relation to the assumptions made and their applicability to the project situation.

Table 4.3 - Driver characteristics recommended for rural/low-volume roads

Parameter	Design Guide		
	SATCC	TRL ORN6	ARRB
Driver eye height (m)	1.00	1.05	1.15
Brake reaction time (secs)	2.50	2.00	2.50
Object height (stopping) (m)	0.10	0.20	0.20
Object height (passing)(m)	1.00	1.05	-

Speed Kills – Kill Speed

Non-standard sign intended to shock drivers into driving carefully.

Design Speed

The *design speed* is probably the most influential factor affecting the geometric design of a LVSR and is influenced by the following factors:

- nature of the terrain
- classification of the road
- density and character of the adjoining land use
- traffic volumes and composition expected on the road
- cross-section

Design speed is normally taken as the maximum speed that 85% of the drivers are expected to adopt over a specified section of the completed road when conditions are so favourable that the design features of the road govern the driver's choice of speed. The higher the design speed, the higher, usually, the cost of construction. In undulating country, a rough rule of thumb is that an increase of 20 km/h in the speed standard doubles the cost of earthworks.

It is noteworthy that the conventional design speed approach to specifying alignment design standards carries implicit assumptions regarding driver behaviour which have not been substantiated by empirical research[15]. Alternative design procedures have been developed which ensure compatibility between alignment standard and observed driver-speed behaviour, and in which emphasis is placed on consistency and driver expectancy rather than absolute minimum standards. Such an approach is believed to result in safer operations, particularly for low-standard alignments, than the conventional design speed approach[16]. As a result, it would appear better suited to the SADC region where driver behaviour is a critical determinant of operational, and hence, design speed.

"The expertise required by the low-volume road designer may lie in his ability to make his intentions clear to the road user and to create a state of mind in the driver such that he will be content to travel at safe speed". However, while the approach is sound, quantitative guidelines are still lacking.

Although speed has been viewed traditionally as the most influential factor affecting the geometric design of LVSRs, it is also suggested that life-cycle costs could be considered as the most important factor[3]. The rationale behind this approach is that cost will continue to be the most critical constraint on LVSR provision. This cost minimisation approach also applies to the horizontal and vertical design (4.4.3 Elements). Speed, geometrics etc. would then emerge as the outputs from the life-cycle costs analysis.

Speed limits can be used to influence driver behaviour, but only if they are realistic. When the speed limit is set at a level that is significantly different from the 85th percentile of the free speed, this tends to produce an accident prone situation as drivers tend not to adjust their speeds to the notional classification of the road but, rather, to its physical characteristics. Attention should therefore be given to creating a road environment which tailors the operating speed to a level commensurate with the constrained alignment[17].

Box 4.5 - Design versus operational speeds in the SADC region

There are marked differences in the physical environments of countries in the SADC region which, as a result, have a large influence on the application of a number of geometric parameters. For example, the terrain in countries such as Botswana and Namibia is mostly flat. As a result, operational speeds tend to be much higher than the design speed and, *from a traffic safety perspective, there may be need to introduce special measures to constrain the high operational speed close to the design speed*. In contrast, in countries such as Lesotho, Seychelles and Mozambique, the terrain in parts is very mountainous. As a result, the design features of the road govern and sometimes constrain the driver's selection of speed.

Braking distance and those factors which depend on it, such as sight distance, are approximately proportional to the square of the speed and every increase in the design speed represents a significant increase in the value of these factors. However, extra construction costs are usually offset by the benefits to traffic, namely increased safety, capacity and convenience, and lower road user costs.

Guidance on design speeds is given in a number of design manuals [8,9,10,11,12,13] which all purport to apply to rural/LVRs in developing countries. The design speeds recommended vary, presumably depending on the philosophy of design adopted and the environment for which they are meant to apply - examples are shown in Table 4.4. In view of the critical effect that design speed has on the values of other geometric elements and the related costs of implementing them, careful consideration should be given to the choice of this influential parameter.

Table 4.4 - Recommended design speed values for selected design guides

Parameter	Design Guide								
	SATCC			TRL ORN 6			ARRB		
Traffic (ADT)	-			100 - 400			>100		
Terrain	F	R	M	F	R	M	F	R	M
Design Speed km/h	70	70	50	70	60	50	80	70	50

Note: F = flat, R = rolling, M = mountainous.

Design Vehicle

The physical characteristics of vehicles and the proportions of the various sizes of vehicles using a road are positive controls in design and define several geometric design elements. The dimensions used to define design vehicles are typically the 85th percentile value of any given dimension but are, in fact, hypothetical vehicles selected to represent a particular vehicle class.

The dimensions of design vehicles adopted in design manuals developed overseas are, quite naturally, based on vehicle types found in those countries. However, the range of vehicle types found in the SADC region and their operating characteristics, in terms of vehicle performance, condition, usage, traffic mix and road users' attitude, vary quite significantly from those in developed countries. Thus, careful attention should be paid to design vehicle characteristics in the LVSR design process.

Vehicle size regulations in the region have undergone substantial revisions in recent years which have resulted in the emergence of relatively large, multi-vehicle combinations up to 22 metres in length. These developments also indicate the need to adopt design vehicles that are appropriate to the region.

Designs need to accommodate expected traffic over the life of the road.

Design Traffic

The *design traffic* is a critical design control which has a major impact on all geometric design elements of a road. For HVR's, this factor normally applies only to motorised traffic in terms of Annual Average Daily Traffic (AADT) in the *design year*. However, for LVSRs, due account must also be taken of non-motorised traffic, animal-drawn vehicles and large pedestrian flows near urban and peri-urban areas which all affect such design elements as carriageway and shoulder widths. Unfortunately, none of the recent regional guidelines and few international guidelines, fully cater for non-motorised traffic. Measures that could be considered are wider shoulders, sealed shoulders, wider side drains or physical separation from motorised traffic, all of which will increase costs.

Good sight distances on a well-designed LVSR. Note wide shoulder and shallow slope to drainage ditch which both reduce potential hazards.

Sight Distance

A critical feature of safe road geometry is provision of adequate sight distance – the distance ahead that can be seen by the driver. As an irreducible minimum, drivers must be able to see objects on the road with sufficient time to allow them to manoeuvre around them or to stop. The basic elements of sight distance which are important to LVRs include:

- stopping sight distance - the distance needed for safe stopping from travelling speed
- meeting sight distance - the distance needed for drivers of two vehicles travelling in opposite directions to bring their vehicles to a safe stop
- passing sight distance - the distance needed to see ahead for safe overtaking

The values of Stopping Sight Distance (SSD) and Passing Sight Distance (PSD) recommended in various design manuals for rural/LVRs vary quite significantly as shown in Table 4.5. For SSD, this is due to different assumptions regarding brake reaction time and braking distance, which is dependent on vehicle condition and characteristics and object size. For PSD, this is due to different assumptions about the component distances in which a passing manoeuvre can be divided, different assumed speeds for the manoeuvre and, to some extent, driver behaviour.

Table 4.5 - Minimum stopping (SSD) and passing (PSD) sight distances

Design Speed (km/h)	SATTC		TRL ORN6		ARRB	
	SSD	PSD	SSD	PSD	SSD	PSD
40	44	110	35	-	-	-
50	-	-	50	140	50	-
60	79	230	65	180	-	-
70	-	-	85	240	90	-
80	126	420	-	-	110	-
100	185	700	160	430	-	-

Deep V-type drainage ditches leave no room for recovery if a vehicle runs off the road.

Sight distance has an impact on road safety. Poor visibility alone may cause a collision between oncoming vehicles. No local guide is available for LVSRs. In the final analysis, therefore, the designer should be aware of the differences in sight distance recommended by various guides and should adopt values for which the underlying assumptions accord closest to project conditions.

Bio-engineering offers the engineer a new set of tools, but does not normally replace the use of civil engineering structures. The materials and skills are all available in rural areas, however remote.

Environmental Issues

All road projects have an impact on the environment. However, the provision of LVSRs that result in an improvement of existing earth/gravel roads without involving major earthworks or disturbance of existing cut and fill slopes or drainage patterns have little or no environmental impact. Indeed, the introduction of a sealed road as a replacement for an earth/gravel road has an important positive effect on the environment in that there is no longer any dust from the earth/gravel road which would have had a negative impact on the environment, particularly when the road passed through built up areas.

When there is a new road alignment or when spot improvements include excavations in existing slopes, the environmental impacts of the works should be evaluated and suitable remedial measures introduced. Where slope instability or erodible soils present a problem, various remedial measures need to be considered, including bio-engineering methods, sometimes in combination with engineering structures. Such measures can also be used to improve surface drainage, particularly in rolling and hilly terrain with steep gradients.

Because of the low levels of traffic on LVSRs, environmental pollution from these roads is also low. However, there may be some slight increase in air pollution from increased emissions if steeper grades and super-elevations result from a design-by-eye approach. The disturbance due to noise is also increased in hilly areas where the strain on the engines due to steep gradients and heavy loads is extensive. Because of the low traffic volumes on LVSRs, the environmental impacts from emissions and noise are rather limited, but an environmental impact assessment should always be carried out.

In order to minimise the adverse impacts of LVSR provision, it is important to carry out an environmental audit at the commencement of the design process. Such an activity aims to:

- design road corridors to minimise environmental and social/cultural impacts and maximise user safety
- integrate the results of the geometric planning process into the design process
- identify appropriate design options to minimise impacts of the proposal and be compliant with the design brief
- provide an Environmental Design Report that sets out various criteria for minimising environmental impacts
- consider the objectives of all road users, and the natural and cultural values of the community through consultation
- minimise disturbance to the natural vegetation and landscapes
- ensure road drainage systems use natural drainage lines and maintain catch-ment integrity at all times

Lay-bys provide a safe haven where vehicles can pull off the road.

A segregated footpath can be a cost-effective means of catering for high volumes of pedestrian traffic.

Where a segregated footpath is not possible, the use of relatively wide, sealed shoulders provides an acceptable surface for walking or cycling.

4.4.3 Elements

The road design process includes the selection, sizing and linking of the following elements which, to a large extent, is influenced by the chosen design speed:

- cross-section
- bridges and culverts
- horizontal alignment
- vertical alignment

All of the above elements affect road safety by influencing the ability of the driver to maintain vehicle control and identify hazards. It is therefore essential that particular attention should be given to safety as a prime design criterion.

Cross-Section

The following elements of the road cross-section for various classes of LVSRs need to be considered:

- width of carriageway
- width of shoulders
- cross-fall
- width of road reserve

Of particular importance to LVSRs is the issue of catering simultaneously for the requirements of motorised as well as non-motorised traffic and pedestrians. In such circumstances, it will be necessary to consider cost-effective ways of segregating these various types of road users within an appropriately designed cross-section in which carriageway and shoulder widths play a crucial role.

Relatively wide shoulders (typically 1.5 to 2 metres) are particularly important in mixed traffic situations and serve the following important functions:

- movement of pedestrians and non-motorised traffic with minimum encroachment on the carriageway
- provision of additional manoeuvring space for vehicles and on which a driver may regain control of his vehicle if it goes out of control
- provision of space for the use of vehicles which are broken down
- provision of additional width to the cross section thereby improving sight distances

Examples and comments on appropriate values for the cross section elements for various classes of LVSRs are given in Table 4.6.

Severe edge break on a 5.0 m carriageway even at relatively low traffic levels (< 100 vpd).

A segregated footway on a narrow bridge provides protection for pedestrians.

Table 4.6 - Examples of typical cross-sectional widths[9]

Road Function	Indicative Traffic Flow (vpd)	Carriageway		Shoulder	
		Width (m)	Comments	Width (m)	Comments
Primary	> 400	6.0 to 7.0	Two commercial vehicles will pass completely within the carriageway; some movement towards the edge may occur.	1.0	Represents the minmum width recommended. Need to provide edge markings on shoulder. Widths may need to be increased to cater for pedestrians or non-motorised traffic. For traffic safety reasons, sealing of shoulders is recommended. This is also advantageous for structural and maintenance reasons.
Secondary	100 - 400	5.5 to 6.0	Need to maintain a minimum width of 5.5 m to avoid severe edge break even at low traffic levels.	1.0	
Tertiary/ Access	20 -100	3.0	Single lane. Two commercial vehicles will pass completely within the total width of 6.0 m utilising the shoulders.	1.5	

Note: In case of a high percentage of heavy vehicles, say over 40%, it is advisable to increase the carriageway to 5.5, 6.0 or 6.5 metres.

Higher standards will put a higher demand on the construction and maintenance budget and this needs to be considered at the design stage. For instance, increased road width produces a greater area to be maintained, thus increasing costs. However, increased width also spreads the traffic loading over a greater area, thereby to some extent reducing pavement deterioration. Thus, as described in Chapter 3, a life-cycle cost analysis of the various options should be undertaken to provide guidance on the optimum solution.

Camber and cross-fall: A commonly recommended value of all design manuals for the minimum normal cross fall on a paved road is 3%, including shoulders where they have the same surface as the carriageway. The preferable maximum value of super-elevation is normally set at 6 - 7% and with an absolute maximum of 10%. As indicated in Table 4.7, the use of a higher value of super-elevation makes it possible to introduce a smaller horizontal curve based on the same design speed.

Table 4.7 - Design radii for different super-elevations

Design speed (km/h)	Horizontal radius (m) (Super-elevation 6 %)	Horizontal radius (m) (Super-elevation 10%)
60	100	85

Bridges and Culverts

The cross-section on bridges needs additional consideration, particularly where they have been built with a restricted carriageway width. In such situations, there may be insufficient clearance for a truck to pass a pedestrian safely. This engenders a need to provide a segregated footpath and, where this is not possible, to employ traffic calming measures in combination with warning signs.

Horizontal Alignment

The following horizontal alignment elements need to be considered for various classes of LVSRs:

- minimum radius of curvature
- minimum stopping sight distance
- minimum passing sight distance
- super-elevation
- widening of curves

Good combination of curves and adequate horizontal curvature provide for a safe road environment. However, a lack of road markings constitutes a serious safety hazard.

In general, the horizontal alignment should conform to the landscape. On new alignments, long straights should be avoided as they have an adverse impact on the motorist. Measures are required to reduce headlight or sun glare in appropriate circumstances, as well as to reduce boredom and fatigue.

On existing alignments, as far as possible, upgrading should be undertaken without changing the existing curve geometry and cross-section. Curve improvements should focus on low-cost measures designed to control speeds, enhance curve tracking or mitigate roadside encroachment severity.

Minimum horizontal curvature is governed by maximum acceptable levels of lateral and vertical acceleration, minimum sight distances required for safe stopping and passing manoeuvres and values of side friction assumed for the road surface type. These design parameters are, in turn, related to the vehicle speeds assumed in the design. Curvature standards are thus explicitly or implicitly dependent on a number of assumptions which, as illustrated in Table 4.8, result in quite different values of minimum horizontal radii. The choice of minimum radius of horizontal curves has a significant impact on earthworks and costs and therefore needs additional consideration in LVSR design.

Table 4.8 - Comparison of minimum radii of horizontal curvature

Design Speed (km/h)	Minimum radius of horizontal curvatures (m)							
	SATTC			TRL ORN6			ARRB	
	Side f	e=10	e= 6	Side f	e = 10	e = 6	Side f	e=7-10
40	-	-	-	0.30	30	35	-	-
50	-	-	-	0.25	60	65	0.35	45
60	-	110	140	0.23	85	100	-	-
70	-	-	-	0.20	130	150	0.31	100
80	-	210	250	0.19	175	200	0.26	160
100	-	350	420	0.15	320	375	-	-

F = side friction, e = super-elevation

Vertical Alignment

The main components of the vertical alignment include:

- maximum gradient
- minimum stopping or passing sight distances on crest curves
- minimum radius of crest and sag curves

Poor visibility due to hidden sag curve - a potential cause of accidents.

Vertical alignment has a direct effect on construction costs and depends on terrain. Cost can be reduced by reducing earthworks through careful route selection. Greater maximum grades should be considered for lower standard roads than for those with a higher classification. The benefits gained from reducing vehicle operating costs and time costs are unlikely to offset the additional construction costs of implementing minimal grades.

Table 4.9 shows the values for vertical crest and sag curves recommended by different design manuals for rural/LVRs in developing countries. As indicated in the Table, there is a considerable difference between the values recommended for both vertical crest and vertical sag curves, largely because of the different assumptions made in their derivation. The values recommended in the SATTC guide for trunk roads are based on headlight illumination criteria while the values by TRL ORN6 and ARRB are based on driver comfort criteria. In the SADC region, LVSRs serve a number of different functions and in very different terrains. In the absence of a local guide for LVSRs, the designer will need to determine which of the recommended values are most suited to the local terrain and road function (primary, secondary or tertiary).

The 'K' valued for a vertical curve is defined as the length of vertical curve in metres for a 1% change in grade.

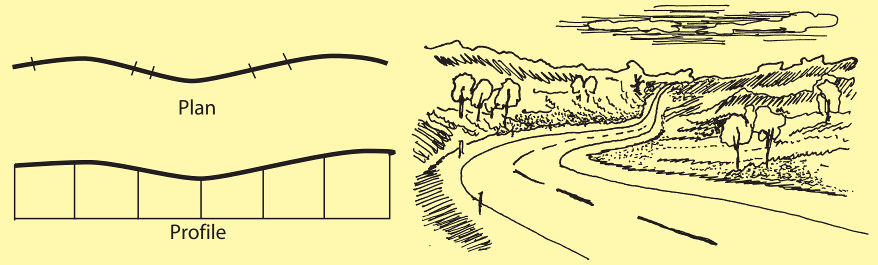
Table 4.9 - Comparison of minimum values of 'K' for vertical curves

Design speed (km/h)	SATTC		TRL ORN6		ARRB	
	Crest curves[1]	Sag curves[2]	Crest curves[1]	Sag curves[3]	Crest curves[1]	Sag curves[3]
40	6	8	3	1.3	-	-
50	11	12	5	2.2	5	4
60	16	16	10	3.5	9	6
70	23	20	16	4.8	14	8
80	33	25	-	-	23	10
85	-	-	30	8.1	-	-
90	46	31	-	-	-	-
100	60	36	60	13.1	63	16

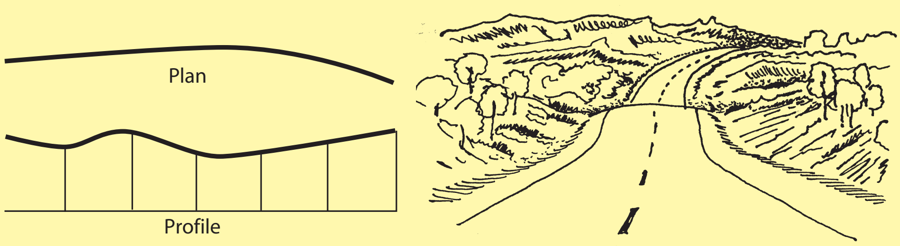
Notes: 1-Based on stopping sight distance. 2-Based on headlight illumination criteria. 3-Based on comfort criteria.

Phasing of Horizontal and Vertical Alignments

Certain combinations of horizontal and vertical curves can result in drivers seeing an apparent distortion in the alignment or grade or both, even though the horizontal and vertical curves comply with design rules. Other combinations can hide a change in horizontal alignment for the driver. Thus, proper sequencing of horizontal and vertical curvature is important for accident prevention. However, such sequencing is usually attained at the cost of extra earthworks and a careful balance must be struck between the costs and benefits of such an undertaking. Examples of good and poor alignment designs are shown in Figure 4.10.



Example of good alignment design - a smooth-flowing appearance results when vertical and horizontal curves coincide



Example of a poor alignment design - uncoordinated horizontal and vertical curves

Figure 4.10 - Examples of good and poor combinations of horizontal and vertical alignments[11]

4.5 Roadside Safety, Education and Enforcement

4.5.1 Roadside Safety

The roadside environment and its design play an important role in road safety. Elements of this environment include:

- roadside furniture and obstacles
- road signs, markings and studs
- parking facilities, lay-bys and passing lanes
- traffic calming measures and lighting

Roadside Furniture and Obstacles

Whilst fulfilling important safety roles, both roadside furniture and obstacles can have negative safety implications as well which include:

- obstructing the view of road users and line of sight of drivers and pedestrians
- causing a risk of vehicles colliding into them

The ideal situation is to provide for a clear zone, which is kept free of hazards, including roadside furniture and obstacles. However, in cases where the provision of clear zones is too expensive or impractical due to topographical, environmental or other constraints, options should be considered to reduce the seriousness of the consequences. Figure 4.11 provides guidance on dealing with roadside hazards in order to provide a "forgiving roadside".

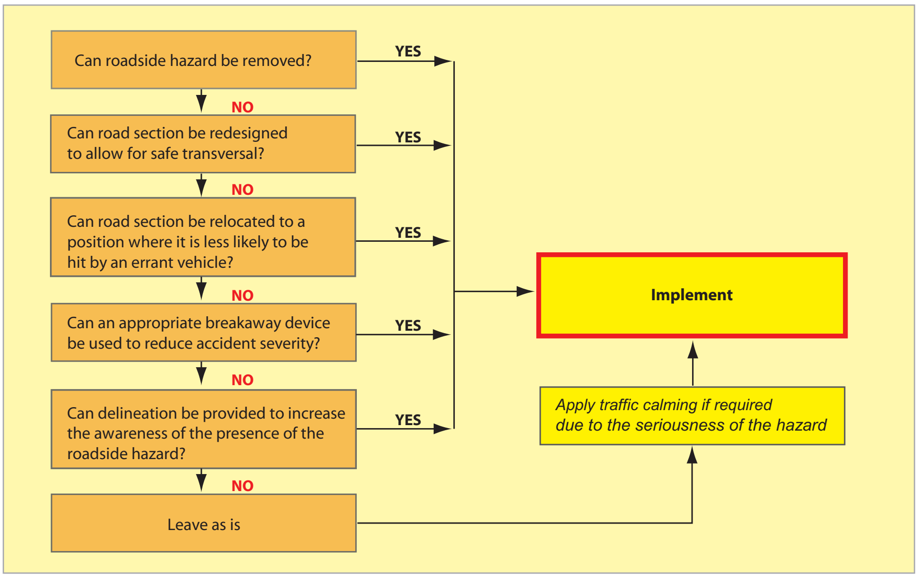


Figure 4.11 - Selection process to ensure a forgiving roadside

Roadside furniture *includes:*

- *Road signs.*
- *Street lighting.*
- *Guardrails, etc.*

Roadside obstacles *include:*

- *Trees.*
- *Shrubs.*
- *Illegally positioned advertising signs within road reserve.*
- *Power lines or other utility poles within road reserve.*
- *Building structures.*
- *Deep side drains.*

An unforgiving roadside is one which is not free of obstacles that may cause serious injuries to occupants of light vehicles.

Non-standard cattle warning sign.

Various SADC traffic signs as contained in the SATCC Traffic Signs Manual.


Additional signage should be provided on dangerous curves.

Road Signs, Markings and Studs

Road safety is greatly facilitated by the provision of road signs, markings and reflective studs, which provide drivers with information about routes, road geometry, etc.

Road signs help to regulate traffic by assigning right of way and indicating regulations in force, warning road users of hazards and guiding the road user through navigational information. Road markings play a complementary role to road signs by conveying additional information to the driver, particularly in terms of delineating various road elements, such as the width of the lane or edge of the carriageway. Road studs, sometimes colour-coded, may be used to supplement road markings where these are subject to conditions of poor or limited visibility. The SATCC Road Traffic Signs Manual[18] should be used as far as possible to maintain consistency throughout the region.

Road signs generally need to be located within close proximity of the roadway (i.e. within the clear zone) and therefore need to afford some protection to errant vehicles. This can be achieved through the use of a simple breakaway device, using a notched wooden support.

Signs, particularly regulatory and warning signs, must be maintained in a sound order (i.e. reflectivity, cleanliness, visibility) as they play a crucial role in terms of road safety in giving information on rules and hazards further ahead (e.g. sharp curves, steep down grades, areas of high pedestrian activity, etc).

Regular maintenance (trimming) of grass verges and shrubs is particularly important at bends, around road signs, and where pedestrians and animals cross regularly. Poles for services and trees in the road reserve are hazardous for vehicles accidentally leaving the road, and they may also hinder sight distance. Large trees may need to be removed from the immediate roadside. The use of high standard guard-rails is safety efficient, but is very costly. Simpler types of guard-rails or delineators made of painted wooden poles may be used instead of the normal types of guard-rails.

In case of financial constraints, first priority in the placement and maintenance of signage should be given to regulatory and warning signs. Reflectivity of road signs must be adequate for the purpose, with higher reflectivity for warning signs and little (or no) reflectivity for guidance signs. Ideally, signs should be reflectorised, but ordinary paint is better than no sign at all. Road studs should only be considered on road sections where mist is prevalent. They can usually be discontinued on shoulders and be replaced by edge lines as they suffer significant wear and tear.

Channelisation of Traffic

Warning signs and reduced speed limits are particularly important near localised areas of high activity, such as stretches of road with ribbon development, where there is inadequate sight distance for normal overtaking manoeuvres, and the crests of hills. Speed calming devices can also be used as self-enforcing measures where compliance to warning signs and speed limits are low.

Simple, innovative measures may help to separate traffic and improve the road safety situation for non-motorized traffic in built-up areas.

Dedicated crossings provide increased safety for pedestrians if correctly positioned and marked.

By deterring drivers from using road shoulders, the use of shoulder humps can improve the safety of pedestrians and cyclists

The easiest and cheapest way of segregating pedestrian and vehicular traffic is through the use of road markings (i.e. demarcation of shoulders.) These can be in white paint; although the use of another colour (e.g. yellow) helps to identify the particular function of the marking. However, kerbs and even guard-rails can be used to physically separate pedestrians and vehicles. They can also be used to give added protection to pedestrians over bridge and other structures. If there is sufficient room in areas of high pedestrian movement, a footpath (perhaps raised with a kerb to dissuade vehicles from using it) can be provided, either alongside the road itself; or preferably separated by a grass or earth verge of some kind.

Even on low-volume roads there will be areas where pedestrian movements and traffic flow are sufficiently high that pedestrians should be provided with assistance to allow them to cross the road safely. This is especially important near schools and shops. This might involve providing clearly signed zebra crossings with or without a central refuge. As well as offering pedestrians protection, crossings and refuges promote traffic calming and also encourage pedestrians to cross where it is safer to do so.

Parking Facilities, Lay-bys and Passing Lanes

If the road topography permits, provision should be made for stopping and parking vehicles. Thus the road design should take account of the need for bus stops, the location of (official or unofficial) street vendors and market stalls, shops and schools. Off-road parking areas should also be provided for rickshaws and taxis and so on.

When there are steep gradients, provision can be made for faster vehicles to pass slow moving lorries and buses safely. This can be provided by having an additional 'crawler' lane, or occasional lay-byes for slow moving vehicles to pull in to let traffic queues pass. However, for LVSRs, the cost-benefit aspects of such measures need to be carefully considered.

At the end of steep descents, 'emergency' provision should also be made for out-of-control vehicles with brake-failures or those travelling too quickly. For example, beds of gravel can be provided to stop vehicles that are out of control and hazardous objects should be protected or removed.

Traffic Calming Measures

Although traffic-calming measures are generally aimed at reducing speeds and diverting traffic (decreasing traffic volumes) in urban areas there are a number of measures that are appropriate for LVSRs. They are normally used on sections of road where there are a high proportion of unprotected/ vulnerable road users (pedestrians, cyclists and animal drawn carts, etc), or where there is a localised (unexpected) change in the design speed. Speed calming measures can basically be categorized according to the extent to which they may have an effect, namely:

- localised traffic calming measures, which include warning signs and markings, speed humps, rumble strips, jiggle-bars, pinch-points, roundabouts together with road surface texture and colour
- continuous traffic calming measures, such as speed humps, along a stretch of road

Well-designed speed humps are an effective means of slowing down traffic.

Speed humps are one of the most effective localised traffic calming measures, but require precision in design and construction to achieve a comfortable ride when traversed at the desired speeds but uncomfortable to drivers exceeding this speed.

Rumble strips in combination with traffic signs and/or speed humps, as appropriate, are traffic calming devices used to gradually reduce high speed before a dangerous spot. Community acceptance is very important for successful implementation of traffic calming devices.

Physical roadway design to enforce speed limits, such as narrowed lane width, can also be employed. This, however, has to be balanced by the need for passing opportunities, which is generally determined by the traffic mix. Visual narrowing of the roadway can have the same effect on speed as physical narrowing and can be achieved by using edge lines or omitting centre lines.

Stray cattle are a traffic safety menace in some countries.

Animals

Many rural communities graze farm animals such as cows and goats on road-side vegetation. Ideally such animals should be tethered or supervised. This can be encouraged by providing community education programmes.

Domestic pets and wild animals can also pose a hazard for road users. In some SADC countries, fencing is used and can be effective if well maintained but the high cost means that it is seldom used along LVSRs. Often when fences are erected, gates are left open and gaps appear due to theft and vandalism, which rapidly reduces their effectiveness.

Street Lighting

This can help visibility and safety but is expensive and generally unaffordable in the context of LVSR. There might, however, be situations where street lighting of the road can be considered, for instance, when passing built-up areas, schools, hospitals and busy intersections.

4.5.2 Education and Enforcement

Road safety education for school children, an important awareness raising tool.

Education

Road safety education (RSE) is an important tool to raise awareness of problems and behaviours related to traffic and road safety. It involves teaching children, and often adults, to be safer road users. It does so by developing:

- knowledge and understanding of road traffic
- behavioural skills necessary to survive in the presence of road traffic
- an understanding of their own responsibility for keeping themselves safe
- knowledge of the causes and consequences of road accidents
- a responsible attitude to their own safety and to the safety of others

RSE should be provided during formal schooling by trained teachers who are provided with suitable resource materials. However, it should also be recognised that not all children attend school and that many adults have never received any proper road safety education. This can be overcome by providing community road safety education programmes in addition to formal teaching in schools. Where literacy rates are low, special teaching methods can be used (e.g. drama, singing and dance) while road safety education can be incorporated into other curriculum topics (such as science and geography). RSE needs to be relevant, practical (participatory) and regular and aimed at the child's level of education and social development. In some situations the children themselves can be used to educate either their parents or other children.

Road safety awareness campaign in progress.

Road safety publicity campaigns can also raise the awareness of problems and behaviour in addition to improving knowledge, shaping attitudes and behaviours, as well as stimulating discussion and debate. These publicity campaigns can include local drama performances in which tribal languages are used in order to reach illiterate persons. Community workshops, radio, television and cinema can also be successfully used.

Box 4.6 - Examples of innovative road safety initiatives

In Swaziland community involvement has been used to solve road safety problems. A project was recently launched whereby children were employed to control stray animals on rural roads during critical times of the year (e.g. during the Easter holidays.) The community was also mobilised to erect roadside fences. The road authorities provided the materials for construction. Once erected, the community became involved in the maintenance of the fences on an on-going basis which provided a valuable source of employment for them.


Enforcement is an essential component for improving road safety.

Enforcement

Traffic law enforcement is meant to achieve the safe and efficient movement of all road users including non-motorised traffic and pedestrians. In this regard, enforcement of traffic rules (such as speed limits, stop signs and rules at pedestrian crossing facilities) can be used to significantly improve road user behaviour and safety.

Unfortunately, because of a severe shortage of trained traffic police, traffic law enforcement is inadequate. As a result, drivers tend to disregard regulations and a general disregard for traffic law often gradually becomes the norm. This situation highlights the need to promote traffic law enforcement more vigorously, including the use of well mounted campaigns which, ideally, should be accompanied by education and publicity. The objective should be to improve the behaviour (and safety) of the majority of road users, rather than to simply 'catch' (and punish) a few. Moreover, such strategies should not be used as a simple means of raising money - but to improve safety.

4.6 Summary

The key points raised in this chapter are:

1. The functionality and characteristics of the LVSR network in the SADC region are quite different from those in industrialised countries. Traffic operations tend to be complex, comprising a mixture of both motorised and non-motorised traffic and there is often a relatively high proportion of commercial vehicles.

2. There are no geometric design standards for LVSRs in any SADC country based on in-country research into economic and safety factors. National standards are generally based on adaptations of those developed in industrialised countries and often do not cater for the characteristics of the road environment in the region.

3. No single design guide or manual can be recommended for use as they are based on different philosophies and make different assumptions or use different criteria for developing design values for the various geometric design elements.

4. It is essential for the designer to have a thorough understanding of the underlying criteria and assumptions that have influenced the development of existing design guides or manuals as a basis for adapting them, where necessary, to suit the local road environment.

5. Road safety is a major problem with accident rates being some of the highest in the world. There is an overriding need to incorporate road safety measures in the geometric design process. Road safety audits should be introduced as part of the road design process in all countries.

6. Road safety education and enforcement are key factors which can have a major influence on road safety and should be given high priority in order to promote a road safety “culture” for all ages of road users.

This chapter has reviewed established and more recent approaches to geometric design, particularly in the context of road safety. The need for adopting appropriate standards has been stressed and the scope for improving the appalling road safety situation highlighted. Design standards will have an impact on pavement design and road surfacing - subjects that are covered in Chapter 5.

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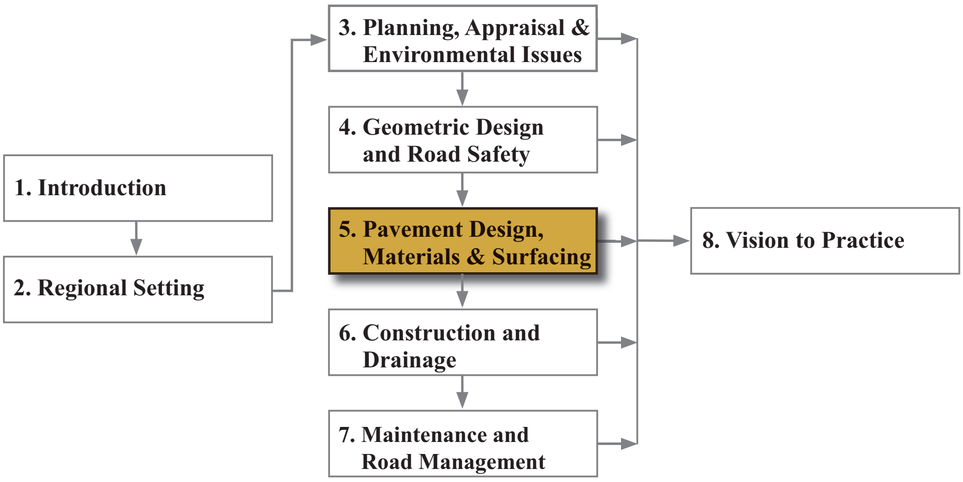
Chapter 5



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Pavement Design, Materials & Surfacing

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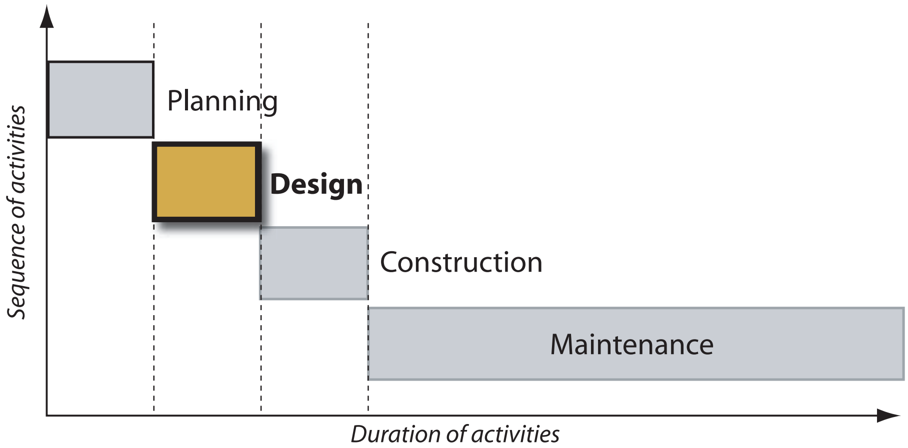
5.1 Introduction

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 for 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.

The outcome of the design process, in terms of the type of structure chosen, is influenced by the preceding phases of planning and geometric design 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 that takes full account of a variety of influential factors, as discussed in Chapter 3.

5.1.2 Materials

Calcrete and laterite are typical examples of natural gravels which, although occurring throughout southern Africa, had generally been considered to be unsuitable for use in base courses. 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 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 by comparison with 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 about 70 per cent, it is essential that the benefits of using them are fully exploited in road construction.

Naturally occurring calcrete found under a relatively thin layer of overburden.

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 make provision 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 more likely 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 of 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.

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 break down oversize may still be necessary. However, a distinction is made between these “natural” gravels, and material produced from crushed hard rock, and is referred to as “crushed stone base”.

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 that, 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

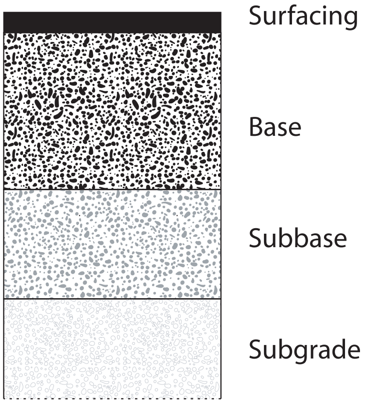
In situations of rapidly dwindling sources of gravel for maintaining unsurfaced roads, the bituminous sealing of a gravel road offers numerous technical, economic and environmental advantages and, in many cases, is unavoidable. However, because of the relatively low levels of traffic carried, there is need to provide 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 greatest 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 now exists in a disparate fashion and has not been adequately synthesized and packaged in an easily retrievable format for dissemination and implementation.

Typical pavement structure.



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 and also provides 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 reduce the surface load by traffic or the environment to a magnitude that can be supported without unacceptable permanent deformation.

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.

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

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 in Section 5.4.3.

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

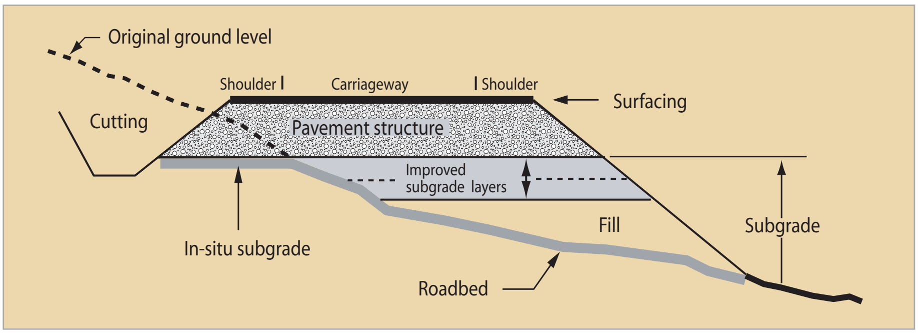


Figure 5.1 - Cross-section of a typical road pavement

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.

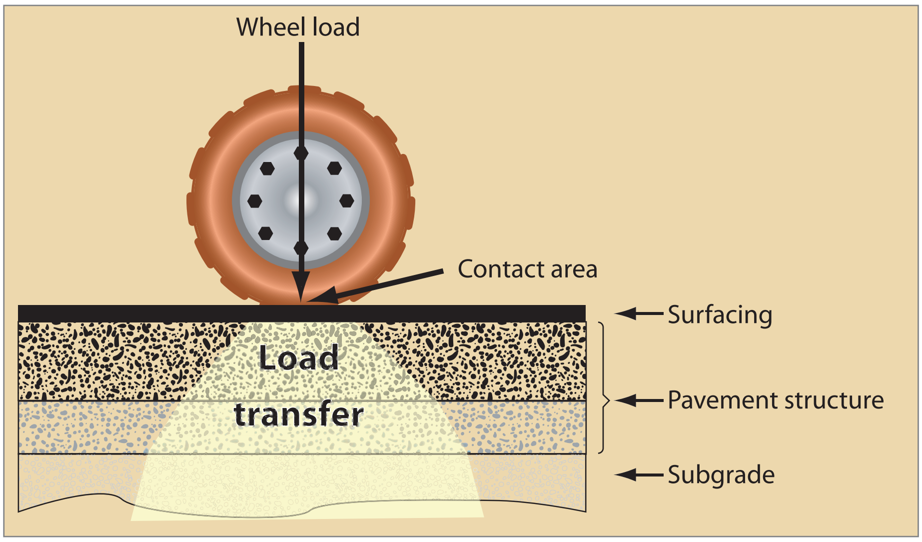


Figure 5.2 - Spread of wheel load through pavement structure

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 which is dependent on the stresses and the number of times they are applied

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.

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.

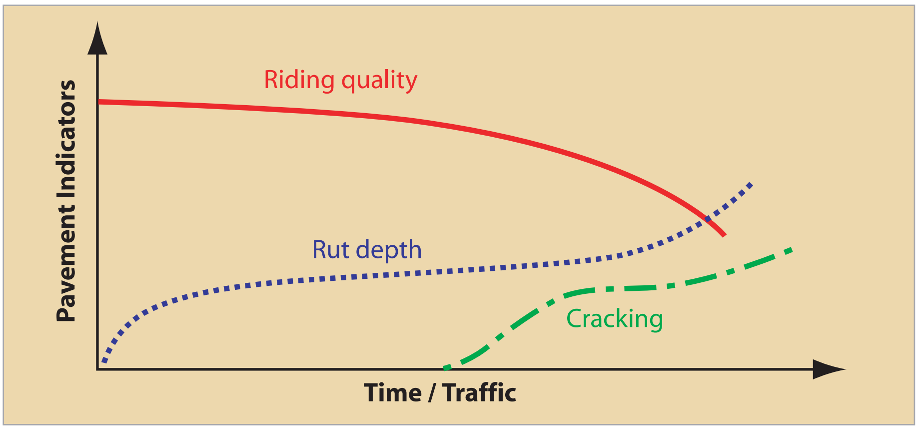


Figure 5.3 - Generalised pavement behaviour characteristics and indicators

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

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 ravelling 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 as result of 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).

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

Traffic Loading

Traffic loading is responsible for the development of ruts and 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.

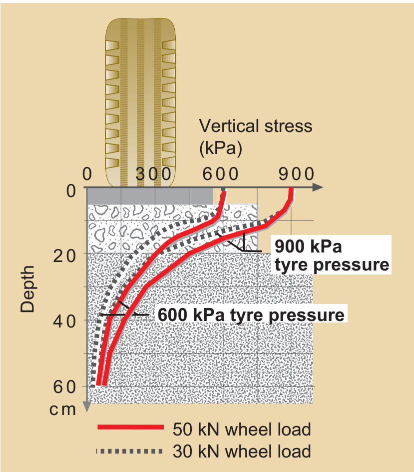
An example of rutting due to permanent deformation of the base layer caused by densification of material.

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

It is noteworthy that most of the 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 in Section 5.4.3.

Tyre Pressures

Tyre inflation pressure is an important parameter that can influence the performance of LVSRs. Prevailing tyre inflation 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 AASHO[1] Road Test (550 kPa), on which many empirical pavement design methods have been based.



Stress distribution versus depth in a pavement subjected to wheel loading [2].

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. on 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 are 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 counter measures should be observed.

5.2.4 Perceived Causes of Deterioration of LVSRs

Based on workshops carried out in a number of SADC countries, the perceived deterioration effects of LVSRs were recorded. These are summarized in Table 5.1.

Table 5.1 - Deterioration effects on LVSRs

Parameter	Related Issues
Poor drainage	• water ingress to pavement structure • inadequate maintenance of drainage structures • poor roadside drainage/flood water scour • poor geometric design
Inadequate maintenance	• poor/lack of/insufficient maintenance • poor maintenance techniques • integrity of seal/delayed reseal/unsealed cracks

Overloading	• 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	• inadequate/poor compaction • poor workmanship/supervision/construction standards • inadequate use of appropriate plant • poor mixing of materials/permeable pavements
Materials quality	• inadequate classification of soils • non-availability of good natural gravels, presence of poor subgrade soils • salt damage • low quality of surfacings • sodic, dispersive and other problem soils
Environmental extremes	• climatic (temperature and weather) extremes • erosion of shoulders and side slopes
Design	• 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) are considered, 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 required other than, possibly, loosening the in situ material by ripping and breaking down (usually with a grid roller) or removing oversize particles. The cost of such materials is, typically, about 25% 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.

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

Standard/traditional materials: These are defined as 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 from LVSRs.

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

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 partly 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 the drier areas of such regions, have often been neglected.

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, grading and plasticity requirements.

A typical surface treatment operation - spraying a thin layer of bitumen onto a road surface prior to the application 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, as regards 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 "non-standard" 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 as a nonstandard 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 of a structural layer of pre-mixed bituminous material. Typical terms include:

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

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.

- asphaltic concrete

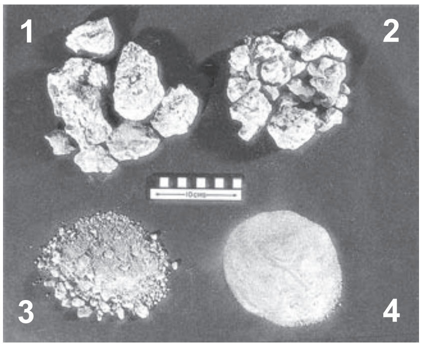
A layer of premixed materials (aggregate and bitumen).

5.3 Materials

5.3.1 Formation and Classification

In contrast to the abundant deposits of clean, durable, fluvioglacial gravels such as those used in much of Europe and the USA, the materials available for pavement construction from southern Africa have undergone considerable depths of weathering or pedogenesis[3]. The materials are therefore mostly residual weathered igneous rocks (e.g. basalt, dolerite and granite), metamorphic rocks (e.g. gneiss and quartzite), sedimentary rocks (e.g. shale and mudrocks) 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 those 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.

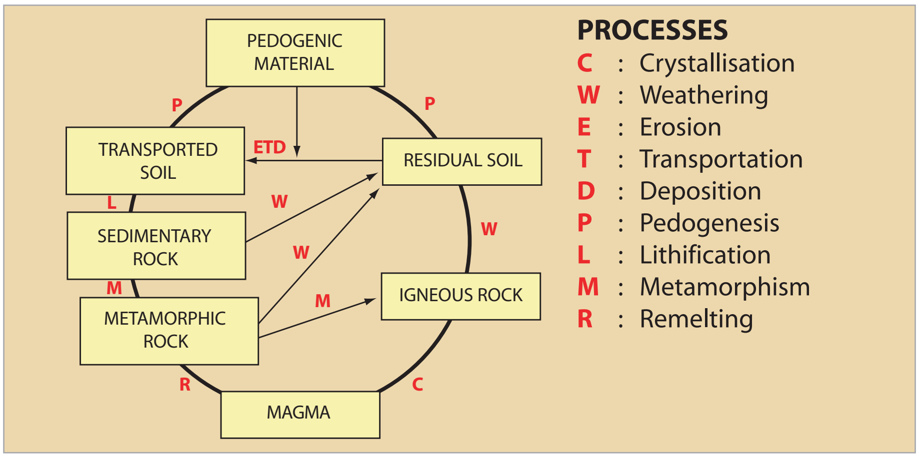


Figure 5.4 - Soil-Rock cycle[4]

Table 5.2 - Differences between conventional and pedogenic materials[3]

Property	Conventional (crushed rock base, river gravels, glacial outwash)	Pedogenic (laterites, calcretes, ferricretes, silcretes)
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.

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 groups[5]:

- 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)
- diamicites (e.g. tillite)
- pedocretes (e.g. calcrete, laterite, ferricrete, silcrete)

Each group has a characteristic range of properties and potential problems that should be taken into account in 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 stabilised[6].

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 stated 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 towards quantifying the conditions under which local materials can be used with confidence.

Weinert's N-Value

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

$$N = \frac{12.E_j}{Pa}$$

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

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 in which such materials are used. 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 5.3 [7].

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 dominant 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 Africa[7]
(currently does not 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 extensively 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 should be paid to the internal and external drainage of pavement.
N = 2-5	Conditions similar to above but the thickness of residual soil cover gradually decreases as the N = 5 contour 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 pozollanic material.

The material types described above derive their strength from a combination of the following intrinsic properties[8]:

- inter-particle friction
- cohesive effects from fine particles
- soil suction forces
- physico-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 that will only be generated at relatively low moisture contents. Special measures 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, possibly resulting 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 relation to 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*.

As the magnitude of soil suction can be very much greater than normal atmospheric pressure, 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:

Shear strength = (cohesion) + [(normal stress) – (pore pressure)] Tan (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 pressure 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 textures may have similar strength, and stiffnesses, even though their moisture contents may be quite different.

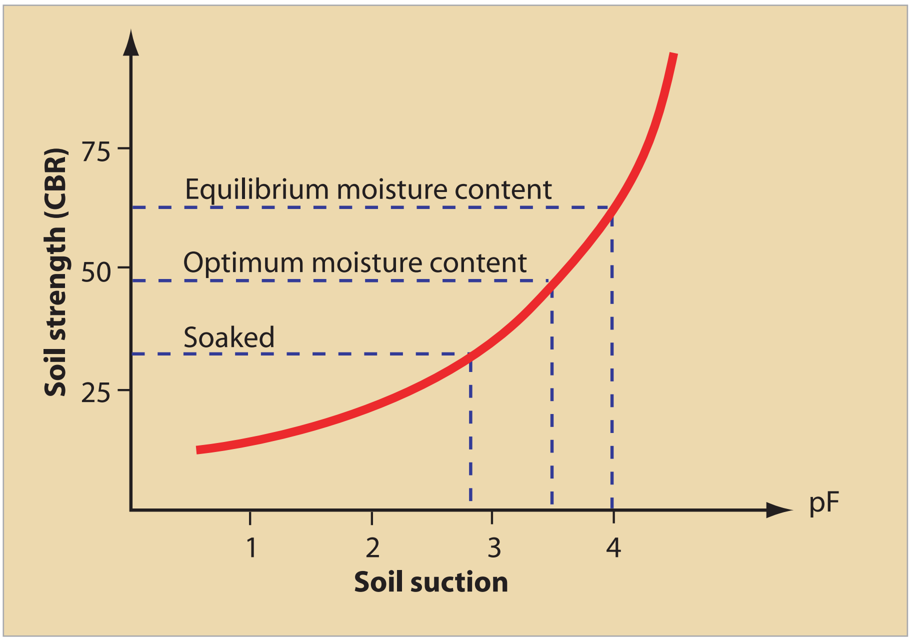


Figure 5.6 - Illustrative soil strength/suction relationship

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:

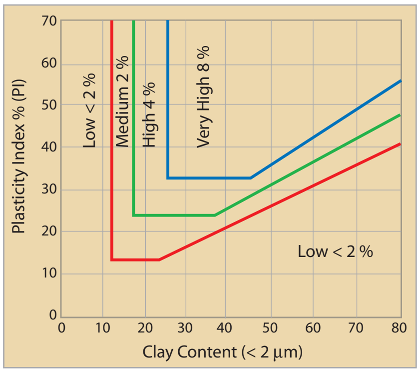
- low-strength soils
- expansive clays ("black cotton" soil)
- collapsible sands
- dispersive soils
- organic soils
- saline soils or presence of saline water
- weathered materials

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 by 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)
- elevation of the vertical alignment to increase soil cover and thereby redefine the design depth within the pavement structure



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

N.B - PI test to be carried out on material passing the 0.075 mm sieve.

Expansive soils: These clay soils exhibit particularly large volumetric changes (swell and shrinkage) following variations in their 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, if the side slopes are not gentle enough these volume changes may produce lateral displacements ("creep") of the expansive soil. When dry, some expansive soils present a sand-like texture and are prone to erosion to a much greater extent than what would be normally expected from their plasticity and clay content.

The measures chosen 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 side slopes (1:6 or flatter)
  - minimum earthworks cover of 0.6 m

Typical longitudinal cracking caused by large volumetric changes in an expansive soil subgrade.

Expansive "black cotton" soil exhibiting widely 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. Useful indicators for assessing the collapse potential of a soil include density and grading (ref. Table 5.5). More rigorous tests to quantify collapse potential include the single odometer test in which an undisturbed sample is loaded at its natural moisture content up to 200 kPa and then saturated. The collapse potential of the material is a mathematical expression, in percentage terms, of the reduction in

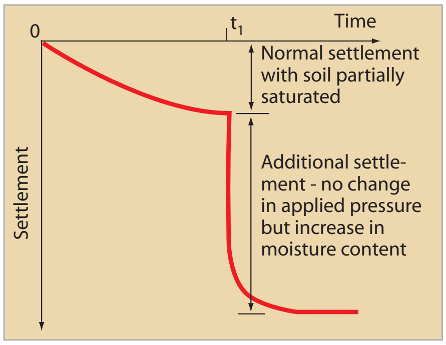


Figure 5.7 - The basic concept of additional settlement due to collapse of soil fabric[9]

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

Collapse settlement in excess of 150 mm after impact rolling.

voids ratio, in relation to the thickness of the potentially collapsible material and provides a guide to the potential severity of the problem.

Table 5.5 - Indicators of collapse potential and severity of problem[10]

Property	Guide to Collapse Potential[a]
Dry density (kg/m^3)	< 1600
% passing 2.0 mm and retained on 0.75 mm sieve	> 60%
% passing 0.075 mm sieve	< 20%
Relative density	< 85%

Collapse Potential (%)	Degree of Severity
0 - 1	No problem
2 - 5	Moderate trouble
6 - 10	Trouble
11- 20	Severe trouble
> 20	Very severe trouble

a – See Botswana Road Design Manual

Methods of dealing with collapsible soils includes 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 undertake and a careful balance should be struck between the costs and benefits of their 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 when 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 involves the use of a combination of indicator tests, observations of erosion patterns, soil colour, terrain features and vegetation.

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

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

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

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.

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 on repair methods where damage has already occurred.


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

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 construction[13].

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, will 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)
- phosphogypsum (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. As certain materials may also have relatively high soluble salt contents, additional tests should be carried out to ensure that their presence will not influence the performance of the surfacing.

5.3.3 Soil Improvement

Where suitable naturally occurring gravels are not available within an economical haulage distance, it may be necessary to resort to some form of stabilisation – the process by which additives are used to enhance the properties of subgrade and pavement materials - in order to improve the materials' properties, including strength, volume stability, durability and permeability.

The additives in common use in the region are:

- granular materials } Mechanical stabilisation
- portland cement
- lime (quicklime and hydrated lime)
- pozzolans (fly-ash, pumice, scoria)
- bitumen and tar

} Chemical stabilisation

The following factors influence the selection of the most suitable method of treatment:

- site constraints
- materials
- climate and drainage
- economics of the various options

A general guide to the stabilisation of soils with cementitious stabilisers is given in Draft TRH13[13], while the suitability of the various types of stabilisation additives is given in Figure 5.8.

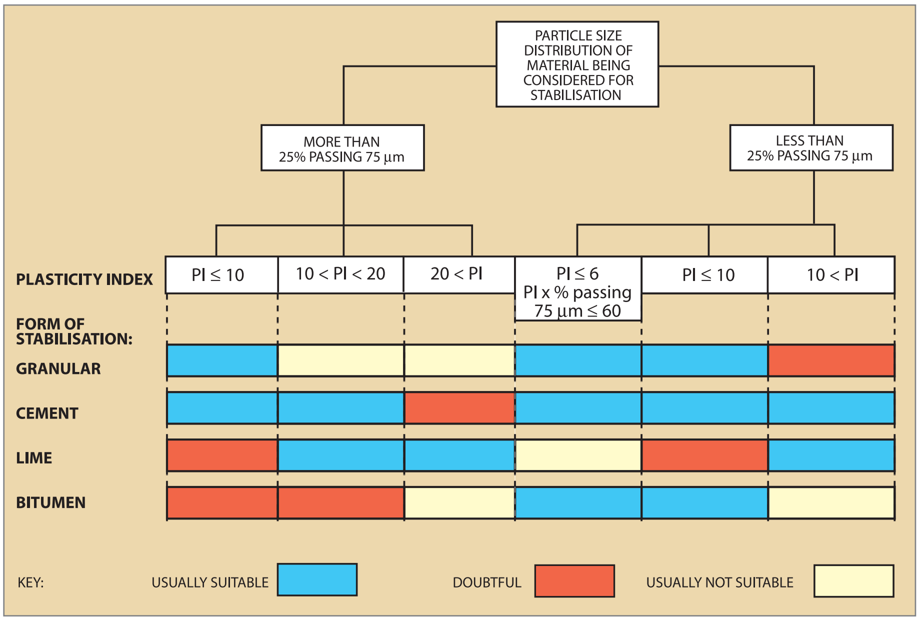


Figure 5.8 - Guide to the method of stabilization[14]

When mixed in the appropriate proportion, two non-standard materials, such as Kalahari sand and Calcrete, often satisfy the specifications of a standard/traditional material.

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 results 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 samples (A and B) increased significantly by over 40 per cent (20 per cent sand added) and 30 per cent (30 per cent sand added) respectively.

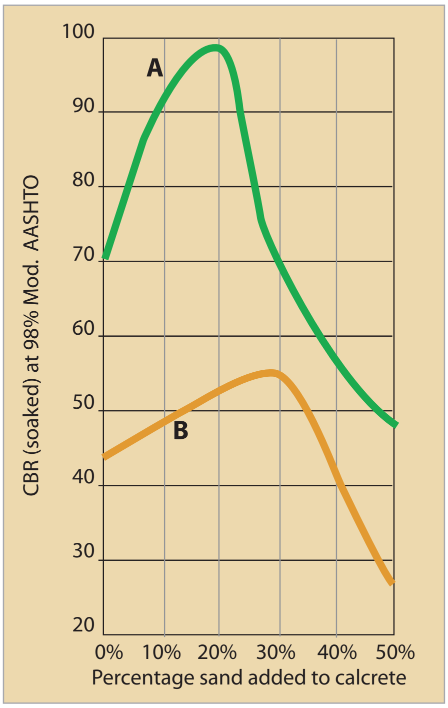
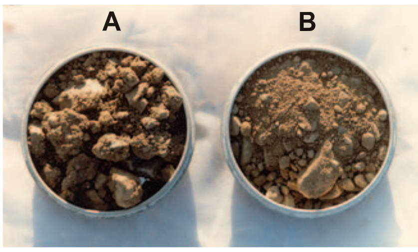


Figure 5.9 - Results of mechanical blending of calcrete with sand[15]

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 of locally available natural gravels for pavement construction, 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 by comparison with 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 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 TRH[13].

Potential problems or pitfalls with these types of materials include:

- propensity to crack because of traffic loading or environmental conditions, particularly with cement treatment
- degradation of the cementing action due to carbonation, particularly in the use of cement and lime treatments
- requirement for greater levels of skill and control during construction (compared with that required for untreated materials) to achieve a satisfactory product

Phenolphthalein reaction in stabilised sub-base.

Box 5.4 - Effects of carbonation

Lime- and, to a lesser degree, cement-stabilized soils, can lose strength through carbonation. This effect is particularly evident in lime-stabilised fine-grained, relatively weak soils (especially calcretes). 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: Various 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

Inexperience tends to cultivate a rigid adherence to 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 the performance of local material in a specific environment (climate and drainage measures) and for specific traffic loadings. The challenge is basically to relate the materials' physical properties with performance in a particular environment.

Traditional specifications for base gravels typically specify a soaked CBR @ 98% modified AASHTO density of ≥ 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.

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 on "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)

The above limits originate from situations very different from 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 types of material. Judicious interpretation of existing specifications and application of local knowledge can produce project-specific and more appropriate specifications.

The art of the roads engineer consists, to a great extent, 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.

Box 5.5 - Transferability of materials specifications

Materials specifications are not always simply 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 were made to the test results.

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

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 if traditional specifications were used.

Based on a 4-year programme of research in highway engineering materials[17], specifications have been developed for a variety of commonly occurring natural gravels in which their geological origin as well as climatic and traffic loading factors relevant to the region are taken into consideration. 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 was inappropriately high for many LVSRs. *New limits are recommended depending on traffic, materials and climate.*
- The grading envelopes for natural gravel bases were 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 of 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


Proper planning is essential for a successful materials prospecting survey.

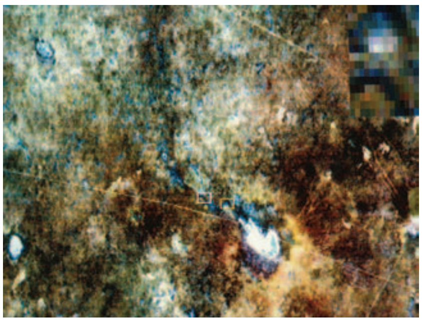
Large quantities of natural gravel are required for constructing and maintaining LVSRs. It is therefore essential that optimum use be made of all materials available at the lowest possible cost. Very often, gravels occur as relatively small localized deposits scattered around the landscape, and are usually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

The art of prospecting involves looking for clues as to the occurrence of useful materials and then digging 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 five 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

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.

The above sources of information are all analysed together to assess the likelihood that gravel may occur at a particular place. A typical flow diagram for materials prospecting is shown in Figure 5.10.


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

Desk Study
- Specification and quantity of materials required
- Interpretation of background material
- Provisional materials map

↓

Plan Survey
- Decide on methodology and procedure
- Carry out in-house or use consultants
- Consider environmental aspects

↓

Find and Map Sources of Materials
- Reconnaissance field survey
- Detailed field survey

↓

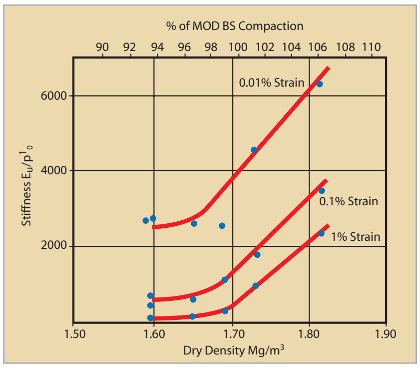
Source Evaluation (Laboratory)	**Source Evaluation (Field)**
• Laboratory testing	• Areal extent • Profile description • Visual classification

↓

Data Capture and Feedback
- Reporting

Figure 5.10 - Flow diagram stages for material prospecting [26]

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 expected in the field.

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 that obtained on an ASTM Liquid Limit device[18]. 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 countries[6]. 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*. Both are dependent on moisture content and density and can be affected by the wetting and drying history or to 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) test: 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.

*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 poor reproducibility, with an overall coefficient of variation of the order of 20 per cent. 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, a 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 5.11, 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.

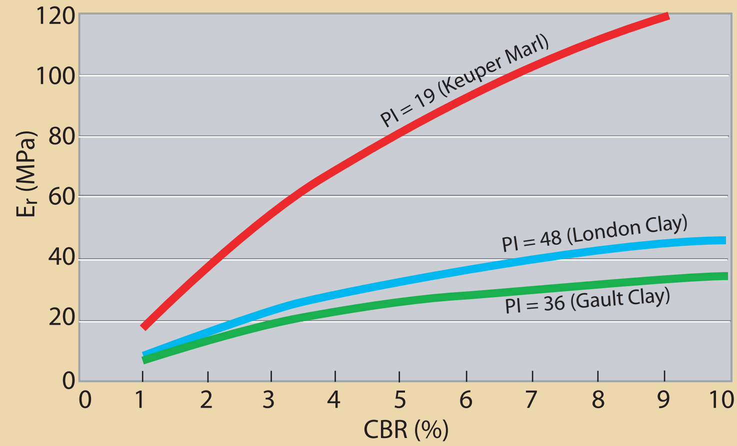


Figure 5.11 - Relationship between elastic stiffness and CBR for a stress pulse of 40 kPa[21]

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 test[22].

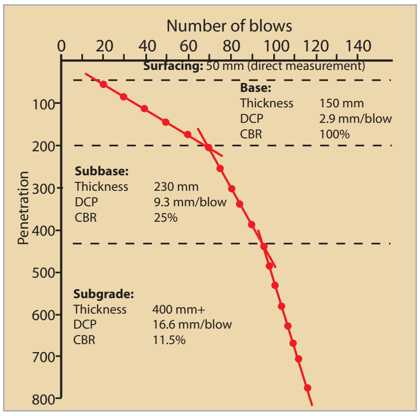
Texas Triaxial Test: An alternative to the CBR test, is the *Texas Triaxial test* which is used in Texas, Australia and Zimbabwe. This test is based essentially on the relative stiffness of the material in the form of stress strain characteristics and measures the fundamental strength parameters - cohesion 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.

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 1970s[23] 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 by 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 cycle[24]. Thus, although not yet commonly used, the K-Mould 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.



Typical DCP test result plot.

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 level[25]. 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	• Central record keeping. • Source of readily available/easily retrievable information. • Reference for future development.
Reducing costs	• Reduced consultancy costs.
Materials management	• Rapid/easier materials location and identification. • Input into national engineering geological maps.
Link to other management systems	• 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	• Support to on-going research. • Fine-tuning local materials and design specifications. • Development of local materials/performance correlations.
Other	• 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.

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.

5.4 Pavement Design

5.4.1 Objective

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 consider carefully 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.

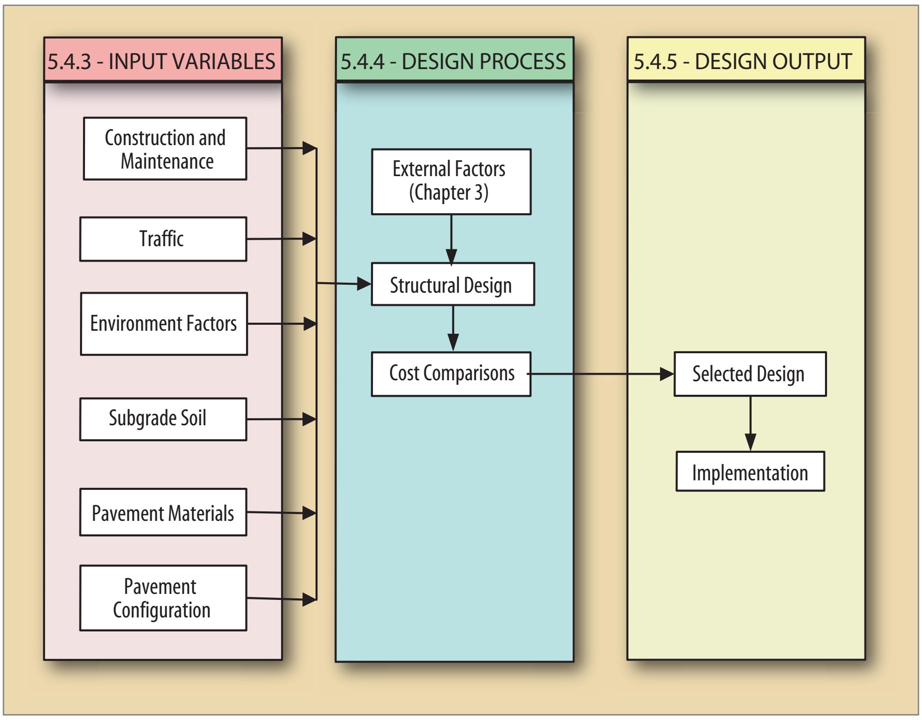


Figure 5.12 - Pavement design system

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 later in this section. The more general construction and maintenance issues are discussed 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 - 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.

Design life (Years): The design life of a pavement depends on a number of factors including, particularly, its function. 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.

*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.*

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 analysis is 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 31[27]. 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 determine the performance of the roads.

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.

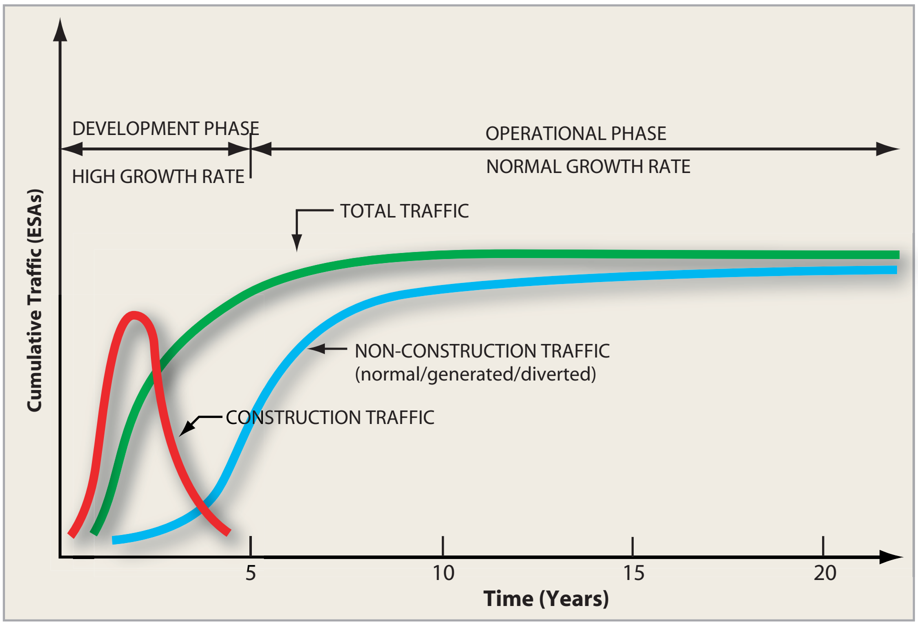


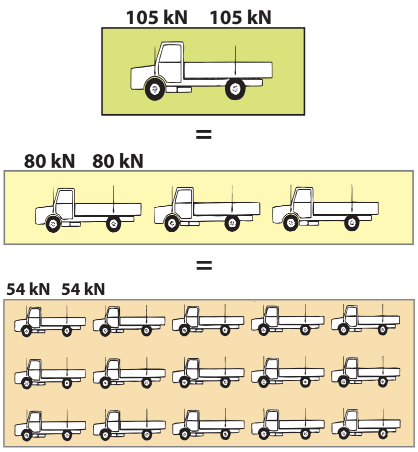
Figure 5.13 - Typical traffic growth pattern for a LVSR

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 were described in Section 3.2.7 of Chapter 3.

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:

$N = (W/Ws)^n$ where

- N = load equivalence factor
- W = axle load
- Ws = standard axle
- n = power law exponent



Three groups of heavy vehicles with equal damaging effect.

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 loadings 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].

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 effect on pavement performance. This is particularly the case with low-volume roads where environmentally induced distress rather than load-associated distress determines pavement performance[17]. 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.

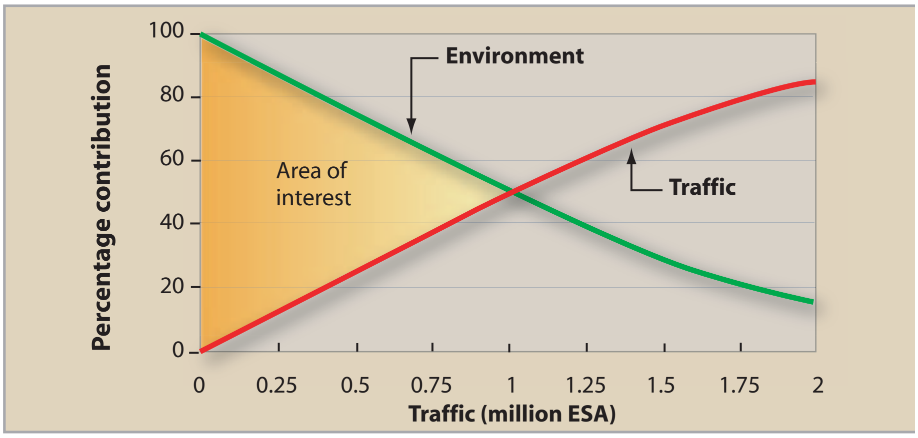


Figure 5.14 - Traffic loading versus dominant mechanism of distress

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 0.3 million ESA over their design life, priority attention should really be paid to mitigating 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: 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.

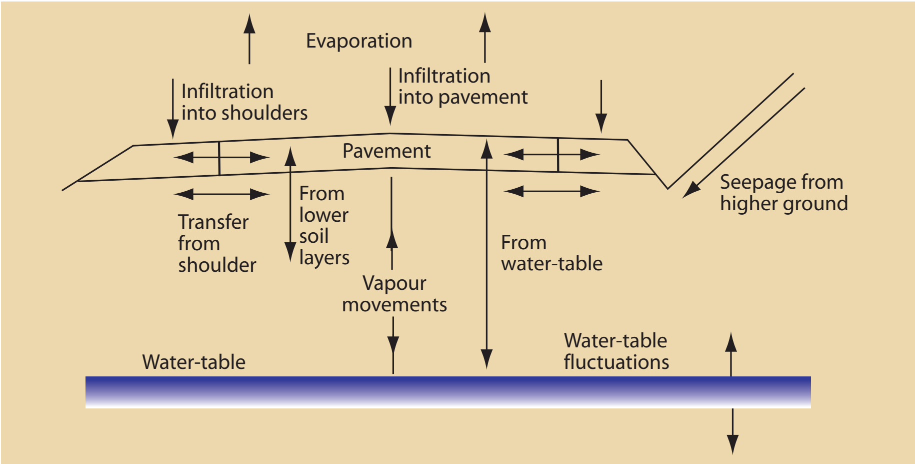


Figure 5.15 - Moisture movements in pavements and subgrades (NAASRA, 1987)[30]

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 (i.e. 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 the subbase and subgrade since many subgrades consist of cohesive fine-grained materials. Under these circumstances, a more conservative design approach is required that specifically caters for these conditions.

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

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 that[31]:

- 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 about two years after 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 horizontally from 600 mm to 1000 mm from the edge of surfaced pavements, and is 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 shoulders should be one metre for design traffic of less than 3 million ESA and 1.2 metres for design traffic greater than 3 million ESA.

From the above, it follows that, if the pavement of a typical LVSR has un-surfaced 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 at least one metre in width, 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.

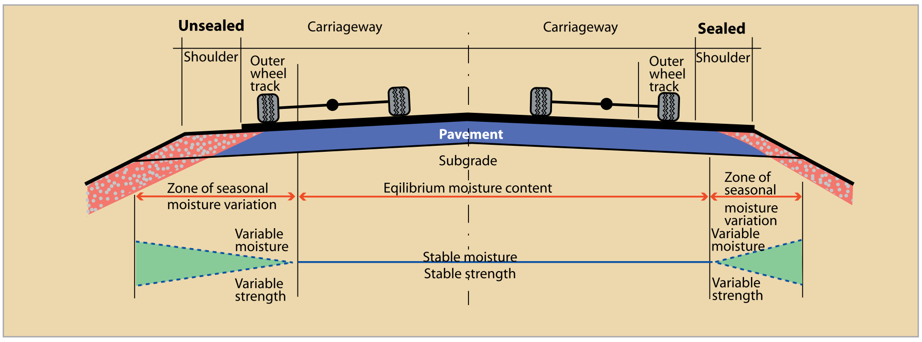


Figure 5.16 - Moisture zones in a typical LVSR

Temperature and humidity: Temperature and humidity play an important role in the performance of a road pavement with a bituminous surface, 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 to 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 layer[32]. Under certain temperaure 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 base course temperature above 20^{O}C and especially if the diurnal base course temperature range is greater than 10^{O}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.

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.

Measures to overcome the adverse effects of temperature, including a judicious choice of surfacing type and binder, are discussed 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 overstressing 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 be obtained as a basis for establishing the *design subgrade condition,* which provides a basic input into most low-volume road design methods.

From investigations carried out across a wide range of climatic regimes and soil types in the SADC region [17,31], 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 zone[10]

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 research[17] 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 in the base it is almost independent of climate

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 loading (represented by the design ESAs)
- environment (represented by the Weinert N-value/rainfall)
- material properties (represented by the material's plastic modulus calculated by multiplying the PI by the percentage passing the 0.425mm sieve)
- pavement configuration (cross-section)

Material Characteristics: Table 5.9 summarises the characteristics of various material types that 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.

Table 5.9 - Pavement material categories and relative characteristics

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

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, i.e. increasing crown height.

Pavement Configuration

As highlighted above, pavement configuration is influenced by the properties of the materials being utilized and by 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, 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 unsealed shoulders, relatively low permeability if they do not otherwise impede internal drainage (Section 6.7).

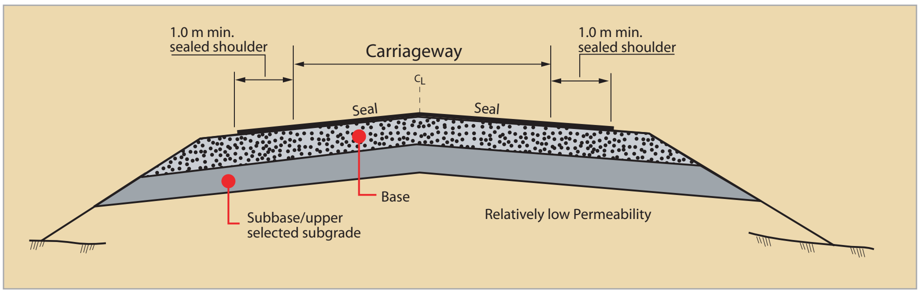


Figure 5.17 - Pavement configuration for Zone A materials (unprocessed, unbound materials)

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 failure[33]. 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 sealing shoulders, as well as on using pavement materials that can provide a frictional component of shear strength.

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

(a) internal friction which is maximized when the aggregate is hard, durable and well-graded (granular, unbound materials), or

(b) physico-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 fractions[33]. To avoid this situation, various positive design features are required including:

- sealed shoulders
- use of low-permeability selected lower subbase to protect the subgrade from moisture movements
- a subbase 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.), were discussed in Chapter 3 and are not repeated here.

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 obtained 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 higly variable, naturally occurring materials, which make up the bulk of LVSR pavements, is questionable and they are very poor at simulating environmental deterioration and therefore not well suited to LVSRs.

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 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 designs[35].

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 catalogue[36].

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. It should thus allow the designer to produce an appropriate pavement structure of sufficient bearing capacity to carry the anticipated traffic over its design life at 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:

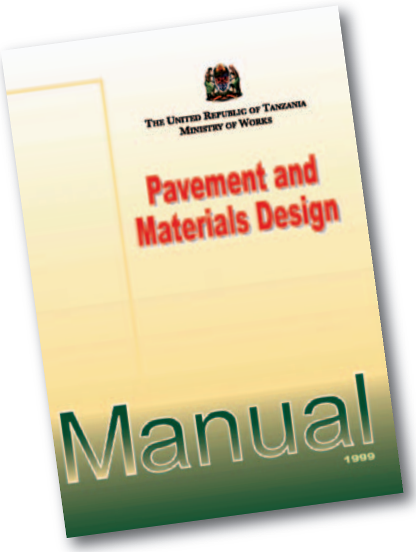
- subgrade design classes: These should be narrow enough to take advantage of the range of strong subgrade materials which predominate over extensive parts of the region
- design traffic classes: These should be relatively narrow to cater incrementally for design traffic loadings in the range up to 500,000 ESA
- materials classes: There should be a 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: These 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 mentioned in Table 5.10 were generally found to be suitable, with the proviso that they 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:



- 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 the 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, that uses the in situ measured bearing capacities of existing pavements, 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 countries mainly tropical and sub-tropical. 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

Although 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.

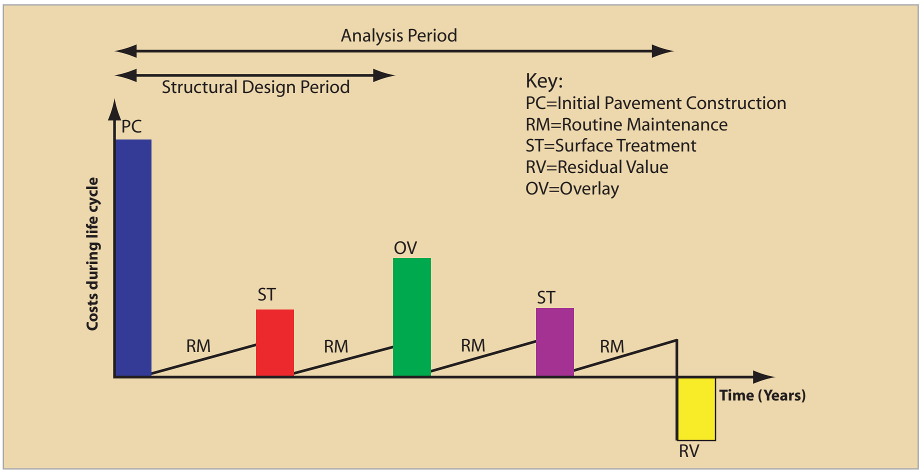


Figure 5.18 - Components of a typical life-cycle cost analysis

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 related[42]. 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.

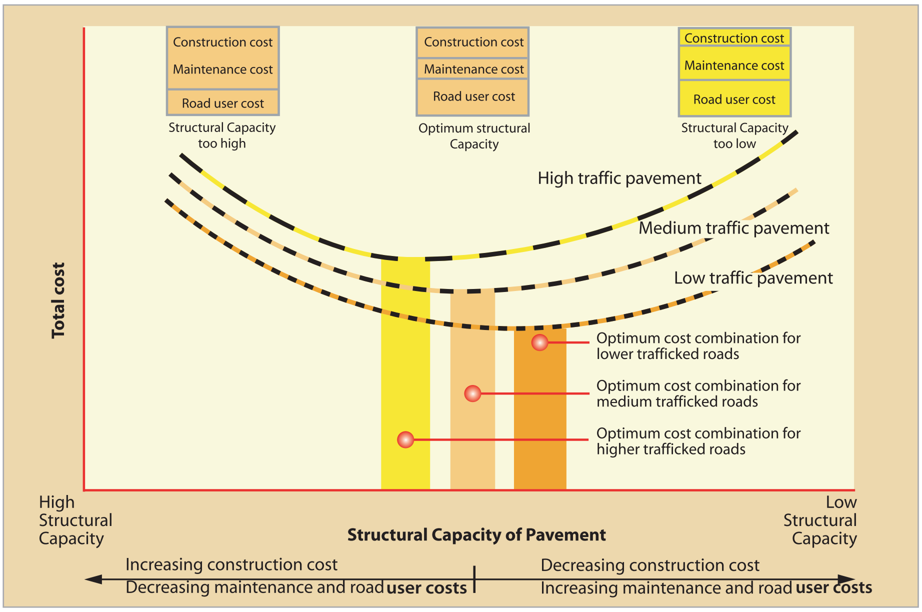


Figure 5.19 - Combined cost for various pavement structural capacities

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 provision
- 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 of 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 5.9 - 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 4^{th} power law) and poor maintenance. The following factors may explain this:

- reduced traffic loading (extended "life") due to inappropriate damage exponent
- good (strong) subgrade materials
- pavement design thickness based on unduly conservative saturated subgrade conditions
- predominantly dry environment
- stiffer pavement layers than anticipated at the design stage (base, subbase and subgrade)
- 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 more cost-effective than 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

Typical gravel road.

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.
- Types and Performance Characteristics.
- Constituents, Properties and Specifications.
- Selection of Surfacing Type.
- 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. The characteristics of these functions are:

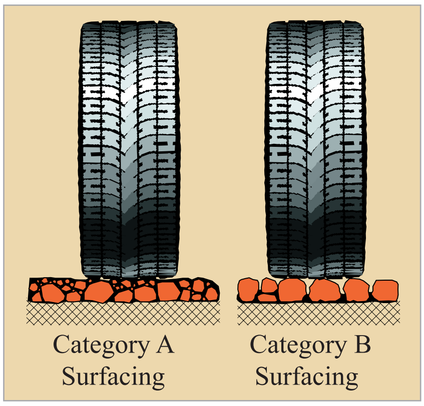
Typical LVSR offering many advantages over an unsealed road. In certain circumstances a bituminous surfacing may be warranted at traffic levels of less than 100 vpd.

- seal and protect the base and provides strength at the road surface so that the latter can resist the abrasive and disruptive forces of traffic
- transmit to the base the vertical and horizontal forces imposed by moving traffic. Have no significant load-distributing properties
- protect the pavement from moisture ingress, thus preventing loss of pavement strength, thereby permitting the use of many materials that would otherwise not be appropriate
- improve 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
- prevent gravel loss, resulting in elimination of the costs of replacing gravel, a finite, non-renewable resource
- generate savings in vehicle operating costs due to improved riding quality and lower maintenance costs to maintain an acceptable level of service

Sand seal surfacing.

Double chip seal.

Single Otta seal with sand seal cover.



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

5.5.4 Types and Performance Characteristics

Surfacing types

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

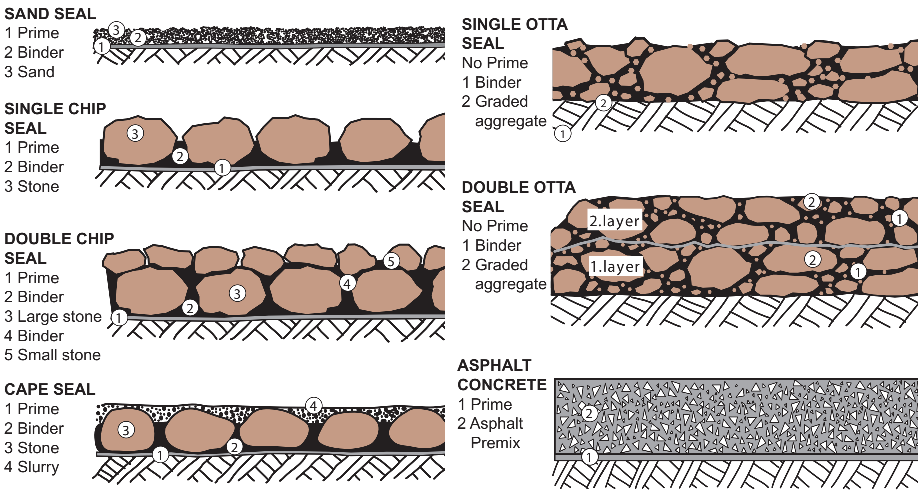


Figure 5.20 - Schematic common types of bituminous surface treatments

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 comprising of a bitumen/aggregate admixture - a mechanism of performance which is quite different from 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, in-sufficient 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 that of a very thin bituminous premix, which tends 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 guide-line and trial design on site. Amenable to design changes during construction.	Rational approach. Relies on confirm-atory trial on site. Not easily amenable to design changes during construction.
Construction	Not sensitive to standards of work-manship. Labour-based approaches relatively easy to undertake if desired.	Sensitive to standards of workman-ship. Labour-based approaches relatively easy to undertake 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, inter-sections, etc.)

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

Experience in the SADC region has indicated the approximate ranges of 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 sand seal	6 - 9
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	10 -14

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.

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 oversize material.

Screened gravel used as surfacing aggregate in the Otta seal.

Aggregates

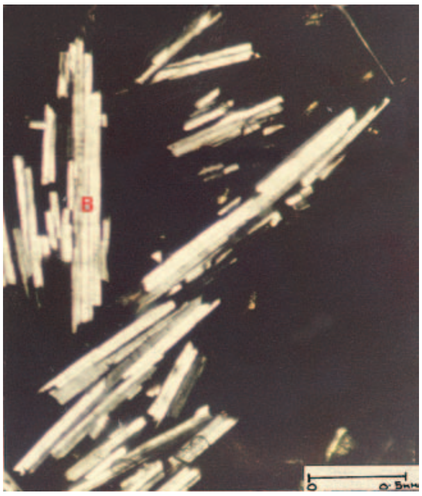
The main functions of the aggregate are to provide:

- 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	• 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: - 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	• 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: - 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	• need for good adherence to binder and non-susceptibility to stripping so as to prevent loss of aggregate/ravelling • aggregates containing acidic minerals (e.g. quartzite, granite) or very fine grained aggregates 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 emulsionsand/or anti-stripping agents and/or pre-coating of aggregate • specification limits placed in terms of: - Riedel and Weber test. - Static Immersion test (Modified Vialit adhesion test). - Fines and dust content


Photomicrograph of fresh basalt unaltered plagioclase microphenocrysts.


Cubical chipings are essential for good particle interlock in Chip seals.

Water and binder absorption	● 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	● need for good resistance to polishing in order 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	● 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 content 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	● need for aggregate to be free of contaminants so as 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	● 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 ● the use of 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	● for some seals (e.g. chip seal) need for aggregate to be as cubical as possible for better particle interlock ● particle shape is 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 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 the binder 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^{O}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 that of the SADC region. This relationship shows the significant effect of temperature on the ageing/hardening of bitumens. A 5^{O}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 Test[43]

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 ^{O}C. Bottles are then withdrawn periodically, the bitumen is removed and its viscosity measured at 45 ^{O}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 of 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 Otta seals, together with the sand seal or the rich slurry (in Cape seals), 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.

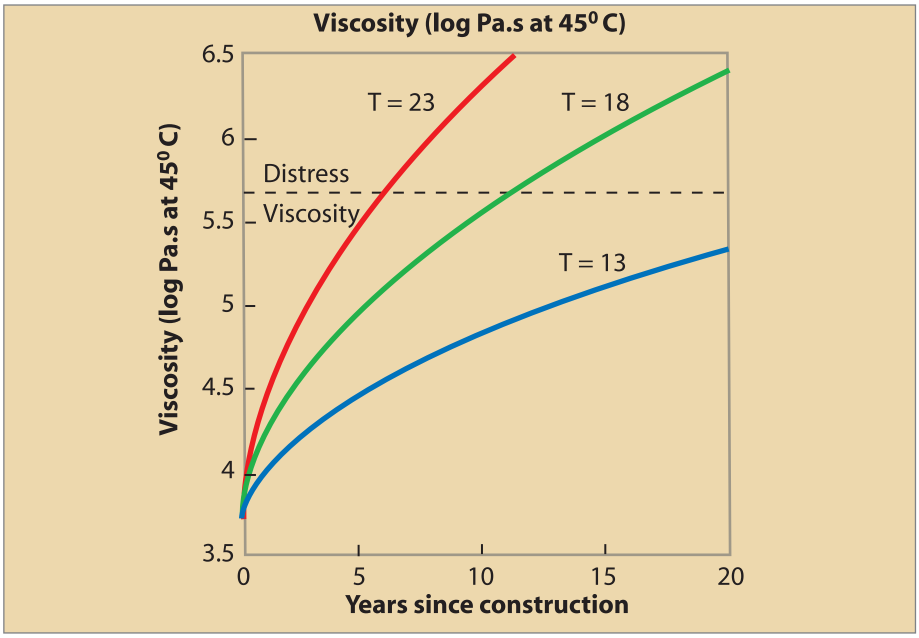


Figure 5.21 - Bitumen hardening graph for bitumen of a given durability[44]

Health aspects of foamed tar[45]

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, cold-placed foamed tar is a safe, viable construction material for stabilisation of sub-standard pavement materials.

The model illustrated in Figure 5.21 takes the following form:

$$\text{Log}\ \eta = 0.476TY^{0.5} - 0.0227DY^{0.5} + 3.59$$

(Pearson multiple correlation = 0.93)
(Standard error of estimate of log η = 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
$T = (T_{max} + T_{min})/2$ (T_{max} = yearly mean of daily maximum air temperature (°C)
(T_{min} = 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 in most surface treatments, except in Otta seals which require softer grades, usually in the form of cutback bitumens.

- As a general guide, the viscosity of penetration grade binders is chosen with regard to the prevailing temperatures during construction and the stability under traffic. Harder (high 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 diluents evaporate with time and the binder reverts back to its original penetration grade.

- *Bitumen emulsion:* Both anionic and cationic emulsions with 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 tars (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 with 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.

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 and 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 - Wet/Dry ratio	 > 210 > 0.75	 > 210 > 0.75	 > 120 > 0.65	 > 135 > 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 5.10 - 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 a 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, 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 aggregates with 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 Otta seals 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 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 type of 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.

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.

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

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. 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 types of seals types constructed on light pavement structures in southern Africa has revealed that seal life was very dependent on the stiffness of the pavement[46]. 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).

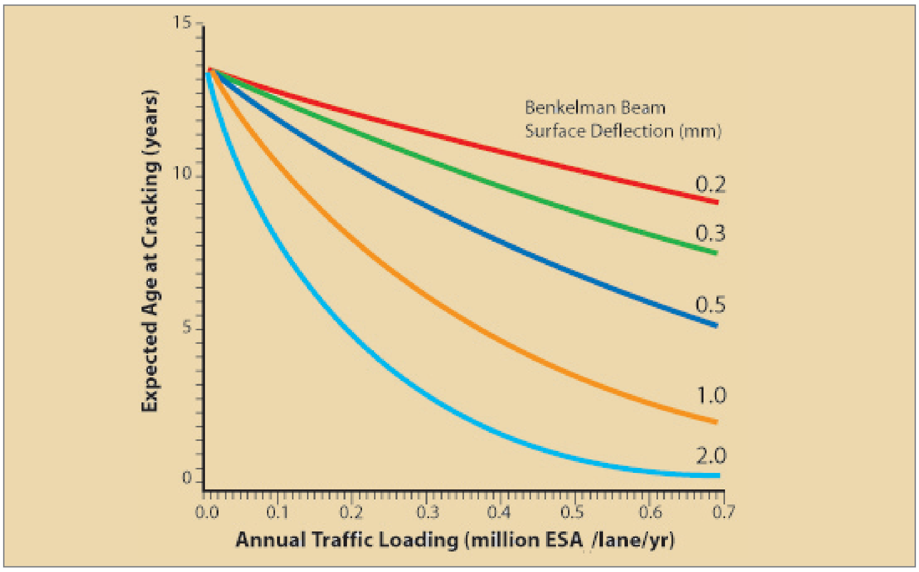


Figure 5.22 - Effect of surface deflection on seal life[46]

In situations on LVSRs, where weak subgrades occur (e.g. in expansive or soft clay areas) or where seasonal moisture variations are high (leading to relatively high deflections in the wet season), then the seal types which are more tolerant of 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, thus 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 steelwheeled 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	Otta, sand	Chip, slurry

Loss of second seal due to bitumen hardening and embrittlement.

Environment: Environmental conditions in terms of the exposure of the seal 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 resulting from 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, owing to the close interlocking aggregate texture and sand or slurry cover that protects 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, 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 preferable to sand, slurry or single chip seals.

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

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, because of their better skid resistance properties, would be preferable to sand or slurry seals.

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

Maintenance: Where maintenance capacity is high, ravelling, 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 where 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. The relative costs of 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 sand seal	0.90	0.70
Double chip seal	1.00	N/A
Single Otta seal plus sand seal	1.00	0.75
Cape seal (13mm + single slurry)	1.20	0.60
Cape seal (19mm + double slurry)	1.60	0.90
Double Otta seal	1.00	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, SlS = 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	SlS	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

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 seal performing very satisfactorily after more than 13 years in service and without any surfacing maintenance in a harsh environment.

Box 5.11 - Advantages and disadvantages of Otta seals

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 Otta seals 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 types of seals, such as chip seals and the 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 as 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 3[48].
- SABITA Manual 10[49].

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

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

- Ministry of Works and Transport, 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.
- Ministry of Works, Tanzania:
  Pavement and Materials Design Manual - 1999.

5.6 Summary

The key points arising in this chapter are:

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 important. 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 levels of traffic different from 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 which often perform much better than expected.

3. Measures that provide an improved (drier) road environment, such as sealing of shoulders and deepening of 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 that are based on research in the region and include local environmental factors are now available. 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 by comparison with that of 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 have been made through research in the region. The judicious use of the recommended designs together with the appropriate construction methods covered in Chapter 6, will reduce sealed road construction costs and increase the provision of rural road infrastructure.

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