DRAFT TRH 20

UNSEALED ROADS: DESIGN, CONSTRUCTION AND MAINTENANCE

Version 1.5 - APRIL 2009

PREFACE

TECHNICAL RECOMMENDATIONS FOR HIGHWAYS (TRH) have traditionally been aimed at informing the practising engineer about current recommended practice in selected aspects of highway engineering, based on proven South African experience.

Companion TRH, TMH and COLTO documents to TRH 20 are given on pages iv and 5.

This document was produced by a committee of practitioners from the public, private and research sectors. To confirm its validity in practice, it will be circulated in draft form for a trial period.

Any comments on this document may be addressed to:

Department of Transport
Private Bag X193
PRETORIA
0001
Republic of South Africa

DISCLAIMER

The information given in this document is based on the knowledge and experience of organisations and individuals concerned with unsealed roads. This document only provides guidelines for the design, construction and maintenance of unsealed roads and is neither a specification document nor a complete manual for the training of inexperienced personnel.

The views expressed and recommendations given are based on the experience of the Committee responsible for the compilation of the document and cannot cover the entire spectrum of possible situations.

The information contained is given in good faith and gives guidelines on how to deal with the problems likely to be encountered. No responsibility will be accepted by the Department of Transport or by any members of the committee that compiled this document for any adverse consequences arising out of the use of this document.

LIST OF COMPANION TRH DOCUMENTS

TRH 1 Prime coat and bituminous curing membranes	TRH 14 Guidelines for road construction materials
TRH 3 Surfacing seals for rural and urban roads	TRH 15 Subsurface drainage for roads
TRH 4 Structural design of flexible pavements for interurban and rural roads	TRH 16 Traffic loading for pavement and rehabilitation design
TRH 5 Statistical concepts of quality control and their application in road construction	TRH 17 Geometric design of rural roads
TRH 6 Nomenclature and methods for describing the condition of asphalt pavements	TRH 18 The investigation, design, construction and maintenance of road cuttings
TRH 7 Use of bitumen emulsions in the construction and maintenance of roads	TRH 19 Standard nomenclature and methods for describing the condition of jointed concrete pavements
TRH 8 Selection and design of hot-mix asphalt surfacings for highways	TRH 20 Unsealed roads: Design, construction and maintenance
TRH 9 Construction of road embankments	TRH 21 Hot-mix recycling
TRH 10 Design of road embankments	TRH 22 Pavement Management Systems
TRH 11 Guidelines for the conveyance of abnormal loads	TRH 23 Concrete Pavement Maintenance
TRH 12 Bituminous pavement rehabilitation design	TRH 25 Guidelines for the hydraulic design and maintenance of river crossings
TRH 13 Cementitious materials in road construction	Note: TRH 2 is no longer available

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SYNOPSIS

Draft TRH 20 was first published in 1990. The document has been widely implemented in South Africa and other countries with significant success. Since about 2000, implementation of the suggested material and construction requirements has resulted in significant improvements in the performance of unsealed roads, which, together with additional research carried out subsequent to publication of the original document has resulted in a revision of TRH 20. This revised document highlights aspects of unsealed roads and summarises the practical aspects. Recommendations on procedures for the location and selection of materials, the structural design, optimum construction techniques and maintenance strategies for unsealed roads are included. Unsealed roads are susceptible to various modes of distress and the cause and methods of avoiding these problems are fully explained. Methods for quantifying the economic benefits of various maintenance and upgrading strategies are introduced.

ABBREVIATIONS

AASHTO	American Association of State Highway and Transport Officials
ADT	Average daily traffic
AGL	Annual gravel loss
ARRB	Australian Road Research Board
CBR	California Bearing Ratio
E80	Equivalent standard 80 kN axles
G_c	Grading coefficient ((Percentage passing 26.5 mm - percentage passing 2.0 mm) x percentage passing 4.75 mm)/100
GPS	Global Positioning System
GRMS	Gravel Road Management System
HDM 4	Highway Design and Maintenance Model 4
I_o	Oversize index (percentage of material coarser than 37.5 mm)
MMS	Maintenance Management System
N	Weinert N value (Weinert, 1980)
OMC	Optimum moisture content
P26	Percentage of material finer than 26.5 mm
PF	Plasticity factor = Product of plastic limit and percentage of material finer than 0.075 mm
Sabita	Southern African Bitumen Association
SADC	Southern African Development Community
SMME	Small, medium and micro enterprise
S_p	Shrinkage product (Linear shrinkage x per cent passing 0.425 mm sieve)
TMH	Technical Methods for Highways
TRH	Technical Recommendations for Highways
VOC	Vehicle Operating Cost
vpd	Vehicles per day

1 INTRODUCTION

1.1 *Background*

The importance of the road network in the economic well-being of a country should not be under-estimated. The increasing need for access and mobility dictate the need for an ever-improving road network. The agricultural, mining, forestry and tourist industries of all countries depend almost totally on an adequate network of all-weather roads for their economic viability and sustainability. Unsealed roads are the major component of the road network in most developing countries and comprise the dominant proportion of the network even in many highly developed countries such as the United States. It is unlikely that the overall percentage of unsealed roads will decrease significantly in the foreseeable future and techniques for improving the performance, cost-effectiveness and sustainability of unsealed road networks are thus becoming increasingly important.

South Africa currently has about 750 000 km of road (proclaimed and unproclaimed) (DOT, 2006) of which it is estimated that about 600 000 km (80%) are unsealed. Some of these carry in excess of 1 000 vpd and, although sealing would be the normal choice, the resources have not yet become available to upgrade these.

Many unsealed roads are presently designed with very little technical input and are constructed using the nearest available material, irrespective of its mechanical and physical properties. Minimal attention is directed towards providing an adequate formation or effective drainage or selecting material which is appropriate for the prevailing conditions. As more pressure is put on funding for roads, the quantity and quality of maintenance for unsealed roads is decreasing rapidly. It has, however, been clearly shown that worthwhile benefits can be obtained from an appropriate level of engineering input (Ferry, 1986). The need to minimise the use of non-renewable natural resources by ensuring that the maximum life is obtained from gravels placed on unsealed roads is also becoming increasingly important.

This document provides guidelines for the design of unsealed roads and identifies construction techniques that will result in better roads with minimal need for additional funds. The document has a stronger focus on unsealed roads in rural areas than those in urban areas, although, other than drainage and access characteristics, the fundamental principles are generally similar. Recommendations for improving the maintenance of unsealed roads are provided and various appropriate maintenance techniques are discussed. Fundamentals of management strategies for unsealed road networks that will optimise the use of available funding are also considered. Aspects such as the planning of unsealed road networks and the geometric design are not considered in any detail. Appropriate references are, however, provided.

1.2 *Definitions*

In line with current usage (SADC, 2003), the term *unsealed* roads has been adopted in this document for roads that are not *sealed*. This includes all roads that do not have a bituminous, concrete, block or other paved surfacing and on which **vehicles travel directly upon a gravel or soil layer**. Unsealed roads may be classified as earth tracks, earth roads or gravel roads.

Earth tracks are the simplest "low volume roads" and generally consist of parallel ruts separated by vegetation, delineating a lightly trafficked rural access route. These tracks are not engineered and are often impassable during wet weather conditions. In most cases they carry less than about five vehicles per day. They are often restricted to private and trust lands and are not constructed or maintained by a recognised road authority. They are often important means of access by non-motorised traffic such as pedestrians, bicycles and animal-drawn carts.

Earth roads are classified as those on which no imported gravel is used, but the in situ material is cleared of vegetation and lightly compacted. The roads may be shaped making use of the material which is removed from the side of the road during the construction of side-drains. In this way, a small embankment is formed and the road is raised slightly. These roads are usually constructed by a road authority or regional development institution and are important for the economic or social advancement of the area. Unlike earth tracks, periodic maintenance should be applied to earth roads.

Gravel roads consist of a layer of imported selected natural soil or gravel material which is typically constructed to a specified standard and provides an acceptable all-weather surface. The vertical and horizontal alignment is generally upgraded to the desirable standards. Maintenance of gravel roads is carried out on a more regular and systematic basis and a higher Level of Serviceability[1] is obtained although the road roughness varies considerably with time and depends significantly on the maintenance activity.

This manual is primarily intended for use with gravel roads but many of the guidelines and recommendations are equally applicable to earth roads, particularly where the in situ materials have properties similar to those recommended for unsealed roads. Many of the recommendations are equally applicable to gravel shoulders on sealed roads.

1.3 *Classification*

A road classification system is useful for the consistent treatment of roads in a network and for communication among engineers, administrators and road users. Various systems have been devised and implemented depending on the specific application (Lea, 1996). These schemes generally **classify roads according to their purpose, the traffic that they carry, the expected Level of Serviceability, the environment in which they are built (eg, rural or urban) or a range of other parameters selected by the classifier**.

The South African road network has been classified (DOT, 2006) on a combination of a functional basis and the significance of the roads. Focus is placed on the service that the road provides, its importance in terms of its location in the road system and its contribution to achieving the economic objectives of the country (DOT, 2006). The system is seen as a high level strategic classification and was not expected to replace the administrative, technical and safety classification systems implemented by individual road authorities. Roads are classified in terms of their strategic function and functional nature without explicit differentiation between whether they are sealed or unsealed. The implication is that both sealed and unsealed roads can occur within any road class.

Most provincial road authorities in South Africa classify their road networks on either a hierarchical (eg, trunk, major, minor) or a functional basis related to the connectivity of the road (eg, provincial, district, access). However, there is generally no distinction within any of these classifications between sealed and unsealed roads, with either type of road being possible in any road class. In reality, the lower the class the less likely the roads are to be sealed and the greater the percentage of unsealed roads. The RISFSA strategic functional classification system (DOT, 2006) has been adopted for this document and is summarised in Table 1.

The majority of roads within this classification system that are unsealed will fall into Classes 3, 4 and 5 although it is possible that routes in any class could be unsealed.

---

[1] Note that the Level of Serviceability used in this document refers to the functional performance of the road provided to the road user, whereas the Level of Service (LOS) is the term generally applied to highway traffic capacity.

Table 1 Strategic functional road classification system (DOT, 2006)

Class	Strategic function
1 Primary distributor	High mobility roads with limited access for rapid movement of large volumes of people, raw materials, manufactured goods and agricultural produce, of national importance
2 Regional distributor	Relatively high mobility roads with lower levels of access for the movement of large volumes of people, raw materials, manufactured goods and agricultural produce of regional importance in rural and urban areas
3 District distributor	Moderate mobility with controlled higher levels of access for the movement of people, raw materials, manufactured goods and agricultural produce in rural and urban areas, of regional importance
4 District collector	High levels of access and lower levels of mobility for lower traffic volumes of people, raw materials, manufactured goods and agricultural produce in rural and urban areas of local importance
5 Access roads	High access and very low mobility routes for the movement of people and goods within rural and urban areas
6 Non-motorized access ways	Public rights of way for non-motorized transport providing basic and dedicated movement

In order to assist with the design of unsealed roads, it is necessary to be able to relate the required geometric standard and Level of Serviceability to the various road classes. This aspect is dealt with in Section 3.2 and Appendix B.

1.4 ***Traffic***

Unsealed roads are nearly always "lightly" trafficked or classified as *low volume roads*. There is, however, currently no widely accepted definition of low volume roads. Most road agencies or even some countries have specific definitions for low volume roads related to, not only the number of vehicles using the road, but the traffic composition and type as well as the road function. **Roads carrying less than 400 vpd, for example, are classified as very low volume local roads by AASHTO** (2001). In the South African context, the majority of unsealed roads carry traffic of less than about 200 vpd, although there are certainly some unsealed roads carrying in excess of 1 000 vpd.

Research into the performance of unsealed roads in South Africa has shown that the effect on conventionally constructed and maintained unsealed roads of light vehicles (cars, pickups, etc) and heavier trucks (80 kN plus axle loads) is very similar. The damage caused to the road by faster moving light vehicles is in most cases greater than slower moving heavier vehicles, which compact the road and actually improve its performance. However, during repeated use of roads by loaded trucks in inclement weather or on roads carrying a high proportion of fast moving empty heavy vehicles (returning from deliveries) significant damage and deterioration of the riding surface can occur.

It has been shown that at relatively low traffic levels (< 100 vpd) it can be economically viable to surface unsealed roads using light pavement structures and thin bituminous seals (SADC, 2003). Software such as SuperSurf (Sabita, 2005) can be utilised to determine the break-even traffic for the economic justification of improving unsealed roads or upgrading them to sealed standard.

This TRH is mainly applicable to roads carrying less than about 200 vpd, with less than 60 of these being heavy (axles legally permitted to carry 80 kN loadings), although much of the discussion is applicable to roads carrying up to 400 light vpd or more.

In developing areas, and particularly related to access roads, the non-motorised traffic component should not be neglected. This includes pedestrians, cycles and animal or even human drawn carts or barrows. Improvements to such access roads can benefit this traffic significantly, but the pavement surface and fundamental geometric requirements (eg, carriageway width, horizontal curve radii, etc) should be considered in relation to this traffic and its accompanying safety implications.

Of particular note is the tendency for drivers to increase their speeds on better roads. There is no doubt that the riding quality of unsealed roads is improved when the specifications and methods described in this document are diligently applied. The likelihood for the average speed on such roads to rise is therefore also increased significantly and the onus rests on drivers to respond responsibly. In urban areas, small concrete structures for water control can be considered for judicious use as traffic calming measures.

1.5 *Basic economic principles*

The fundamental theory of economic analysis applied to unsealed road construction and/or improvement is the comparison of the benefits and costs of providing the alternative facilities. The benefits are the expression in economic terms of the advantages of the particular action, e.g. fuel and time savings with reduced roughness, a reduction in dust and maintenance on paved roads compared with unsealed roads, reduced accidents, etc. The conventional cost analysis of a project should follow the "life-cycle costing" process and involves a combined function of the initial construction cost, the routine and periodic maintenance costs, road user costs and the salvage value of the facility over the design life or analysis period selected for the project.

The benefits and costs for each alternative are analysed in terms of the "economic cost" (i.e. excluding taxes, subsidies and duties) and discounted over the expected design lives of the facilities. Discounting is necessary to allow the direct comparison of costs and benefits between the first and subsequent years.

A number of techniques are available for the economic evaluation of alternative options, the most common ones being the "present worth of costs", the "benefit/cost ratio", the "internal rate of return" or the "net present value" and the one most appropriate for the purpose should be selected.

Many more problems occur in the economic analysis of unsealed roads compared with sealed roads. **Unsealed roads are dynamic systems requiring ongoing maintenance and the condition can be significantly affected by periods of excessive traffic volumes or inclement weather. The accurate estimation of road maintenance costs is therefore difficult.**

Other aspects such as expressing the effects of dust in residential areas in economic or social terms, or the effect of improved passenger comfort on the lengthy commuter routes unique to the southern African situation in monetary terms complicate the analyses. The environmental and sustainability costs associated with the prolonged use of a non-renewable resource are also difficult to evaluate. A further problem often encountered is quantifying the percentage of the vehicle operating cost savings which the client authority can be reasonably expected to offset in increased road construction and maintenance costs.

Aspects such as the effects of stimulation of the economy in a region through improved access to the region should not be neglected in the overall planning of the road network in the region.

1.6 *Design of unsealed roads*

A number of factors need to be accounted for in the design of unsealed roads. Traditionally the primary concern with unsealed roads has been to provide a layer of selected material that will protect the underlying subgrade (in situ material) from deformation under traffic loading and provide a suitably safe and comfortable wearing course for the movement of vehicles with their passengers and goods. The road should be passable in both wet and dry weather and should not be excessively rough or dusty or require a high degree of maintenance.

A design method that provides for adequate cover to resist excessive subgrade deformation and yet will require minimal maintenance is presented.

1.7 *Construction of unsealed roads*

The provision of adequate good quality material for the wearing course will not ensure good performance of the road unless the construction is of high quality. It is essential to ensure that the subgrade preparation, material placement and compaction and drainage provision is carefully supervised and controlled. Guidelines are provided in Section 0.

1.8 *Maintenance of unsealed roads*

Appropriate, timely and **high quality maintenance** of unsealed roads is necessary to ensure that unsealed roads continue to provide the required level of service to the road user. Any deficiency in the maintenance activities will result in deterioration in the road quality with consequent increased road user costs and significant future difficulties in restoring the correct shape and quality to the surface.

Maintenance techniques are discussed broadly, with little operational detail, which is available from other documentation (Larcombe, 1999; Skorseth & Selim, 2005).

1.9 *Management of unsealed roads*

Since the rapid increase in computing power and availability in the middle to late 1980s, the application of computer based road management systems has advanced considerably. It is now common-place for almost everyone involved in road design and maintenance to have access to sophisticated processing power, which has allowed the widespread use of various information systems pertaining to roads. Improved management of aspects such as road inventories, condition, maintenance needs and inputs, material resources, etc is discussed in the document.

There is no doubt that unsealed roads are a compromise between requirements and resources and as such **provide a service between having no road and having an all-weather sealed road**. On this basis, it should be noted that safety will always be affected more than on sealed roads, although drivers are expected to adapt to the conditions. In addition, road user costs will always be higher than on equivalent sealed roads.

1.10 *Companion documents*

This TRH document should be considered in conjunction with a number of other documents. These include:

TMH 1 Standard methods for testing road construction materials (1st edition) (NITRR, 1979)
TMH 1 Standard methods for testing road construction materials (2nd Edition) (NITRR, 1986)
TRH 5 Statistical concepts of quality assurance and their application in road construction (NITRR, 1977)
TRH 14 Guidelines for road construction materials (NITRR, 1985)
TMH 5 Sampling methods for road construction materials (NITRR, 1981)
TMH 12 Pavement Management Systems: Standard visual assessment manual for unsealed roads (Jones and Paige-Green, 2000)
Standard Specifications for Road and Bridge Works for State Road Authorities (COLTO, 1998)

A number of these documents are currently undergoing or are likely to undergo updating and revision, and the latest version should always be referred to.

2 PERFORMANCE OF UNSEALED ROADS

Unsealed roads react to the traffic and environment (usually negatively) far more than sealed roads in both rate and degree. **They thus perform differently and are prone to the development of characteristic problems in the short term, differing from those affecting sealed roads. These problems include dustiness, potholes, stoniness, corrugation, rutting, cracking, ravelling erosion, loss of shape/profile, slipperiness, impassability, loss of gravel and excessive loose material and have a major influence on the performance, maintenance requirements and costs of operating unsealed roads**.

Deficiencies in the performance of unsealed roads can be classified as either structural or functional problems. Structural problems relate to the inability of the pavement structure to support the traffic under the prevailing environmental conditions and occur within the wearing course or support layers. Functional problems are essentially surface defects arising from poor material selection (eg, excessive stones), poor construction methods and traffic or weather conditions.

Descriptions of the typical problems with their respective causes and practical means of reducing their effect on the road authority and user follow. Although the distinction between structural and functional defects is usually obvious, a number of overlapping factors can contribute to the primary problem. For example, although many potholes develop as a result of inadequate support (structural) or material quality, poor maintenance and drainage can also contribute to their formation. In the following sections, the defects are classified under the predominant type of problem. Poor drainage can also result in both structural and functional problems.

The influences of environment and traffic are also discussed.

2.1 *Structural defects*

2.1.1 Impassability (trafficability)

The primary objective of importing gravel as a wearing course during the construction of an unsealed road is to provide an all-weather surface. This objective is not met if the material becomes impassable in wet weather. This is often a particular problem with earth roads where the in situ materials **(usually with low bearing capacity and shear strength**) are used. Impassability can be defined in two ways:

The failure of a vehicle to proceed in the horizontal direction (impassability) can be caused by a loss of traction at the surface (slipperiness) or at depth (shearing). The former may even relate to fairly flat grades but is usually related to steep grades, while the shearing of material at depth is the result of insufficient strength in the load-bearing material.

It is generally considered that an adequately high material strength (in terms of the California Bearing Ratio (CBR)) will provide a trafficable surface under all conditions. Values for the CBR recommended in international specifications vary from a soaked value of 15% at 95% Proctor compaction up to a value of 60% at 98% Mod AASHTO compaction (Netterberg and Paige-Green, 1988). Very little evidence of failure of unsealed road wearing courses caused by inadequate material strength at depth has been observed in southern Africa.

Passability is, however, a function of the shear strength in the top layer of the wearing course. As with erosion, if the tractive stresses exerted by the rotating wheels exceed the shear strength (or cohesion) of the material at the surface, shearing will result and the vehicle will fail to proceed normally. Repeated shearing will result in churning of clayey materials and the road becoming impassable in that area. Sandy materials on the other hand can have high bearing strengths but low shear strengths/cohesion resulting in a rapid loss of traction of vehicles. The accumulation of water in potholes, however, is frequently accompanied by churning of the material in the area around the pothole and enlargement of this area.

Local research and experience have indicated that **a soaked CBR of 15% at 95% Mod AASHTO compaction is sufficient to prevent the road becoming excessively churned up** unless the surface drainage of the road is very poor and excessive ponding of water results (Paige-Green and

Bam, 1992). Sufficient coarse gravel in the upper layers assists with the interlock of the material and provides strength to resist churning. It must, however, be remembered that the gravel coarser than 19 mm is usually excluded from the laboratory CBR test (NITRR, 1986) and the result obtained is therefore often not a true reflection of the actual in situ material strength.

2.1.2 Potholes

Potholes play a significant role in the development of roughness on unsealed roads and could cause substantial damage to vehicles if they are allowed to develop and increase in size. The effect of potholes on vehicles depends both on the depth and diameter of the pothole. The potholes which affect vehicles most are between 250 and 1 500 mm in diameter with a depth of more than 50 to 75 mm.

Potholes may arise from the following processes:

- Deformation of weak subgrades and wearing courses;
- Poor road shape and drainage;
- Plucking of oversize material by the grader;
- Compaction of material behind oversize stones under wheel loads;
- Enlargement of corrugation troughs;
- Subsidence of animal and insect burrows;
- Disintegration of highly cracked roads (i.e. excessive plasticity);
- Disintegration of soft oversize material;
- Dispersive soils (Paige-Green, 2008);
- Poor compaction, and
- Material and moisture variability.

Once the formation of potholes has been initiated (irrespective of the cause), the drainage deteriorates, water ponds in the depressions and the potholes are enlarged by traffic. The enlargement occurs through both compaction of the weakened material (in the soaked state) and removal of the material from the hole by wheels and splashing. **Materials with a low soaked strength are thus likely to develop larger and deeper potholes in shorter periods. The influence of drainage on pothole formation is clearly manifested by the general absence or reduction of potholes on grades. Potholes are usually worst at the bottom of vertical curves in the alignment, on level road sections with poor cambers and near bridges and culverts**.

Potholes present significant repair problems, very few being successfully repaired by routine grader maintenance or by manual filling behind the grader. The only way to successfully repair potholes is by enlarging and deepening the hole with vertical sides, filling it with moist gravel (ie, at about OMC) and then compacting it (in layers if necessary). Many potholes have been recorded in the same location for periods in excess of two years, gradually becoming wider and deeper despite routine grader maintenance. Where pothole-susceptible materials are common, it may be necessary to have maintenance teams that are trained and have time dedicated specifically for effective pothole patching.

2.1.3 Ruts

Ruts are parallel depressions of the surface in the wheel tracks. They may form by deformation (compaction) of the subgrade, compaction of the wearing course or by the loss of gravel by abrasion of tyres from the wearing course, the latter being the most common on most gravel roads that have been designed and constructed properly. The rut depth has traditionally been the criterion for failure of unsealed roads (Visser, 1981; Skorseth and Selim, 2005) but under local conditions rutting is usually insignificant in terms of the overall unsealed road performance. The probable reason for this is the typically strong, free-draining, sandy subgrades prevalent over much of southern Africa as well as the deep water tables that mostly occur locally.

Deep ruts pose potential problems as they tend to retain rain water which softens the wearing course and allows additional deformation under traffic. Routine blading of unsealed roads replaces the gravel lost from the ruts and simultaneously compensates for any subgrade deformation that may have occurred. However, after grading, no definite wheel tracks are usually visible and new ruts often begin to form in slightly different positions from the previous ones. This results in an ongoing recovery or repair process. It is often necessary to compact the gravel in a moist state in order to ensure that ruts are effectively repaired.

The main cause of rutting in southern Africa is the ravelling of low-cohesion materials under traffic movement. A secondary cause is the deformation of highly cohesive wearing course materials under traffic during wet conditions. Both of these require a different gravel if the rut formation is such that maintenance becomes necessary too frequently or excessively costly.

Excessively wide roads lead to the formation of definite ruts in both directions which tend to be deeper than those on roads of normal width. The probable reason is that no lateral movement of vehicles is necessary when they pass from opposite directions and all the vehicles travelling in each direction thus consistently travel in the clearly demarcated ruts.

2.2 *Functional defects*

A variety of functional defects can affect the serviceability of unsealed roads. These are discussed individually below. It should be noted, however, that many of these functional defects can be exacerbated by poor construction and/or maintenance techniques.

2.2.1 Stoniness

Stoniness is the relative percentage of material in the road which is larger than a recommended maximum size (usually 37.5 mm). Excessively stony roads result in the following problems:

- Unnecessarily rough roads;
- Difficulty with grader maintenance;
- Poor compaction of areas adjacent to stones (leading to potholes and ravelling);
- The development of corrugations;
- The presence of oversize material (loose stones) on the surface after blading, and
- Thick loose material is necessary to cover the stones effectively.

This is one of the few defects of unsealed roads that can be controlled. Oversized stones can be removed or reduced in size through processing described in Section 2.14. It should also be noted that stones can be embedded in the wearing course (affecting maintenance and riding quality) or loose on the surface of the road (affecting safety and vehicle damage) (Figures 1 & 2). Although the loose stones are usually derived from the embedded stones, these two types of stoniness should be differentiated during visual pavement assessment (section 3.1).

Figure 1 *Embedded stones in wearing course surface (some loose stones on surface)*

Figure 2 Loose stones on wearing course surface

Many geological materials, particularly shale and hornfels, produce flaky or sharp stones under crushing or grid rolling. These can cause extensive damage to tyres and affect the safety of the road significantly. Consequently, use of materials exhibiting these characteristics should be avoided where possible. It may, however, be possible to crush such materials to obtain better shaped aggregate using appropriate crushing equipment (eg, mobile vertical shaft impactors).

2.2.2 Dustiness

Dust is the fine material released from the road surface under the wheels of moving vehicles. Silt-sized particles (5 - 75 ìm) are the predominant elements in dust and the quantity of dust generated by a vehicle is a function of a number of factors including the aerodynamic shape and travel speed of the vehicle and the surfacing material properties. The moisture content of the material plays a significant part in dustiness, the worst conditions prevailing when the road is dry and no dust being generated when the road is wet. This is an important aspect to be recorded when assessing the dustiness of a road.

Dust is undesirable from a number of points of view:

Safety
Dust affects the visibility significantly and can result in highly unsafe following and passing conditions during busy traffic conditions.

Comfort
Excessive dust can result in significant discomfort to drivers and passengers, especially in the hotter areas of southern Africa where it is impractical to drive with the vehicles’ windows closed.

Health
Although local evidence of the detrimental effects of dust on the health of road users is circumstantial, the problem has been investigated in the United States. Certain materials such as asbestos and silica dust which may occur in some wearing course gravels can certainly be considered undesirable from the health viewpoint. Dust generated by vehicles can equally affect the health of communities living adjacent to the unsealed road.

Vehicle damage
Dust can significantly increase the rate of wear of moving parts of vehicles and necessitate more frequent replacement of air and lubricant filters.

Vegetation and animals

The effects of dust on roadside vegetation, crops and farm animals is difficult to estimate, but is considered to be significant in certain areas, especially where intensive agriculture or stock and game farms occur. The settlement of dust generated from roads in fruit farming areas on the young fruit increases the risk of insect infestation of the fruit and can lead to significant economic losses. Reports of excessive wear of sheep's teeth as a result of dust on sparse vegetation in the area have been recorded.

Environmental
Excessive dust generation results in air pollution, this being particularly prevalent in deep valleys during winter. Temperature inversions result in thick blankets of dust remaining suspended in the air.

Economic
The loss of wearing course material in the form of dust results in a change in the properties of the wearing course gravel and the need to replace the material prematurely. Materials which initially had adequate plasticity may start forming corrugations as the fines are blown away necessitating more frequent regravelling.

Dust is generally considered unacceptable by the travelling public when it is such that vehicles are totally obscured behind a moving vehicle or after passing a vehicle from the other direction.

The potential dustiness of a material can be predicted relatively accurately from the silt and clay component of the soil (i.e. percentage passing 6 µm) (Jones, 2001). Although the material properties are the major characteristics affecting dustiness, aspects such as the vehicle mix and speeds, the moisture content of the road, maintenance frequency and wind, however, all affect the apparent dustiness.

In many cases it may be beneficial to apply dust palliatives to unsealed roads in order to bind the dust particles together. This is discussed later in the document (Section 6.2).

2.2.3 Corrugations

Corrugations are one of the most disturbing defects of unsealed roads causing excessive roughness and poor vehicle directional stability. Their cause has been debated for decades but consensus seems to have been reached on the "forced oscillation theory" (Figure 3 after Heath and Robinson, 1980) as the predominant mechanism. More recent research in South Africa has produced evidence to support this (Paige-Green, 1990). The theory is based on initiation of wheel bounce by some irregularity in the road (or possibly even worn suspension components such as shock-absorbers). The process results in kick-back of non-cohesive material and compression and redistribution of the wearing course as the wheel regains contact with the road.

Corrugations can be either "loose" or "fixed" (Figures 4 & 5). Loose corrugations consist of parallel crests of loose fine-sandy material at right angles to the direction of travel. Fixed corrugations on the other hand consist of compacted, parallel crests of hard, fine-sandy material. The troughs are compacted by the force of the wheel regaining contact with the ground. **Loose corrugations are easily removed by blading, whereas fixed corrugations need cutting or even light ripping (using the tines) with the grader before the material is spread again**. The wavelength of the corrugations is dependent on the modal speed (ie most frequently occurring speed) of the vehicles using the road, with longer wavelengths formed by faster traffic. Numerous observations from all over southern Africa indicate that the wavelength of the corrugations in centimetres is approximately numerically equal to the modal speed of the vehicles using the road in km/h.

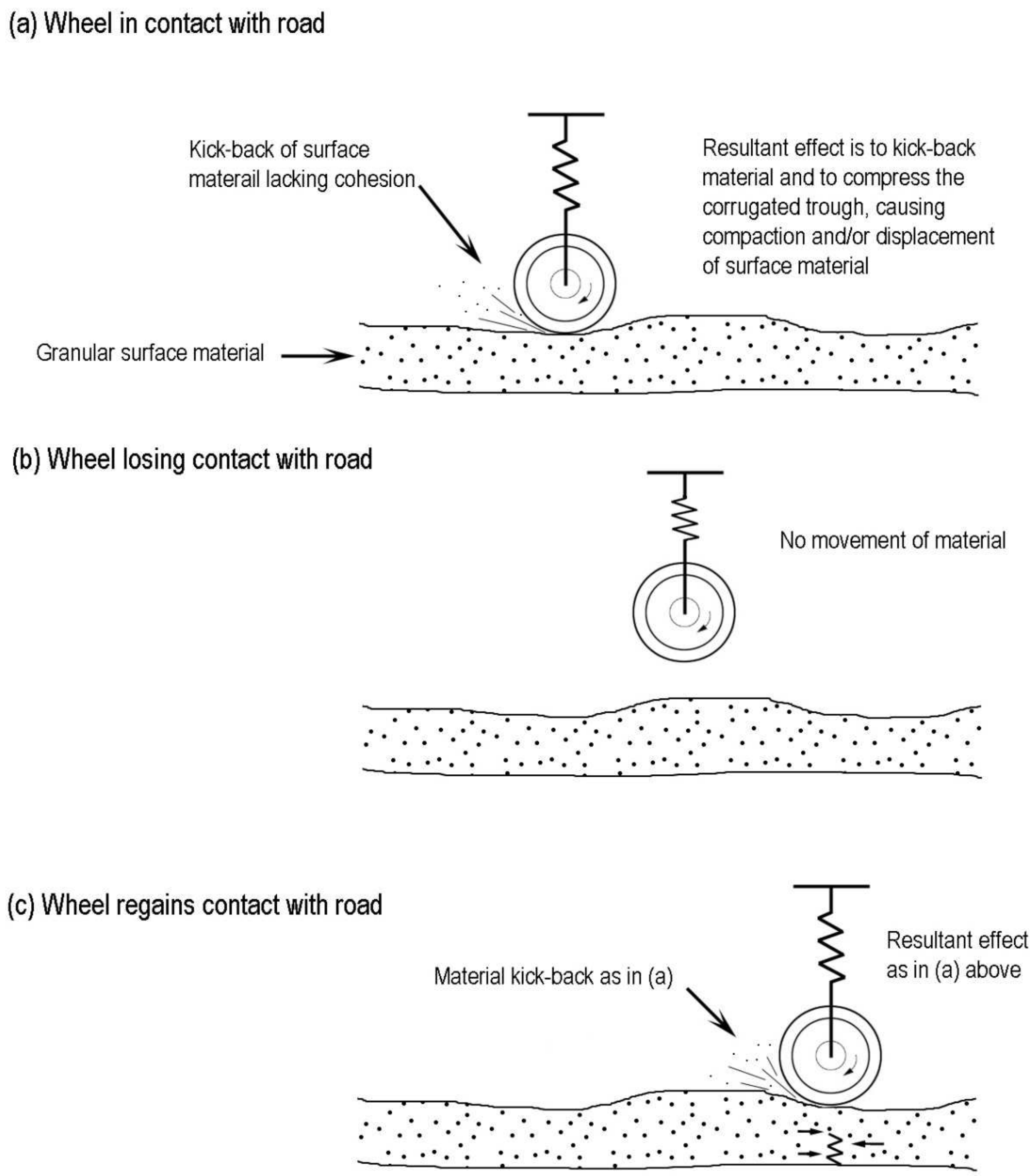


Figure 3 Forced oscillation theory for the formation of corrugations

Figure 4 Typical example of loose corrugations

Figure 5 Typical example of fixed corrugations

Only fine-grained, low plasticity materials corrugate significantly. However, many roads with gravels having plasticity indices of up to 9% have produced corrugations. These form when the material is repeatedly spread during grader blading maintenance from windrows and the sides of the road back onto the road. The resulting material is usually deficient in binder (most of it having been blown away with time as dust or lost in the continual working of the material) and the material forming the corrugations has a low plasticity or is non-plastic.

Corrugations seldom form to any significant extent during the wet season, as the material is slightly "cohesive" in its wet state through capillary suction and is not adequately mobile to form corrugations. Roads which have very low modal speeds (less than 20 km/h) such as mine or forestry haul roads do not usually corrugate.

Regular maintenance of roads susceptible to the formation of corrugations is necessary to avoid the loose corrugations becoming fixed. On many sandy roads, regular grader blading (perhaps as often as once a week) is not economically viable but simple towed drags are suitable for the removal of corrugations. These can be towed behind an ordinary light vehicle (or even a draught animal if necessary) to retain the road roughness at acceptable levels. The sand-cushioning technique (Jones, 1998) makes use of this principle and is described further in section 2.19.

Long wavelength (2.5 to 3.0 metres), fixed corrugations at an angle of 45° to the direction of traffic are found on some roads. These are caused by the grader operation (excessive bouncing and/or excessive speed) and once formed are not easily removed by normal grading. The best way to remove them is by rotating the grader blade through 90° or extending the blade from the side of the grader and keeping the grader on the shoulder or an uncorrugated portion of the road.

2.2.4 Cracks

Cracks *per se* are not a major problem on unsealed roads but bad cracking may lead to the formation of potholes. **Cracking of the wearing course (which usually occurs only during the dry season) is the result of volume changes (shrinkage) due to the plasticity being too high or the material being very fine grained (eg, dolomitic wad). Those materials that show significant cracking tend also to become slippery when wet and could be avoided by following the material selection guidelines in section 2.9**.

Certain highly cracked roads resulting in “blocks” of 100 to 150 mm dimension have been found to break up under traffic during the dry season and form potholes.

2.2.5 Ravelling

The generation of loose gravel by ravelling under traffic is a significant economic, safety and maintenance problem. Loose gravel may be distributed over the full width of the road but more frequently is concentrated in windrows between wheel tracks or alongside the travelled portion of the road. The major problems with roads susceptible to ravelling are:

- The windrows are a safety hazard;
- Loose stones from the gravel or windrows may damage vehicles or windscreens, and
- The rolling resistance of vehicles (ie, the frictional retardation of forward movement) is increased by loose material with concomitant increases in fuel consumption and vehicle operating costs.

Ravelling is mainly caused by a deficiency of fine material (and hence cohesion), a poor particle size distribution (e.g. gap or skip grading) in the wearing course gravel and inadequate compaction. Materials with a grading coefficient (G_c) in excess of 34 and/or a shrinkage product (S_p) of less than 100 are particularly prone to ravelling. **Ravelling is generally worse in the dry season than it is in the wet season when capillary suction results in an effective "cohesion"**.

Fine material can be blended with the gravel to increase cohesion and this has been used successfully and economically. A good degree of compaction at a suitable moisture content (OMC) can also be used to reduce ravelling.

2.2.6 Erosion

Erosion (or scour) is the loss of surfacing material caused by the flow of water over the road. The ability of a material to avoid erosion depends on the shear strength (equal to the cohesion as the normal stress is zero) in the condition at which the water flow occurs. If the shear strength of the material is less than the tractive forces induced by the water flowing over the material, grains will become detached and erosion will occur. **Finer grained and poorly graded materials with minimal coarse aggregate (grading coefficient less than 16) are particularly susceptible to erosion**.

The result of erosion is runnels (run-off channels) which, when occurring transversely, result in extreme roughness and dangerous conditions and when occurring longitudinally (on grades) form deep "ruts". **Associated with this problem is the significant loss of gravel which is eroded from the road surface.** Much of this gravel is deposited in drains and culverts necessitating extensive manual maintenance.

Erosion can be prevented by:

- increasing the shear strength of the wearing course material, or
- decreasing the shear stresses induced by the flow of water.

The shear strength of the material can be increased by improving the grading of the material and ensuring a well-graded mixture with adequate gravel up to 26.5 mm in size. Good compaction (at OMC) also increases the shear strength by improving the granular interlock, allowing suction forces to develop and decreasing the permeability of the material.

The shear stresses of the flowing water can be decreased by retarding the rate of flow of the water. This is best done by decreasing the grade and the camber or cross-fall and ensuring that the length of the flow path of the water is minimised. The camber/cross-fall should be greater than the longitudinal grade (up to a maximum of 5%) in order to remove the water to the side of the road and prevent it from flowing down the full length of the grade and building up speed (and shear stress). Erosion can be expected on most roads with grades or cambers greater than about 5% unless precautions are taken.

Erosion of the wearing course can result in a change of the properties of the wearing course material as various fractions of the material can be selectively removed as water flows over the material.

Careful attention to the drainage of water from the road will minimise the potential for erosion.

2.2.7 Shape

Poor cross sectional shape of the road usually results in bad drainage which accelerates the formation of potholes and ruts as well as erosion. **Routine maintenance of unsealed roads should be carried**

out timeously with a major objective of retaining the crown of the road and ensuring adequate camber/cross-fall and thus road drainage. Excessive deterioration of the road prior to maintenance results in difficulty in restoring the desired shape.

On vertical grades, the development of ruts can be a major problem as they form drainage channels during storms and erode rapidly. Special attention must thus be paid to elimination of ruts on grades during maintenance.

2.2.8 Slipperiness

Slipperiness of the surface of an unsealed road can be a significant safety problem. In wet weather, slipperiness is caused by the migration of fine or plastic clayey materials in the wearing course to the surface under the impact of rain as well as through “pumping” by tyres. Even materials with adequate coarse aggregate may become slippery if the fine silt and clay fractions become concentrated at the road surface. This is a natural phenomenon under applied pressures, where on gravel roads the elastic effect of tyres together with excess pore water pressures generated under the loaded tyres results in “pumping” of the fines to the surface when the road is wet. It should, however, be noted that at appropriate vehicle speeds, the extremely weak clay/water mixture would shear under tyre load, allowing the tyres to interact with the stronger and less slippery aggregate/matrix layer at the top of the wearing course.

This wet clay material on the surface could have a similar effect to aquaplaning of tyres on sealed roads, resulting in a thin layer of clay/water forming between the tyre and the aggregate in the road surface. Like aquaplaning, this is essentially a problem of excessive speed.

Special care should be taken with the use of certain mudrocks (Venter, 1989) which are susceptible to slaking on exposure to the atmosphere. An initial granular material can soon become a fine clayey mud.

In dry weather, unsealed roads may become slippery if an excess of loose, fine material (usually between 0.85 and 2 mm in diameter (Lea and Jones, 2007)) accumulates on the road surface. This layer behaves like a layer of ball bearings and the skid-resistance is significantly reduced. This is especially a problem on sharp corners. The material used in proper "sand-cushions" (section 2.19) is generally unlikely to lead to significant dry-weather slipperiness as it is too thick and results in a ploughing type of slipperiness (Lea and Jones, 2007).

Materials with a shrinkage product (S_p) of greater than 365 tend to be slippery at speeds in excess of 50 km/h under wet conditions.

The only cure for excessively slippery roads is to replace the high plasticity material with better gravel (i.e. having a lower shrinkage product) and for those which are slippery when dry, to increase the coarse material and binder content as well as the grader blading operation. The practice of adding a gravel or sand to high plasticity material is recommended in some manuals but this only partly avoids the possibility of the fine material migrating or pumping to the surface. A significant quantity of gravel is usually required to reduce the percentage passing the 0.075 mm sieve sufficiently to affect the shrinkage product.

Unlike many sealed roads, all unsealed roads can be expected to increase in slipperiness when wet. It is not usually necessary to indicate this with warning signs, unless a conscious decision has been made to use excessively slippery materials (ie, those with a shrinkage product higher than 365) in very arid areas (a practice in arid areas with low traffic and only very occasional rainfall), in which case appropriate warning signs should be provided.

2.2.9 Gravel loss

The loss of the wearing course material from the road surface under traffic and climatic conditions (rain and wind) is inevitable and the replacement of this lost material is the most costly maintenance operation. The rate of gravel loss is related to the traffic, precipitation and materials properties and material prone to excessive ravelling is that most likely to result in a high gravel loss.

Although the major contributor to the gravel loss is the traffic, significant reductions in gravel loss can be obtained by selecting material with high plastic factors and percentages passing the 26.5 mm sieve (Section 2.8). Well-graded gravels resist gravel loss better than materials deficient in either fine or coarse fractions. A high degree of compaction at OMC also reduces

gravel loss. Road sections designed and constructed in the Western Cape (Van Zyl et al, 2005; 2007) fully in accordance with recommendations provided in TRH20 (1990) indicate a reduction of approximately 50% in the rate of gravel loss as predicted by both the existing TRH20 and HDM4 performance models.

2.2.10 Excessive loose material

Excessive loose material over the road surface which has resulted from poor compaction or has been generated by ravelling or poor grader blading can result in unsafe conditions and increased road user costs. Selection of better materials and an improved grader blading technique is necessary to avoid this condition.

2.3 *Traffic*

Unsealed roads are directly influenced to a far greater extent than sealed roads by the direct forces of wheels on the road. High shear stresses are generated by vehicles, these increasing with the mass and power of the vehicles using the road. High shear stresses are also generated under acceleration, braking and cornering by most vehicles.

It has been found during the investigation of the performance of typical South African rural gravel roads that no general significant differences in the modelling of gravel loss and riding quality deterioration were found by splitting the traffic into light and heavy vehicles. This was despite monitoring of sections of road on a range of horizontal curve radii and vertical grades. Subsequent observations have indicated that unloaded heavy vehicles (particularly with trailers) travelling at high speeds can cause a rapid deterioration of unsealed roads under dry conditions.

It should be noted that if the pavement structure can carry the load, then only the performance of the wearing course is relevant. However, rapid deterioration has been observed on certain mine and quarry haul roads carrying predominantly slow-moving, heavy vehicles.

2.4 *Environment*

The structural materials in sealed roads are to a large degree protected from the direct influence of environmental effects (particularly rainfall) by the application of an essentially impermeable surfacing. The structural layers of unsealed roads, however, are directly exposed to environmental forces (moisture, heat, rain impact, wind, etc), which can have a rapid effect on their performance. The application of good construction processes, however, can minimise some of these influences.

2.5 *Geometric design*

3.1.1 Background

The geometric design of unsealed roads is not considered in great detail in this recommendation. It should, however, be borne in mind that the primary difference between the surface characteristics of sealed and unsealed roads are the natural and weather-related variability in the latter as well as differences in the frictional properties. Few guidelines on geometric standards for unsealed roads (specifically in developing areas) exist and, taking into consideration the earlier statements, conventional geometric design standards are generally applied. Additional details are available elsewhere (DOT, 1989; ARRB, 2000; AASHTO, 2002).

One of the principal factors affecting the geometric design of roads is the design speed of the road. In South Africa, a general speed limit of 100 km/h applies to all public roads outside urban areas (additional restrictions exist for certain classes of vehicles) unless otherwise prescribed (National Road Traffic Regulations of 1997). No specific details differentiating between sealed and unsealed roads exist, implying that unsealed roads are subjected to the same requirements. Conventionally, the design speed of a road is based on the 85th percentile speed of that road (or a similar road in the area). On the basis of the legal speed limit and the 85th percentile speed, the design speed of all rural unpaved roads would probably be between 80 and 100 km/h, which is often impracticable in rural areas.

Unless the road is likely to be sealed in the foreseeable future, the road alignment should be adapted to the prevailing conditions as far as possible. A different philosophy should be applied to roads opening up areas and those which are likely to be forerunners of paved roads (based on relatively high traffic volumes and/or high expected growth rates). It is not usually economically feasible to construct deep cuts, high fills or large radius horizontal curves in mountainous areas in order to accommodate traditional geometric standards. Economic constraints usually dictate that the geometric standards need to be compromised (with speed restrictions or warning signs where necessary). Where possible, construction along watersheds is suggested, although the potential negative impacts of roads in these areas on the environment should first be assessed.

The width and alignment of unsealed roads should generally be appropriate to the prevailing traffic, climatic and topography and geometric standards for unsealed roads should be flexible enough to provide for this. **Care should, however, be taken to create a speed environment with matching geometric elements that eliminate the element of surprise and avoid unsafe conditions to which driver awareness is not sensitive**.

It is important that unsealed roads are constructed in the middle of the road reserve as far as possible. Problems have been encountered where existing roads are at the edge of the road reserve and the improvement of, for example, horizontal curves during upgrading is difficult to fit resulting in the necessity to move the original alignment.

Aspects such as the reduced friction of gravel wearing surfaces against conventional sealed surfaces on horizontal and vertical curves, longer stopping distances and flatter superelevations to minimise surface erosion need all be considered. Other factors such as dust would also affect sight distances compared with conventional sealed roads. **It has been suggested (ARRB, 2000) that to allow for "often poor and changing conditions with low surface friction values" associated with unsealed roads, higher geometric standards on horizontal and vertical curves and stopping sight distances should be provided.**

It should also be noted that the adoption of good geometric design principles can also improve the performance of the gravel wearing course. Good cambers, superelevation, grades and radii of curvature reduce the applied vehicle and environmental stresses on the road, which can reduce surface deterioration and gravel loss.

Taking cognisance of the above, the following sections provide some guidelines regarding suggested minimum standards on proclaimed gravel roads. Compatibility of the geometric design with the required Level of Serviceability for different road classes is essential (see Section 3.2). Additional information can be found in "Guidelines for upgrading of low volume roads (DOT, 1993).

3.1.2 Design speed and alignment

Except for mountain passes, the design speed for a particular road section should be constant for a minimum length of 4 km. The recommended minimum design speed for Class 4 roads is 60 km/h. Due to the existing proclaimed road reserves and alignments that follow the topography, the improvement of many unsurfaced roads to achieve the recommended design speed is not possible without major expense.

Current suggested guidelines for improvement of the horizontal and vertical alignment can be obtained from the AASHTO Guidelines for geometric design of very low-volume local roads (AASHTO, 2002). An example of the minimum recommended horizontal radii from AASHTO (2002) is provided in **Table** 2).

Table 2 Minimum recommended radii of horizontal curvature without super elevation

Material type		Gravel compacted (Dry)						
		Gravel compacted (Wet)						
			Gravel loose (Dry)					
			Gravel loose (Wet)					
				Earth (Dry)				
					Earth (Wet)			
							Clay (Wet)	
Design Speed (km/h)	Traction coefficient	0.8	0.7	0.6	0.5	0.4	0.3	0.2
20	Minimum Radius (m)		15	15	15	20	35	
30			15	20	25	40	75	
40			30	35	45	65	130	
50			40	50	70	100	200	
60			60	75	95	145	285	
70			80	100	130	195	385	

Note: Super elevation on curves is required (maximum 5%) for design speeds in excess of 70 km/h.

Curve radii could be reduced when super elevation is provided. When calculating the minimum radius the following equation could be used, accepting the maximum side friction factor (f_{max}) as being the traction factor provided in Table 2 minus 0.2 and the maximum rate of superelevation (e_{max}) permitted as 5%.

$$R_{min} = \frac{V^2}{127(0.01e_{max} + f_{max})}$$

Where

R_{min} = minimum curve radius (m)

e_{max} = maximum rate of superelevation permitted by road authority

f_{max} = maximum side friction factor

3.1.3 Cross-section

A typical recommended cross-section for unsurfaced Provincial roads, carrying less than 200 vehicles per day, is shown in Figure 6, which is applicable to road reserve widths of 20 m or more. However, numerous unsurfaced proclaimed roads, especially Minor roads, have reserve widths of less than 15 m, resulting in non-adherence to the recommended cross-sectional detail.

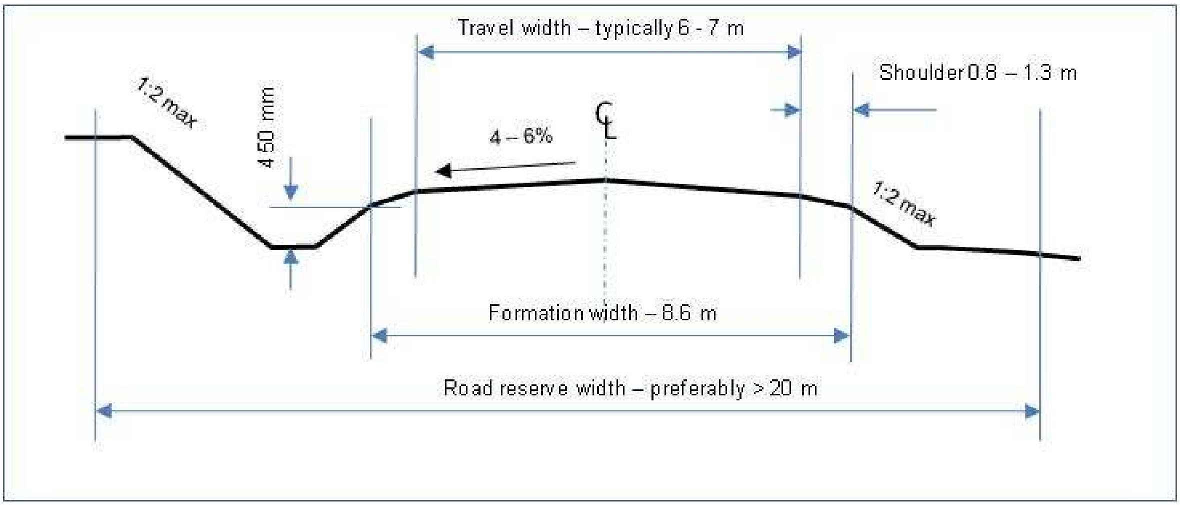


Figure 6 Typical cross section detail applied on Provincial gravel roads

3.1.4 Road width

A significant problem in southern Africa is the occasional construction of unnecessarily wide unsealed roads (roads with travelled ways of up to 10 m and with up to 14 m between shoulder breakpoints have been recorded). This results in excessive surfacing gravel and grader maintenance being required and a rapid loss of shape of the road. On the other hand, excessively narrow roads result in deep rutting, poor safety standards and high gravel losses.

The majority of road widths on proclaimed formed roads in South Africa typically vary from 4 to 9 m. The road width is often governed by the number of grader passes required for blading (equal number to maintain a crown e.g., 2 or 4, resulting in 4.0 to 5.0 m or 6.0 to 8.0 m road widths).

Experience elsewhere (ARRB, 2000) indicates that the following unsurfaced road widths are considered safe and appropriate:

- 6.0 m for roads carrying less than 50 vpd
- 7.5 m for roads carrying between 50 and 200 vpd
- 8.6 m for roads carrying more than 200 vpd or those carrying large vehicles.

Experience in some provincial road authorities suggests slightly different appropriate widths based on road reserve widths, topography, traffic and potential upgrading strategies. Table 3 serves as a guideline.

Table 3 Minimum recommended road widths

<table>
<tr><th>Terrain</th><th>Existing traffic (vpd)</th><th>Minor roads and tracks</th><th>Formed minor roads</th><th>Divisional roads</th><th>Main roads</th><th>Trunk roads</th></tr>
<tr><td rowspan="4">Flat and rolling</td><td>< 20</td><td>3 m
(Note 1)</td><td>4 m
(Note 1)</td><td rowspan="2">6 m</td><td rowspan="2">6 m</td><td rowspan="4">8,6 m</td></tr>
<tr><td>20 – 50</td><td>5 m</td><td>5 m</td></tr>
<tr><td>50 – 200</td><td></td><td>6 m</td><td>7 m</td><td>7 m</td></tr>
<tr><td>> 200</td><td></td><td>6 m</td><td>8.6 m</td><td>8.6 m</td></tr>
</table>

Mountainous		4 m (Note 2)	4 m (Note 2)	5 m (Note 2)	6 m (Note 2)	7 m (Note 2)
Surfacing			Formation 8.6 m Surface 6.8 m	Formation 8.6 m Surface 6.8 m	Formation 8.6 m Surface 6.8 m	Formation 8.6 m Surface 6.8 m
Notes 1 Clearances (turnouts) to be provided at regular intervals to allow vehicles to pass. Widening at crests should be considered. 2 Each situation should be assessed for selection of an appropriate solution						

3.1.5 Crossfall

Typical recommendations for crossfall and camber on unsurfaced roads vary between 3% on narrow slippery roads and 5% on straight sections with a minimum width of 6 m. However, experience indicates that 1% of the crossfall is lost soon after construction. Therefore, it is recommended that the **initial** crossfall during construction be specified as 4 to 6%, depending on the terrain. In wet areas, the crossfall during service of the road should not exceed 4% in order to minimise the risk of vehicles sliding off the road.

Note:
Several road authorities suggest that unsurfaced roads should be maintained at 4% crossfall.

3.1.6 Superelevation

Camber at curves can be designed for the operating speed. However, experience and several publications recommend a maximum of 5% in order to reduce erosion damage.

The development length of the superelevation is a function of the design speed, the crossfall and the maximum superelevation.

Typical development lengths from -5% crossfall to 5% superelevation are shown in Table XXX for different design speeds

Table 4 Development length for -5% crossfall to 5% superelevation

Design Speed (km/h)	20	30	40	50	70	80	90	100
Development length	15	25	30	40	50	55	90	100

Note;
Two thirds (66%) of the maximum superelevation should occur before the tangent point of the curve

2.6 *Cross drainage*

3.2.1 General

Cross drains must be provided to facilitate the natural flow of water across the surrounding topography. The road formation should not act as a dam under any circumstances, nor should water flow across the road, unless:

- A low level structure is provided,
- Flood design periods are in excess of 10 years,
- Causeways or low lying areas allow easy repair and accessibility can be achieved using other routes, or
- Downstream protection walls are installed.

3.2.2 Low level structures, concrete drifts and cut-off walls

Several road authorities in southern Africa allow low level structures as shown in **Figure 7**. A typical approach for the design of such structures is to allow 90% of a twenty-year design flood to overtop.

More detail could be found in the research report **Guidelines for upgrading of low volume roads** (DEPARTMENT OF TRANSPORT, 1993)

Figure 8 provides the detail of concrete cut-off walls as constructed in Namibia.

Figure 7 Low-level structure

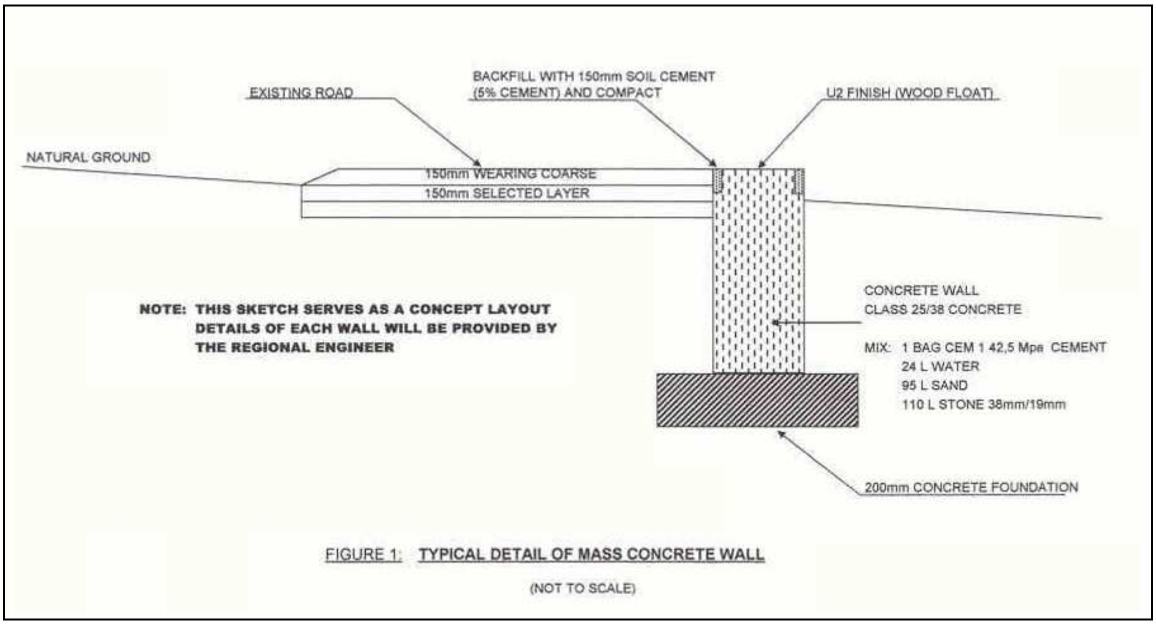


Figure 8 Cut-off wall

Note: The down-stream side of the cut-off wall is often protected with gabion matrasses.

3.2.3 Bridge structures

Bridge structures are expensive and require proper investigation and design. Practitioners are referred to SANRAL's Code of Procedure for the Planning and Design of Highway and Road Structures in South Africa (SANRAL, 2002).

3.2.4 Culverts

Type and minimum size

On unsurfaced roads, cross drains are usually concrete pipes or box culverts. 600 mm diameter pipes are preferred, but 450 mm diameter is the minimum size permitted although maintenance of such small diameter pipes can be difficult. The minimum box culvert size is 750 x 450 mm. Several pipes can be laid next to each other if flow volumes are high.

Placement
The flow of water through a culvert should be disrupted as little as possible and thus should align with the natural flow and have the same slope as the natural ground.

During periodic maintenance investigations, information should be obtained from local inhabitants regarding drainage problems, and each situation evaluated on its merits.

Slope and cover
A minimum fall of 2% and a minimum cover thickness of 300 mm (on pipe culverts) and 150 mm (on box culverts) are recommended, excluding the wearing course layer (refer also to supplier specifications). However, situations often occur where additional layers must be imported for cover, or extensive excavation is required to daylight side drains. Isolated cases could therefore be accepted where the minimum cover could be reduced and the minimum fall be reduced to 1.5%.

Head- and wing walls
Although some road authorities specify concrete head- and wing walls, good performance of masonry and stone-built structures have been reported. Dependent on the topography and material properties, head walls are often not provided on very low volume roads in southern Africa..

2.7 *Pavement thickness design*

3.3.1 Background

The purpose of the wearing course is to provide a maintainable surface, as skid-free, dust-free and impermeable to moisture as possible. Ideally a pavement should consist of a wearing course and the structural layer(s) which cover the in situ material.

The purpose of the structural layer(s) is to protect the in situ material from excessive deformation while not breaking or deforming within a specific design period. Most of the deformation observed in normal gravel roads in South Africa due to subgrade deformation is usually made good during grader maintenance or, in extreme cases, by spot regravelling. Unsealed roads constructed strictly to the specifications recommended in this document, however, will generally require considerably less maintenance and the rectification of such problems will thus not occur at the desired frequency. **It is therefore important when using highly processed materials to ensure that subgrade deformation is minimised**.

The appropriate initial thickness of the wearing course is dependent on the expected rate of gravel loss, the policy regarding minimum regravelling frequency, and a minimum "buffer" thickness to prevent deterioration of the in situ sub-grade or imported structural layer(s).

The appropriate thickness of the structural layer(s) is dependent on the strength of material to sufficiently reduce the stress on the in situ material. The strength is a function of the material properties, the density and the moisture content under which it operates.

Many areas in South Africa are blessed with excellent in situ road building materials, to the extent that the **existing materials, if properly compacted, could provide a strong enough pavement structure to carry the expected traffic for many years**. The benefit of strong in situ materials is that, provided the drainage is adequate for the situation, no additional structural layers might be required, even if application of a bituminous surfacing is considered as a feasible strategy.

Given the fact that a high proportion of unsurfaced roads carry a very low volume of traffic (80% probably carry less than 50 vpd), the in situ material is often both suitable as a wearing course and strong enough to carry the traffic load for at least ten years. In such cases, the road could be formed, shaped and compacted, using only material from within the road reserve. The entire pavement structure is therefore made up of the in situ material, where the upper part functions as a wearing course and structural layer(s).

3.3.2 Design approach

Several models have been developed and are used world-wide for determining the required gravel thickness to protect the subgrade. However, the majority of these do not take into consideration the volume and load characteristics of traffic.

Typical traffic volumes (average daily traffic - ADT) on gravel roads in South Africa range from less than 50 to more than 500 vpd, often with a heavy vehicle component of more than 20%. Therefore, although a simplified approach is useful and applicable to minor or very low volume roads, it is not considered sufficient in terms of a longer-term road maintenance strategy and phased upgrading.

The pavement structure should be able to carry the traffic load over the design life with a reasonable estimate of the risk of failure. The intention is that:

- Only the wearing course would need replacement at intervals related to the annual gravel loss, and
- Geometry and drainage are upgraded to acceptable minimum levels during periodic maintenance operations.

This approach ties in well with a strategy of phased upgrading to surfaced standard as traffic increases, in that:

- Optimum use could be made of historical traffic compaction,
- The quality of material on a higher-trafficked gravel road would be at least G7 (CBR ≥15% @ 93% Mod. AASHTO density),
- The in situ CBR strength of the subgrade or formation layers protecting the subgrade would be ≥15% at in situ density and moisture as measured with a DCP.

However, the backlog to provided reasonable access to communities in many areas of southern Africa is so big that shorter term solutions are often adopted. The strategy in many cases is to just to do bush clearing, provide minimal side drainage and forming of the road.

3.3.3 Recommended procedure

Moisture regime

The first important decision to optimise design is to estimate the worst moisture conditions that each layer in the pavement structure will be expected to perform under. **This could relate to the climate, local moisture conditions and the elevation of the road above natural ground level**.

In situ material classification

Test pits should be excavated to determine the existing pavement profile (to a depth of at least 500 mm in the case of lower traffic volume, unsurfaced roads) and quality of materials. This is usually done with a conventional centre-line survey (profiling and sampling at intervals of between 100 and 500 m depending on material variability) with road indicator testing (Atterberg limits, grading and CBR) of selected or combined samples.

Existing pavement strength

Measurements during or just after the wet season will normally reflect the worst expected conditions (highest moisture contents). Spacing of DCP measurements is dependent on the observed variation in condition and could be spaced from 25 to 500 m apart. The existing pavement strength should be used to determine uniform sections along the road length, such that a standard thickness design (pavement structure) can be applied to each uniform section.

Select appropriate pavement structure

- Calculate the design traffic (typically 7 - 10 years for unsurfaced roads, but depends on the potential upgrading strategy)
- Select an appropriate pavement structure from the catalogue (Table 5) and draw up a layer-strength diagram
- Plot the DCP layer-strength diagram on similar scale
- Adjust the DCP layer strength diagram (in situ CBR values) to reflect the expected moisture conditions under which each layer/part of the pavement structure will operate.

Table 5 Simplified design catalogue for gravel roads

Existing moisture condition	**In situ CBR from DCP (top 300 mm) (%)**				
Dry	< 15	16 – 25	26 – 45	46 – 80	> 80
Moist	< 10	11 – 15	16 – 25	26 – 45	> 45
Wet	< 5	6 – 10	11 – 15	16 – 25	> 25
Pavement class	**Additional structure required (depth in mm)**				
ES 0.003	WC, 200 G7	WC. 150 G7	WC, 100 G7	WC	WC
ES 0.01	WC, 250 G7	WC, 200 G7	WC, 150 G7	WC	WC
ES 0.03	WC, 275 G7	WC, 225 G7	WC, 175 G7	WC	WC
ES 0.1	WC, 150 G6, 150 G7	WC, 125 G6, 125 G7	WC, 100 G6, 100 G7	WC, 100 G6	WC
ES 0.3	WC, 150 G5, 150 G7	WC, 125 G5, 125 G7	WC, 100 G5, 100 G7	WC, 100 G5	WC

Notes
1. This catalogue is conservative and does not take into account the strength of the wearing course layer.
2. The use of low cohesion materials in the layer supporting the wearing course is risky and should only be considered if the road will be upgraded or regravelled before this layer is exposed to traffic.
3. Example 1: Testing a dry existing structure and obtaining say 20% in situ CBR would require, for ES 0.003 traffic category (3 000 80 kN axles), an additional 150 mm G7 material before placement of the wearing course.
4. Example 2: Testing a moist existing structure and obtaining say 30% in situ CBR would require, for ES 0.03 traffic category (30 000 80 kN axles), no additional layer before placing of the wearing course

Developments in the field of geosynthetics have led to their successful use in reinforcing unsealed roads over very weak subgrades (Holtz et al, 1998) and more importantly acting as separation layers between the in situ material and the imported wearing course. These are not discussed further in this report, but can be considered for very weak subgrades (CBR less than about 3 % or more than 47 mm per blow using a DCP). If they are used the wearing course should not be allowed to become less than 100 mm thick in order to provide some protection from wheel contact, grader maintenance, exposure to the atmosphere and ultra-violet radiation.

2.8 *Wearing course thickness design*

3.4.1 Approach

The recommended approach for determining the wearing course thickness is as follows:

- Decide on an appropriate regravelling frequency (typically 7 to 10 years)
- Calculate the estimated gravel loss over this period – (refer Section 3.4.2)
- Evaluate the sensitivity of the supporting material and typical maximum thickness of the wearing course material to obtain a buffer thickness (typically 25 – 50 mm)

The recommended wearing course thickness should at least equal to the expected gravel loss plus the selected buffer thickness.

The minimum compacted thickness recommended is 100 mm, while the maximum thickness recommended for placement in one layer is 200 mm. The compacted layer thickness should always, however, be more than 1.5 times the maximum particle size.

3.4.2 Predicted annual gravel loss

The annual gravel loss (AGL) of roads constructed according to the conventional method can be predicted with a reasonable degree of confidence (Paige-Green, 1989a) by the following model:

$$AGL = 3.65 \, [ADT \, (0.059 + 0.0027 \, N - 0.0006 \, P26) - 0.367 \, N - 0.0014 \, PF + 0.0474 \, P26]$$

where ADT = average daily traffic
N = Weinert N-value
P26 = Percentage passing the 26.5 mm sieve*
PF = product of plastic limit and percent passing 0.075 mm sieve*

* - all grading analyses to be normalised for 100% passing 37.5 mm.

This simple model can be easily used in a spreadsheet to calculate the expected gravel loss of any material under specified traffic and environmental conditions.

The product of the annual gravel loss and the design period will indicate the total material that will be lost by erosion and traffic abrasion and whip-off over the design life of the road.

It should be noted that gravel wearing courses that have been compacted with a nominal number of passes of a grid-roller can lose up to 30% of their constructed thickness within a short period due to traffic compaction (Paige-Green, 1989a). It is therefore essential that the imported wearing course material is compacted to as high a density as possible at the appropriate moisture content. If a density equivalent to that at about 95% Mod AASHTO effort is achieved, the air voids are about 5 per cent, but at a compaction moisture content 25% dry of optimum (i.e. at about 75% of optimum moisture content), the density is reduced by about 10% and the air voids may be up to 20%. These air voids will decrease rapidly under traffic, effectively reducing the thickness of the imported layer and producing significant ruts. It is thus best to ensure that the material is brought to optimum moisture content and the layer is compacted to refusal with the available plant, provided that the density is not less than 95% of the laboratory determined Mod AASHTO density according to method A7 (NITRR, 1985).

2.9 *Material selection*

Numerous specifications have been employed for the selection of materials for unsealed road wearing courses in southern Africa (Netterberg and Paige-Green, 1988). These have been compared with the performance of a number of in-service roads in southern Africa and found to be generally lacking in their ability to predict the performance of roads constructed with them (Paige-Green, 1989b). Many satisfactory materials are rejected by the specifications while many materials that perform poorly are accepted by them.

Performance-related specifications have been developed for southern African conditions based on the sampling, testing and monitoring of the performance of 110 sections of unsealed road over a period of more than three years (Paige-Green, 1989a). The role of material durability in unsealed roads was found to be unimportant during the investigation. However, mudrocks in certain areas may be subject to rapid disintegration and the potential for this should be evaluated using the 5-cycle wet-dry soundness test (COLTO, 1998).

All material testing should be carried out according to TMH 1 (1979 & 1986) standards or the latest amendments. **Specifications should be applicable after placement and compaction**. Locally, the practice of carrying out testing on material that has been subjected to a Los Angeles Abrasion test to simulate the effects of placement and compaction has been employed. This is recommended for testing during the material location phase.

It should be noted that the grading parameters used for the determination of the Grading Modulus and Shrinkage Product, defined below, must be based on a conventional particle size distribution determination (TMH Method A1(a) - now SANS 3001-GR1) which must be normalised for 100% passing the 37.5 mm screen.

It is also important that prescribed sampling procedures are followed to ensure that only representative material samples are tested. These are fully described in TMH 5 (NITRR, 1981).

Material requirements for various types of road are discussed below.

3.5.1 Rural roads

The following specifications for materials for unsealed rural roads are recommended (Table 6):

Table 6 Recommended material specifications for unsealed rural roads

Maximum size (mm)	37.5
Oversize index (I_o)[a]	≤ 5 %
Shrinkage product (S_p)[b]	100 - 365 (max. of 240 preferable)
Grading coefficient (G_c)[c]	16 - 34
Soaked CBR (at 95 per cent Mod AASHTO compaction)	≥ 15 %
Treton impact value (%)	20 – 65

a I_o = Oversize index (per cent retained on 37.5 mm sieve
b S_p = Linear shrinkage x per cent passing 0.425 mm sieve
c G_c = (Percentage passing 26.5 mm - percentage passing 2.0 mm) x percentage passing 4.75 mm)/100

The specifications for shrinkage product and grading coefficient and their relationship to the expected performance of the materials are shown schematically in Figure 9.

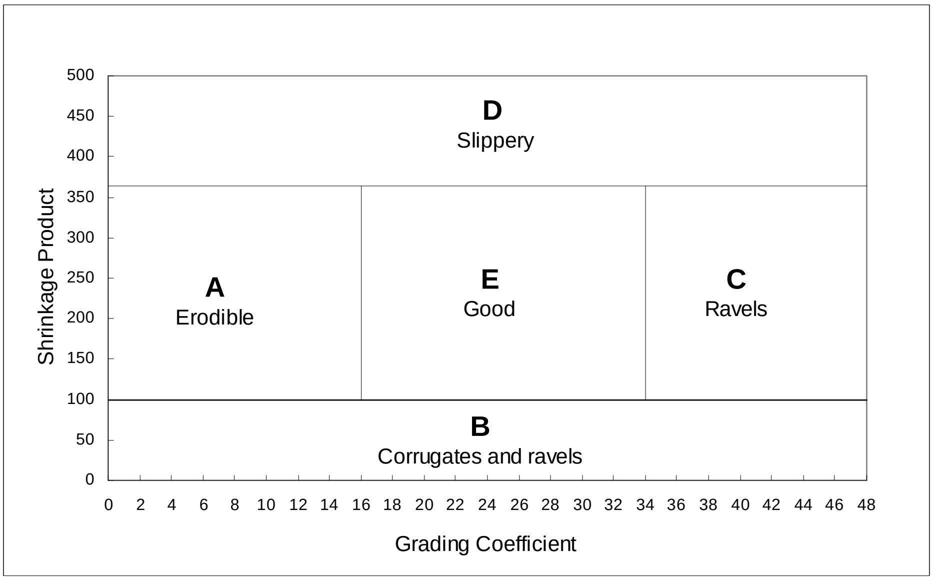


Figure 9 Relationship between shrinkage product, grading coefficient and performance of wearing course gravels

The following conclusions can be drawn about each zone as defined in the figure:

A Materials in this area generally perform satisfactorily but are finely graded and particularly prone to erosion: they should be avoided if possible, especially on steep grades and sections with steep cross-falls and superelevations. Most roads constructed from these materials perform satisfactorily but may require periodic labour intensive maintenance over short lengths and have high gravel losses due to erosion.

B These materials generally lack cohesion and are highly susceptible to the formation of loose material (ravelling) and corrugations. Regular maintenance is necessary if these materials are used and the road roughness is to be restricted to reasonable levels.

C Materials in this zone generally comprise fine, gap-graded gravels lacking adequate cohesion, resulting in ravelling and the production of loose material.

D Materials with a shrinkage product in excess of 365 tend to be slippery when wet.

E Materials in this zone perform well in general, provided the oversize material is restricted to the recommended limits.

It should be noted that these material zones can also be related to suggested crossfalls. While a crossfall of 4-6 % is necessary for materials in Zone E, materials in other zones should have lower values (3 to 4%) in order to minimise the potential erodibility and the risk of vehicles sliding off on more slippery materials (Zone D).

The specifications accept a number of materials that are likely to be unacceptably dusty but many materials which perform well would be eliminated by lowering the shrinkage product to 240. This was considered unnecessarily harsh for rural roads. It is recommended that the predicted dustiness (D) be estimated using the following model (Jones, 2001):

$$D = 20.88 – 0.32(PI) + 1.24 (BLS) – 0.04 (P075) + 0.01 (AIV) – 9.05 (RD)$$

where PI = Plasticity Index, BLS = Bar Linear Shrinkage, P075 = Percentage passing 0.075 mm, AIV = Aggregate Impact Value and RD = Relative Density.

If the predicted dustiness $D>0$ then the dust is likely to be unacceptable in terms of the public acceptability (Jones, 2001). If $D<0$ the dust is likely to be acceptable. Attempts should be made, however, to locate materials with a shrinkage product of less than 240 as far as possible.

By plotting the shrinkage and grading properties of potential unsealed wearing course gravels on Figure 10, an indication of the suitability of the material and any potential problems will be obtained. However, judgement should be used. In flat, dry areas, materials falling into zones A and D may be acceptable if the site-specific potential to erode or become slippery is not excessive. Similarly, if the traffic is very low or a high maintenance capacity exists, materials susceptible to corrugation can be considered for use.

The Treton Impact Value (TIV) limits exclude those materials that are too hard to be broken down with a grid roller (TIV < 20%) or too soft to resist excessive crushing under traffic (TIV > 65%).

Although the general specifications applicable to most materials and roads in South Africa are described, local investigations have shown that the recommended limits can be adjusted based on local conditions. Certain materials, under specific traffic and climatic conditions may perform better or worse than the general specification indicates. Examples of this are shown in Figure 10 and Figure 11 where the limits have been modified for roads carrying heavy traffic and subjected to heavy rainfall respectively in west and southern Gauteng (O Uekermann, pers comm.). Users of this guide, who have for example a specific material type in a certain rainfall area, can, based on local investigations and monitoring, modify the chart in Figure 9 to provide a customised specification for a specific combination of external influences.

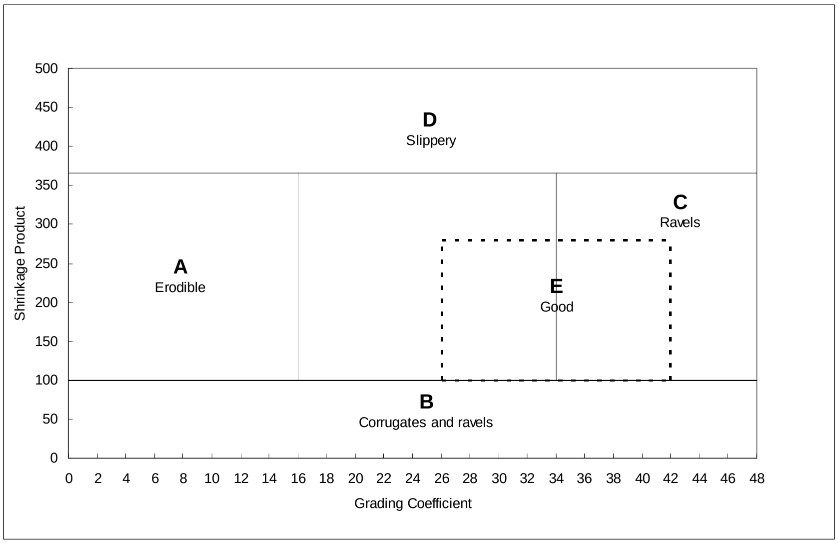


Figure 10 Area outlined shows optimum zone for heavily trafficked roads under normal rainfall in west Gauteng

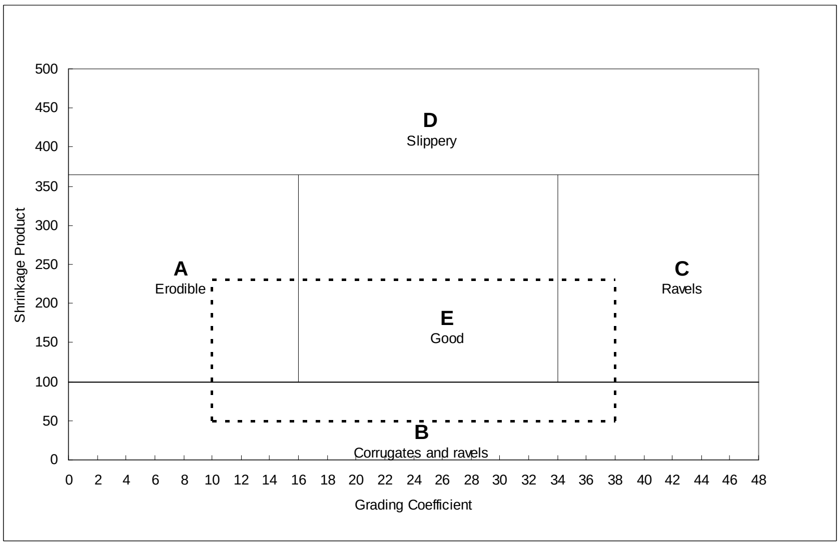


Figure 11 Area outlined shows optimum zone for heavily trafficked roads subjected to heavy rain showers in southern Gauteng

3.5.2 Urban roads

The following specifications are recommended for unsealed roads in urban areas (Table 7):

Table 7 Recommended material specifications for unsealed roads in urban areas

Maximum size (mm)	37.5
Oversize index (I_o)	0
Shrinkage product (S_p)	100 - 240
Grading coefficient (G_c)	16 - 34
Soaked CBR (at 95 per cent Mod AASHTO compaction)	≥ 15 %
Treton impact value (%)	20 – 65

In comparison with the limits for rural roads it can be seen that the limits for the oversize index have been reduced to eliminate stones whilst the shrinkage product has been reduced to a maximum of 240 to reduce the dust as far as practically possible. This lower limit reduces the probability of having unacceptable dust from about 70% to 40%. The actual dustiness can be predicted as discussed in section 3.3.1.

3.5.3 Haul roads

The material selected for an unsealed mine or forest haul road should preferably have the following properties (Table 8):

Table 8 Recommended material specifications for unsealed mine or forest haul roads

Maximum size (mm)	50
Oversize index (I_o)	≤ 5 %
Shrinkage product (S_p)	100 - 365 (max. preferably < 240)
Grading coefficient (G_c)	16 - 34
Soaked CBR (at 95 per cent Mod AASHTO compaction)	≥ 18 %
Treton impact value (%)	20 – 65

An increase in the maximum size and oversize index (within limits) is allowable as large haul-vehicles generally have wider tyres (often with lower tyre pressures) and usually travel at slower speeds than vehicles on rural and urban roads. Road user costs are therefore not as sensitive to the stoniness. A slightly higher CBR is recommended in order to allow for the greater traction forces exerted by the heavily-loaded vehicles usually associated with haul roads. For mine haul roads designed for large trucks (in excess of 50 ton capacity) reference should be made to Thompson and Visser (2000).

It is important that the particle size distribution (grading) of the materials used in any unpaved road is reasonably continuous and certain fractions are not deficient. Although this may not be manifested in the grading coefficient parameter, it is possible and it is important that the full particle size distribution curves are plotted conventionally (NITRR, 1986) and the analysis examined to ensure that a smooth curve is shown and gap graded materials (or significant vertical steps in the particle size distribution curve) are not present. A number of problems related to poor material gradings have been encountered recently and were overcome by additional grid rolling or blending in of an additional material.

2.10 *Material improvement*

Obtaining materials complying with the specifications provided above is often difficult. In many cases, however, it is possible to improve a local material source that is outside the specified requirements by blending it with material from one or more other sources. This obviously involves increased materials handling and hauling but can be more economical than hauling large quantities of material from a source further away. The procedure involves the mixing of materials that have different properties (typically particle size distribution and/or plasticity) to form a material having improved characteristics given the limitations of the source materials. Improvements in strength are usually the primary reason for implementing mechanical stabilization. **However, experiments have indicated that slower deterioration of riding quality and reduced dust levels can be achieved by optimising the particle size distribution and plasticity of the material to within the limits prescribed**. The modification of plasticity should be done with caution as blending of fine materials to reduce the plasticity often results in an artificial decrease in plasticity with a marked loss in smoothness of the grading curve.

A methodology, using a ternary diagram (Figure 12), has been developed to correct deficiencies in the particle size distribution. The Atterberg Limit tests are then used to check plasticity. The ternary diagram has a shaded area that indicates the desirable range (particle size) for optimal performance. The blend is altered until the required grading and plasticity characteristics are met. Input parameters for the ternary diagram are the percentages of silt and clay (<0.075 mm), sand (0.075 - 2.0 mm) and gravel (2.0 mm - 37.5 mm) of the material sources that will be used.

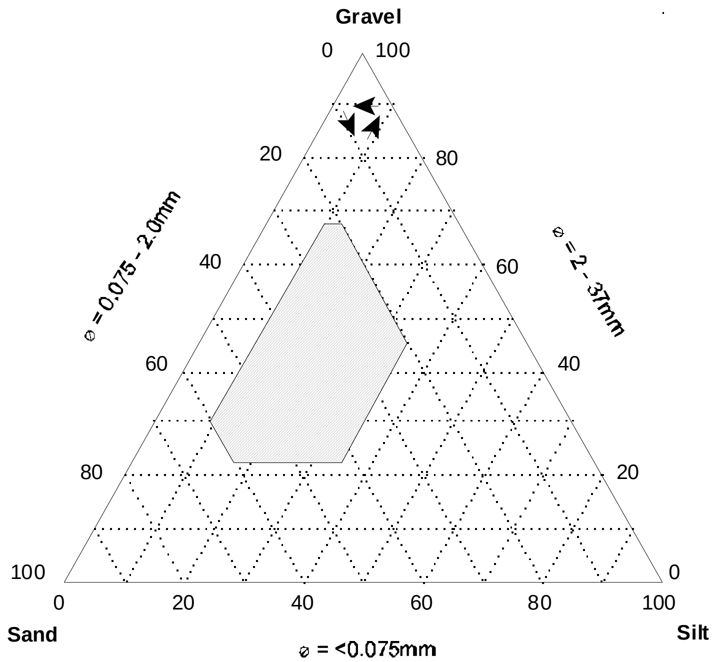


Figure 12 Ternary diagram for blending unsealed road materials

Methodology

The following methodology for determining the optimal mix ratio for blending two or more materials to meet the required specification is proposed.

- Identify potential material sources that can be used to improve the available material.
- Determine the particle size distribution of the available material and that considered for addition or blending (TMH1 Method A1(a) recalculated with 100 per cent passing the 37.5 mm sieve).
- Determine the percentages of silt and clay (<0.075 mm), sand (0.075 - 2.0 mm) and gravel (2.0 - 37.5 mm) for each source.
- Plot the material properties on the ternary diagram as points **a** and **b** respectively (see example in Figure 13).
- Connect the points. When the two points are connected, any point on the portion of the line in the shaded area indicates a feasible mixture of the two materials. The optimum mixture should be at point c in the centre of the shaded area.
- The mix proportions are then the ratio of the line ac:bc. This can be equated to truck loads and dump spacing.
- Once the mix proportions have been established, the Atterberg Limits of the mixture should be determined to check that the shrinkage product is within the desirable range (100 – 365 (or 240 if necessary)). The quantity of binder added should be adjusted until the required

shrinkage product is obtained, but ensuring that the mix quantities remain within the acceptable zone.

- If the line does not intersect the shaded area at any point, the two materials cannot be successfully blended and alternative sources will have to be located, or a third source used for blending.

Example

Source material 1 - Grading coefficient of 20 and a shrinkage product of zero. This material plots in Zone B of the specification and is therefore likely to corrugate and ravel.
Source material 2 - Grading coefficient of 4 and shrinkage product of 470. This material plots in Zone D of the specification and would typically be dusty when dry and slippery when wet.

The particle size distributions and other relevant data of each material are provided in Table 9**.**

Table 9 Characteristics of materials

Parameter	**Material**	
	A	**B**
% passing screen size (mm)		
37.5	100	100
26.5	85	100
4.75	42	97
2.0	38	96
0.425	20	94
0.075	7	92
Linear shrinkage	NP	5
Shrinkage product	0	470
Grading coefficient	20	4
% silt/clay (P075)	7	92
% sand (P2 - P075)	31	4
% gravel (100 - P2)	62	4

The relative proportions for each material are plotted onto the ternary diagram as points **a** and **b** which are then connected (Figure 13). The midpoint of the line within the shaded area is located at point **c**. The mix proportions are thus the ratio of the line ac:ab. In this instance, the ratio is approximately 1:4, which indicates that one part of Material B should be mixed with four parts of Material A (ie, one truck load of Material B for every four truck loads of Material A). After blending, the grading coefficient and shrinkage product are 18 and 138 respectively, which fall within Zone E of the specification.

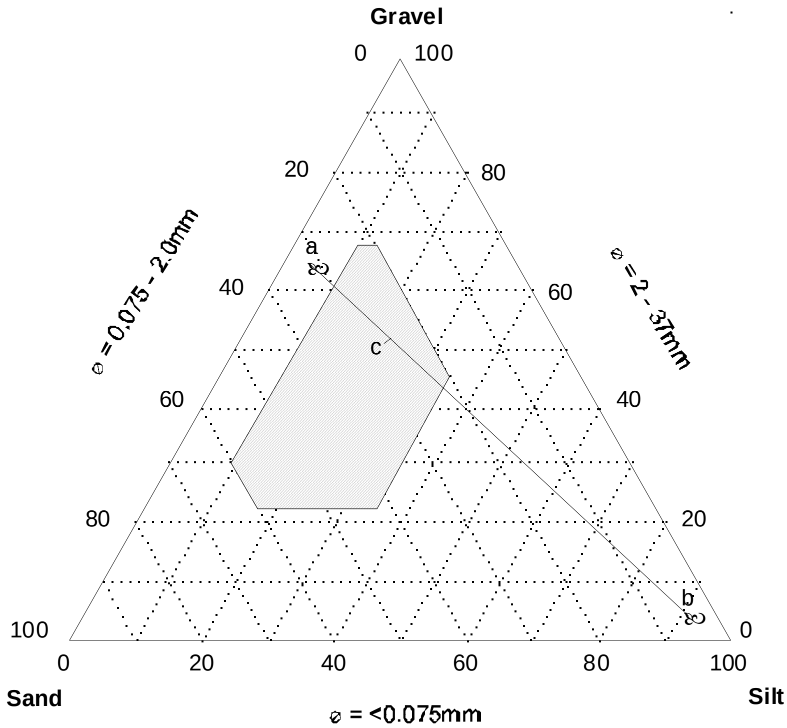


Figure 13 Example of the use of the ternary diagram

2.11 ***Material location***

One of the increasingly difficult problems with unsealed roads is the location of suitable wearing course materials. Many sources of the good wearing course gravels used in the past have become worked out or are no longer accessible. The successful location of new sources of wearing course materials is a specific science and the basic procedure that follows is suggested as a routine process. More information in this regard can be obtained from the Botswana Guideline (MWTC, 2000) and the KwaZulu Natal unsealed road protocol document (Jones, 2002).

Many existing sources of information regarding local materials exist and prior to embarking on a costly material location exercise, these should first be obtained and assessed. These include:

- Local sources and quarries
- Experienced staff and local residents
- Existing source records
- Construction documentation

If no suitable material can be identified within a reasonable distance of the project from the above sources, then a full material location exercise will have to be considered.

3.7.1 Introduction to Material Location

Material location should follow a logical process entailing:

- Developing a basic understanding of the local geology and geomorphology
- Developing an understanding of gravel indicators
- A desktop study of maps and aerial photographs
- A reconnaissance survey
- A detailed field survey
- Reporting

3.7.2 Local geology and geomorphology

The general geology of the area can be determined from geological maps. Maps with a wide range of scales exist and the largest scale maps available will provide the most information (usually 1: 250 000 but in some areas 1: 50 000). An understanding of the geology should embrace a number of characteristics.

- Material type
  The mineralogical components of the rock dictate how the rock will weather, what the end-products will be and how they will perform in the road. Weinert (1980) separated those rocks that decompose from those that disintegrate on the basis of mineralogy (primarily the dominance of quartz in the rock) and climate. On this basis, only the acid and basic crystalline (eg, granite and basalt respectively) materials were considered to be subject to decomposition and the remaining material groups would essentially disintegrate, dependent on climatic influences. It is thus clear that decomposing rocks are likely to yield materials that are more plastic while disintegrating materials would give better gravels.

- Topography
  The topography has a major influence on ground water profiles and gravitational movement of materials, which in turn affect the weathering process. The topographic expression in an area is a function of cycles of erosion over millennia, which are primarily related to sea level changes.

- Depth of weathering
  The depth of weathering is highly variable and is a function of the material type and structure, the main erosion cycles that have affected the material, availability of water and the topography. The depth of weathering varies from a few centimetres where only a thin layer of gravel is found at the surface to very deep clays where, for example, granites beneath the African erosion surface (often underlying a laterite/ferricrete layer) can be weathered to a depth of 20 m or more. In general the soil profile consists of an organic top soil (A horizon), overlying weathered in situ material (B horizon) grading into the C horizon of weathered rock which overlies the R horizon or in situ mostly unweathered rock.

  Natural gravel materials suitable for road construction are typically obtained from the B (residual material without relict structure) and C horizon (residual material with original rock structure or saprolite) and thus various depths of material need to be sampled and tested. In general, the plasticity of the material will decrease with depth towards the unweathered rock whilst the material coarseness and gravel component will increase.

3.7.3 Understanding and Selecting Gravel Indicators

Three types of gravel indicator are typically used for material location. These are the Landform, Botanical indicators (specialised plants) and Animal indicators (traces left by animal activity)

- Landform
  Landform refers to the configuration of the ground surface in a distinctive shape and is important in gravel location, as different types of gravel are associated with particular landforms. This association is due to:

    - The presence of material near the surface giving rise directly to a particular type of landform. (eg, a band of harder rock gives rise to a bump on a slope or a flat hill top, depending upon the rocks position and orientation).
    - The development of a particular type of gravel in relation to a geomorphological feature (eg, a river terrace is typically made up of alluvial gravel).

- Landforms of rock regions
  Rock regions have the typical range of gravel landforms illustrated in Table 10. This table is the key to the landform names given in Table 12.

Table 10 Landforms of rock regions associated with gravel deposits

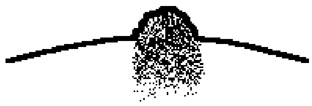
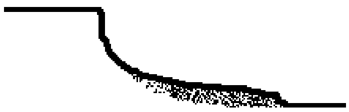
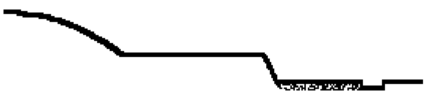
Landform	Diagram (cross-section)
Flat hill top Flat, level hill top (plateau) with sharp edges at margins	
Sloping hill top Inclined, flat hill top with sharp edge between (steep) scarp slope and (more gentle) dip slope	
Conical hill Hill with pointed top, more or less circular in plan. Sides may be irregular or smooth	
Mound Rounded hill top with convex slopes, or convex 'bump' on a plateau or hill top	
Ridge Long, straight, narrow ridge running across country. Usually formed by an igneous intrusion (dyke or sill) or a quartz vein	
Trench Long, straight, narrow depression running across country. Like the Ridge landform (above), usually formed by an igneous intrusion. However, in this case the surrounding rocks are more resistant than the intrusion. Sometimes the trench is formed by a pair of closely-spaced parallel ridges, formed by he surrounding rock being 'baked' hard by the heat of the intrusion	
Footslope Gentle slope at the foot of a steeper slope, formed (in this case) by the accumulation of pedogenic gravel (usually ferricrete) in the soil profile	
Terrace Raised platform situated at the edge of a valley, deposited by a river	
Floodplain Broad, flat valley floor with winding river. Sand and gravel accumulate on the inside of river bends	

Table 11 Types of gravel associated with rock regions

Gravel type	Parent material	Landform	Possible engineering problems
Residual gravels			
Weathered rock	Lava	Flat hill top, sloping hill top	Lava of basic composition may contain weatherable minerals
	Igneous dyke	Ridge or trench	Lavas of basic composition may contain weatherable minerals
	Igneous sill	Ridge on side of hill	Lavas of basic composition may contain weatherable minerals. Sill may be difficult to exploit, owing to position on side of hill (-overburden)
	Granite, gneiss	Mound, None	Gneisses may contain weatherable minerals
	Quartzite	Ridge, sloping hill top, flat hill top, mound	Poor mechanical interlock of particles
	Sandstone	Mound, flat hill top None	Particles may be rather soft
	Conglomerate, breccia	Flat hill top, sloping hill top, mound None	Conglomerate particles are rounded. Properties of the coarse particles may be different from those of the matrix
	Limestone, marble, dolomite	Flat hill top, sloping hill top, mound None	
Vein quartz	Granite, gneisses of all types	Ridge	Poor mechanical interlock of particles
Transported gravels			
Quartz stone line		Footslope None	Poor mechanical interlock of particles. May tend to contain too many fines.
Colluvium		Footslope	May contain too many fines
Alluvium		Terrace Floodplain	Rounded particles, often sandy and lacking in fines

- Landforms of Sand Regions

  The landforms that could be found in sand regions are given in Table 12, and the gravels associated with them are given in Table 13.

  If gravel particles are present in the soil, the processes of weathering and erosion will tend to bring some of these to the surface. The accumulation of a layer of stones and gravel on the surface can give the false impression that the soil is composed of gravel, or that a gravel layer lies at depth. Before considering the area as a potential source of gravel it is important to check that a gravel layer is actually present, by finding an exposed profile.

Table 12 Landforms of sand regions, associated with gravel deposits

Landform	Diagram (cross-section)
Pan with 'platform' Flat-floored pan with no or minimal vegetation. 'Platform' is a low bench situated on the edge of the pan but usually not extending all the way round. May be more than 500 m across, or less	 Note: Platform is not usually as distinctive or obvious as shown here
Pan without 'platform' Flat-floored pan with no development of a low bench around the edge. May be more than 500 m across, or less. May be without vegetation, or contain grasses	
Depression Concave hollow in the sand surface, containing grasses. The grass communities are often arranged in concentric zones around the depression	
Inter-dune hollow Very long, straight concave channel in sand surface. One of many forming parallel linear rises with hollows between. Calcretes are developed at intervals along the line of the hollow.	
Valley (old river channel) A dry river valley, filled in with sand. Takes the form of a broad, gentle elongated depression that extends for many kilometres. In places, easily visible on the ground but in others, so wide and shallow as to be hardly detectable.	
Grey sand No topographic relief, only grey sand contrasting with surrounding reddish or brown sands	

Table 13 Gravel types associated with sand regions

Landform	Material	Characteristics and comments
Pan with platform Around rim	Calcrete, possibly hardpan or nodular Silcrete	The best quality calcrete is found in the pan platform
Pan without platform Around rim	Calcrete Silcrete	Good calcrete may occur but is not usual. Quality is not predictable. Large pans may contain hard or boulder calcrete
Depression	Calcrete can be nodular. Often no occurrence, or calcareous sand	Usually poor quality calcrete. May occur on the side slopes
Inter-dune hollow	Calcrete and silcrete hardpan or honeycomb or nodular	Locally, good quality materials but generally none over most of the hollow's length
Valley (old river channel)	Calcrete, possibly hardpan or nodular	Locally, good quality materials but generally none over most of the valley's length. Some valleys contain extensive calcified sands
No landform - grey sand only, contrasting with surrounding red sand.	Calcareous sand. Possibly some calcrete	Usually poor quality calcrete but may be better if sand is non-plastic. Blackish sands usually yield better quality material

- Botanical Indicators

  The presence of certain plant species and sometimes the nature of their growth can depend upon the mineralogical and physical properties of the soil in which they are growing. Botanical indicators can thus be a useful aid to materials location. However, plants are adaptable and the absence of an indicator species does not necessarily mean that the material is absent, whilst the presence of the indicator species does not always signify that the underlying material is suitable for engineering purposes.

  The correct identification of plants is often difficult without botanical training. However, identification is generally not necessary. Instead, distinct changes in the species type, a dense thicket of a particular species or a change in the form (e.g. multi-stemmed instead of single stemmed, stunted, etc) of the plants are easily observed and are useful ways of identifying a potential source. Plant indicators are particularly useful for locating pedocretes (e.g. ferricrete and calcrete) and dykes and intrusions that are not easily visible on the surface.

  Although botanical indicators are a valuable source of information for material location, certain human and natural influences can limit their effectiveness.

  Species identification may be difficult for inexperienced persons. Reference to a suitable leaf key and books for identification will be helpful.

  Human occupation in rural areas, where shifting cultivation and the regular cutting of trees changes the natural species mix, may suppress the normal spread of indicator plants. Certain species have cultural significance or are used for medicinal purposes. These are left uncut and can become disproportionately frequent.

  In areas where livestock overgrazing occurs, significant changes in the vegetation become evident and indicator species can be trampled or eaten back to ground level. Selective browsing can give the false impression that the remaining unpalatable species are dominant.

In areas where the natural pasture grass is unacceptable for grazing, other more suitable species are often planted, thus giving a false indication of the ecology.

Natural bush fires or regular burning of grassland for grazing purposes may eliminate species that could be suitable for indicator purposes.

Riverine vegetation may give false indications of the underlying material, because some of the species may have been washed in from distant localities.

- Animal Indicators
  The activity of certain animals results in gravel particles, soil or stones being brought to the surface. Examples are termites, porcupines, suricates and squirrels. Examination of the material in termite mounds and anthills, and material excavated from burrows should be carried out.

3.7.4 The Desktop Study

- Maps and Photographs
  - *Topographic Maps*
    Medium- or large-scale topographic maps can indicate landforms associated with gravels. They also contain other useful information such as roads, access, land-use, mines and quarries, development and water, which indicate potential sources of material and assist with appraisal of the area.
  - *Geological Maps*
    Geological maps are probably the most important source of preliminary information available to for material location. They indicate the parent materials in the area and details such as quarries, faults, rock outcrops and igneous intrusions. The types of weathering products can be inferred from this information. All geological maps are accompanied by a narrative memoir. Reference to these is recommended.

    Detailed information can be obtained from larger scale geological maps (eg 1:250 000 and 1:50 000).

    The features of geological maps that prospectors need to be aware of are:

    - The map shows the rocks as they would appear if the superficial deposits such as soil or unconsolidated materials (e.g. thin windblown sand and alluvium) were removed. However, very thick surface deposits such as the sands of the Kalahari region are shown because they are the dominant material for all practical purposes.
    - Geological maps rarely indicate the presence of gravel deposits. However, geological memoirs often contain information on the degree of weathering or fracturing of the rocks and therefore indicate the possibility of a suitable gravel source. Memoirs also describe superficial deposits such as pedogenic and coarse alluvial materials.
    - The map legend (the key to the rock types on the map) may identify features that are related to gravel deposits, such as quartz veins, dykes or alluvial materials.
  - *Agricultural Soil Maps*
    Agricultural soil maps and reports identify the presence of soils and pedogenic gravels if these occur in the area. They are not concerned with the deeper parts of the weathering profile or with gravels specifically, and therefore rarely contain information relating to in situ gravels or transported gravels. However, as with a geological map, it is worth checking the soil legend and regional soil report for mention of features such as “stony phase” of a soil. The accompanying Memoirs include information on “ploughability” and “excavatability” as well as “depth limiting factors”, which can be used to identify potential depths and types of underlying materials.

- Remote Sensing
    - *Aerial Photographs*

      The resolution of modern aerial photographs is of high quality and every detail of the ground surface down to a few metres (depending on the scale of the photograph) in size is shown. Features such as minor rock outcrops can be seen clearly.

      Aerial photographs can be viewed in three dimensions, that is, slopes and relief can be seen. The vertical relief in aerial photographs is exaggerated, making slopes appear steeper than they really are. This characteristic is an advantage because it enables very small changes of elevation, that on the ground are barely discernible, to be seen (e.g. low relief landforms such as depressions associated with pedogenic materials are easily recognised in aerial photographs).

      When carrying out air photo interpretation, the following general characteristics of the terrain should be noted before looking in detail for the landforms described above:

        - Relief and landform: Hill areas, rolling or undulating land, terraces, floodplains and low-lying land. Look especially for relief features that are too small to be shown on maps.
        - Drainage: Note areas where drainage pattern is consistent and boundaries where one pattern changes to another (often signifies geological boundaries). Note particularly areas where drainage is absent (indicating highly permeable soils), or consists of parallel streams or straight stream courses (rock is controlling the stream pattern and is therefore near the surface).
        - Vegetation and land use: Although it is not possible at normal air photo scales to distinguish individual plant species such as gravel indicator plants, plant communities of a type that may contain indicator plants are often identifiable.
        - Human features: Farm boundaries, mining company fences and buildings give indications of the extent of properties and where the owners may be contacted.

    - Satellite Images

      Satellite images are vertical pictures of the earth's surface showing landform, drainage patterns and vegetation cover, but on a much smaller scale.

      As with aerial photographs, interpretation of satellite images is based on the shape of objects (including their size and context). These are often in colour but lack the benefit of a stereoscopic view. The appearance of the "false colours" can, however, often be problematical. However, the most important aspect of colour in satellite images is that areas of colour similarity or colour differences are clearly shown.

Desk Study Methodology

The desk study forms the first stage of project planning and is undertaken at the office prior to any fieldwork necessary for material location. The issues covered in the desk study are:

- Project briefing

  This establishes the purpose for which the materials will be used and the quantities required.

- Interpretation of background information:

  This phase entails the collection and analysis of information about the project area. Information is often available from projects constructed elsewhere in the region.

- Collation of information:

  During the desk study, the following procedure (in check list form) should be followed:

    i. Obtain two sets of 1:50 000 topographic maps covering the route corridor. One set will be used as base maps for collation of information coming from various sources during the desk study. The other is for general project use and navigation in the field.
    ii. Mark out the road or route corridor on the base maps.

iii. Confirm the quality and quantity of material required for the project.
iv. Establish land use, land ownership and potential environmental constraints within the route corridor.
v. Obtain relevant materials investigation reports from previous projects.
vi. Discuss material types and existing and potential sources with district maintenance supervisors and other people with experience of the area. Establish whether there is sufficient gravel at existing and known sources. If not, continue with the study.
vii. Obtain geological maps, agricultural soils maps, aerial photographs and, if necessary, satellite images, as well as any past records for this and other roads in the area.
viii. Determine the coordinates of existing gravel sources and locate these on the base maps, photographs and images. Note the terrain features at these coordinates and then look for other similar features elsewhere along the proposed corridor. Transfer the information to the base map.
ix. Examine the topographic maps, looking for the occurrence of any of the landforms discussed earlier.
x. Examine the geological maps and:
xi. Draw the road corridor on the geological map or a copy, in order to determine the approximate chainages at which geological units cross the road alignment. A 1:250 000 geological map is recommended for this exercise.
xii. Read the map legend and the accompanying geological report for any mention of rocks that are potential sources of gravel-sized weathering products. Note the geological units within which these are found.
xiii. Identify these geological units on the map, within the exploration corridor. Pay particular attention to 'oddities' on the map such as minor igneous intrusions and unusually prominent hills (often named). These features often contain gravels when the surrounding country has none.
xiv. Identify possible sources of material.
xv. Study the identified areas of geological interest in aerial photographs to pinpoint the locations most favourable for field investigation.
xvi. Study the aerial photographs (in stereoscopic mode) in conjunction with information from the topographic, geological and agricultural soil maps to identify landforms associated with gravel. Make notes of all features, no matter how small, and mark their location and extent on the base map.
xvii. Transfer all relevant information to the base map and identify the best potential sites, as well as the best location to begin field work and the route to follow.
xviii. Obtain the necessary permission or authorisation to prospect.
xix. Contact the landowners and arrange access to properties during the reconnaissance visit.
xx. Establish the most appropriate method for the field survey. Indicators of this by region are provided in Table 14.

Table 14 Summary of prospecting method per prospecting region

Regions	Methodology									
	Desk study				Field survey					
	Geological maps	Air photos	Satellite images	Past records	Macro topography	Micro topography	Vegetation	Animal	Soil colour	Aerial survey
Rock	1	1	2	1	2	1	2	2	3	2
Sand	2	1	2	1	3	1	1	1	1	1

1 Strongly recommended
2 Useful
3 Of marginal benefit

By the end of the desk study, locations of potential sources of material (and their appropriate indicators) should be known and transferred to the base map.

- Planning the field survey:

  Three issues are important when planning the field survey:

  - Logistics of the survey
  - Equipment and labour
  - Appropriate sample bags

  Where possible, local labourers should be used and sourced from the nearest village. The number of labourers required will depend on the size and time constraints of the project.

3.7.5 Reconnaissance Survey

The main purpose of the reconnaissance survey is to familiarise the prospector with the corridor, mark the existing pits and potential sites identified during the desk study as well as to note any other potential sites that may have been missed. The detailed study would involve more intensive investigations, but can then be planned to optimise resources, based on the findings of the reconnaissance survey.

The most successful field survey procedure is to systematically traverse the route relating the information on the map prepared during the desk study to the prospecting corridor. The following procedure is recommended for the reconnaissance survey:

i. Begin the traverse of the road or the proposed alignment well before the actual start (there may be very good material at the beginning of the project). Continually refer to the base map and aerial photographs.
ii. The first traverse should confirm the conclusions drawn during the desk study. Visit existing gravel sources and potential sites identified. Use GPS to record their locations. Estimate the areal extent and available quantities without excavation. This can be done with simple techniques such as a calcrete probe or a DCP.
iii. Identify any significant geomorphological, soil or vegetation characteristics at existing gravel sources that can be used to indicate similar sources elsewhere along the route. Identify these characteristics on the maps and aerial photographs and look for similar features elsewhere on the images.
iv. Study the geomorphology and decide which areas are likely to have a high potential for material (e.g. scree slopes and drainage channels).
v. Study the vegetation and note any significant changes, such as species groupings or changes in plant characteristics (e.g. shape, height, form).
vi. Note accessibility to each site.
vii. List GPS co-ordinates of potential sites and summarise the observations.
viii. Plot new sites on the sketch map. Review the pattern of sites on the map to see if they lie in clusters or straight lines, which would help in showing where to look for additional material.
ix. Record other important information including thickness of overburden and ease of access.
x. Update the base map accordingly.
xi. Draw up a plan for the detailed study, prioritising the most suitable sites according to the required material qualities and quantities. Identify a second set of sites in case the first selection proves to be unsuccessful.

If the area in which the reconnaissance is carried out is flat and featureless, the ground reconnaissance survey may be difficult, if not completely unsuccessful. In such cases, a visual survey from a helicopter or ultralight aircraft should be considered. Normal fixed-wing light aircraft are not suitable as they are too fast to allow inspection of potential sites. Although expensive, it is very quick and the costs incurred are usually considerably less than lengthy ground surveys that often miss potential gravel sources. The following procedure is recommended:

i. The aircraft should be flown approximately 200 m above the ground along the proposed alignment.
ii. Any abnormalities in micro-topography (eg, pan rim), vegetation (distinct change of species, dense thicket of one or two species, change in plant morphology (eg, stunted or multi-stemmed)) or soil colour should be sought to the left or right of the route alignment.
iii. Once observed, the aircraft is flown to these areas and a closer inspection is made from the air while circling the area. If a suitable site is available, the aircraft can be landed and a closer inspection made with a probe. If landing is not possible, GPS co-ordinates should be taken and the site revisited after the aerial survey has been completed.
iv. Once a site has been inspected, the aircraft is flown back to the route alignment and the flight along the route is continued until another potential site is observed.
v. Since it is difficult to write in a helicopter or ultralight aircraft, a pocket tape recorder should be used for recording descriptions during the flight and for noting GPS co-ordinates or waypoints. Depending on the stability of the aircraft, photographs can be taken of potential sites and studied in more detail on the ground.

3.7.6 Detailed Field Survey

The process of searching for suitable gravel sources culminates with the evaluation and proving of the potential construction material source. The objective of this part of the investigation is to establish:

- The areal extent of a potential gravel source
- The thickness and hence quantity of the identified deposit
- The characteristics of the identified deposit (i.e. in which layer they can be used)
- The type and properties of the overlying material
- The thickness and hence volume of the overburden
- Suitability of the material and waste (e.g. percentage oversize)

- Survey Procedure

For each potential source identified, the following procedure should be followed:

i. Demarcate the approximate areal extent of the site with stakes. This can be determined with a calcrete probe or DCP. In sandy areas, the calcrete probe should also be used to determine the thickness of the overburden.
ii. Identify the source with a unique location number, its chainage and direction from the start of the route and the offset from the centreline.
iii. Lay out a 50 m staggered grid. The grid pattern may be reduced to a 25 m spacing in one or both directions if the material within the potential source changes over a short distance. The grid can be aligned in any direction convenient to cover the shape of the deposit. Setting out of the trial pits should be carefully planned taking the characteristics of the site, such as vegetation and rock exposure, into consideration. Trial pitting should also incorporate as much of the potential gravel source as is necessary to establish the deposit's extent and variability.
iv. Record the grid pattern with holes running in one direction left to right being labelled A, B, C, D, etc and holes running perpendicular to this (i.e. top to bottom) being numbered 1, 2, 3, 4, etc. Trial pits should be selected statistically (preferably on a stratified systematic herring bone pattern) and would then be numbered A.1, A.2….B.1, B.2……..D.1, D.2 etc. The use of a grid system ensures a well co-ordinated study and simplifies the location of each trial pit. The system also facilitates selective stockpiling if different areas of the gravel source are recommended for different pavement layers or for blending.

Note:
GPS coordinates of each test pit should be recorded.

v. Excavate a pit to the bottom of the suitable material. This can be done either manually or by machine depending on the particular circumstances of the project. The width of the pit will vary depending on the excavation method. Ensure that the necessary safety precautions are taken during excavation and examination of the pit.

   Note:
   The type of machine used to excavate and difficulty of excavating should be recorded. This information provides and indication of the effort and equipment required to develop the borrow pit.(this may assist the contractor in pricing)

vi. Describe the soil profile in detail using the standard Jennings, Brink and Williams (1973) method. Profiling must include the overburden and the ratio of overburden thickness to gravel thickness should be recorded. During profiling, identify the horizons that are potentially suitable for meeting the material requirements of the road design.

   Note:
   Photographs, using a flash, should be taken of each test pit. Reference information of the specific test pit must be visible on the photograph.

vii. Collect sufficiently large samples of material for the intended tests. Place the sampled material in bags (it is suggested that high quality sewn canvas bags are used for sampling) and carefully label each bag ensuring that the label is permanent. Label tags should be placed in a transparent waterproof plastic bag before being placed inside the sample bag to avoid moisture damage. Information on the label must include the following:
   - Project name
   - Date
   - Source location number
   - Trial pit number
   - Depth
   - Name of person sampling

   Note:
   A minimum of 12 (twelve) test pits are normally required. Each uniform horizon should be sampled (minimum of 5 samples per horizon)

viii. Reinstate the pits with similar quality material from within the staked area. Remember that this material may be used in the road and therefore deleterious material from outside the staked area should not be used for backfill. If the pits have to be left open for more than one day, they should be clearly identified with hazard tape or covered with wood to prevent people or animals from falling into them.

ix. Estimate the volume of gravel in the source by determining the mean thickness of the gravel and multiplying it by the areal extent of the source.

x. Draw a detailed sketch map of the area and include the following:
   - Distance from the road.
   - Potential access routes.
   - GPS co-ordinates.
   - Trial pit grid and location of pits that were sampled. Also include any additional information gathered from calcrete probe or DCP penetrations.
   - Pertinent features such as outcrops, anthills, big trees (which may be protected by order), streams, etc.
   - North direction marker.
   - Any services or structures.

xi. List any potential problems that may affect exploitation of the pit such as boulders, presence of water, etc on the sketch map.

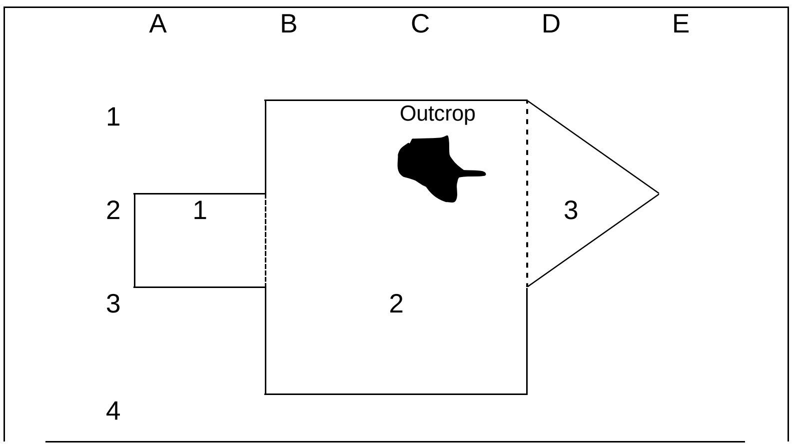
xii. List any environmental, archaeological or historical factors of concern in the area.

xiii. Where necessary list the names of landowners (e.g. if the potential gravel source is in a field or farm or affects other land users).
xiv. Mark the position of each potential gravel source on the 1:50 000 topographic map which serves as the working map.
xv. Repeat this process for each identified source. When each source has been evaluated, add the estimated total volume from each and compare this figure with the project requirements. Remember to make sufficient allowances for compaction or bulking and wastage (e.g. oversize).
xvi. Photographic records of all salient features and observations must be made.

- Estimating Material Quantity

There are various methods of estimating the volume of material in a potential source. The main objective, however, is to establish the thickness over a portion of the entire area. A simple, yet adequate method is outlined below:

i. Divide the gravel source into segments with simple ‘shapes’ - squares, rectangles and triangles (Figure 14).
ii. Determine the total area of each segment and make adjustments for obstacles such as big trees or vegetation that should be preserved, rock outcrops, areas of unsuitable materials etc, to determine a ‘useable’ area.
iii. Within each segment, determine the average thickness of the material strata of interest (overburden or gravel) from trial pit profiles or as estimated with DCP, calcrete probe or auger.
iv. Determine the approximate volume of the material that the strata can yield per segment by multiplying the average thickness by the area of each segment.
v. Add the volume of material from all segments.
vi. To account for compaction or bulking factor, waste during stockpiling, transportation and construction, reduce the estimated quantities according to the degree of induration (solidity) of the in situ gravel in comparison with the expected densities after compaction.
vii. Consider whether all materials from the pit would be used. In particular, note oversize materials that are not likely to break down during construction. However, the total volume of the material from the source (including oversize) must be reported for estimating transport costs unless such oversize can be removed at the source.
viii. Carefully study the trial pit logs and determine whether the thicknesses reported in the logs are based on refusal (i.e. whether the pit was sampled to its full depth) or no refusal and whether the trial pits were excavated by machine or labourer (the reason for refusal should be given on the logs – whether the machine depth was exceeded or the material became too hard). For pits not sampled to full depth the volume calculated could be conservative while pits sampled to refusal could imply that no additional material will be excavated, especially if a machine, such as a tractor/loader/backhoe (TLB), was used for trial pitting.
ix. While preparing for digging, make a location plan of the site in relation to roads, access tracks, old gravel sources, major vegetation features, and any other landmarks or surface features that make the site easy to find.



Segment 1:	Square with area 50x50 = 2 500 m2
Segment 2:	Rectangle with an area 100x150 = 1 5000 m^2, less outcrop of 20x10 = 14 800 m^2
Segment 3:	Triangle with an area (100x50)/2 = 2 500 m2
Total:	19 800 m2

Figure 14 Subdividing a gravel source

- Laboratory Testing

  Routine indicator and classification testing must be carried out before submission of the prospecting report.

3.7.7 Material Investigation Report

A brief material investigation report should be prepared to record the material location survey and to provide a reference for future materials location exercises. Reports should be filed together for easy future access. The report should comprise two parts, namely:

- o The factual or descriptive record
- o The engineering interpretation and recommendation

The factual report should describe concisely and accurately the site, the work carried out and the results obtained. The interpretation of results should detail the analysis of field and laboratory results together with recommendations for use.

The report must contain the essential information that is needed to exploit the gravel or to tender for its exploitation.

All borrow pit information and test results should be included in a Materials or Borrow Pit Management system (see Section 3.1), to allow easy and widespread access to the valuable information obtained. This is of significant value for use in future material investigations.

2.12 ***Environmental and Sustainability Issues***

Environmental issues relating to unsealed roads are of utmost importance. These range from assessing the initial environmental impact of the road and the construction material sources through to the operational impacts of the road in terms of dust and erosion of surface materials.

By their nature, unsealed roads have significantly greater impacts on the environment than sealed roads. The major impact is that of the continual replacement of lost gravel (lost mostly into the atmosphere as dist and into streams through erosion), which is a non-renewable resource. The long term sustainability of unsealed roads should thus always be considered during their design. Mechanisms for reducing the loss of gravel should always be considered.

Depending on the status of any unsealed road project, (ie, new construction, regravelling, upgrading) various environmental requirements are dictated by law. These fall under the National Environmental Management Act, 1998 (Act No 107 of 1998) and the Environmental Impact Assessment (EIA) Regulations of 2006.

The nature of the project will dictate the EIA requirements. In certain instances (eg, only localised borrow pits) an exemption from the EIA process may be applied for and obtained. However, in general, either a Basic Assessment Report (Table 15) or a full Scoping and Environmental Impact Assessment process (Table 16) need be followed. If the project activities have only a small likelihood of having significant environmental impacts only a Basic Assessment Report is usually necessary. However, even this requires public notice and the necessary participation, consideration of the potential environmental impacts of the material extraction and road construction, assessment of possible mitigation measures, and an assessment of whether there are any significant issues or impacts that might require further investigation.

Table 15 Basic Assessment Report Requirements

Activity	Possible impacts
The construction of a road that is wider than 4 metres or that has a reserve wider than 6 metres, excluding roads that fall within the ambit of another listed activity or which are access roads of less than 30 metres long.	Road construction and its supporting infrastructure (e.g. toll booths) may have the following impacts: • ecosystem degradation by creating a barrier between ecosystems; • increasing road strikes of birds and wildlife (especially slow-moving organisms like frogs, tortoises); • soil erosion; and • interruption of ecosystem processes, especially if the road is built through sensitive areas (ie, streams, wetland or alongside coastal strip). There may also be socio-economic opportunities and impacts. Increased access to remote areas may bring economic benefits but may also result in transmission of diseases like HIV, degradation of natural areas due to increased human visitation and negative impacts on local livelihoods and culture.

Table 16 Scoping and Environmental Impact Assessment

Activity	Possible impacts
The route determination of roads and design of associated physical infrastructure; including roads that have not yet been built for which routes have been determined before the publication of this notice and which has not been authorised by a competent authority in terms of the Environmental Impact Assessment Regulations, 2006 made under section 24(5) of the Act and published in Government Notice No. R. 385 of 2006; where a. it is a national road as defined in section 40 of the South African National Roads Agency Limited and National Roads Act, 1998 (Act No. 7 of 1998); b. it is a road administered by a provincial authority; c. the road reserve is wider than 30 metres; or d. the road will cater for more than one lane of traffic in both directions.	Road construction and the supporting infrastructure construction (e.g. toll booths) may have the following impacts: o ecosystem degradation by causing a barrier between ecosystems; o increases road strikes of birds and wildlife (especially slow-moving organisms like frogs and tortoises); o soil erosion; o contaminated water run off; and o interruption of ecosystem processes especially if the road is built through sensitive areas (ie, streams, wetland or alongside coastal strip). Socio-economic opportunities and impacts may also result. Increased access to remote areas may bring economic benefits but may also result in transmission of diseases like HIV, degradation of natural areas due to increased human visitation and negative impacts on local livelihoods and culture.

If a scoping and full EIA exercise is necessary, this requires a comprehensive programme to be carried out. This includes an initial Scoping Report (including a Plan of Study for the EIA), which requires the following:

- a description of the proposed works and any possible alternatives, a description of the property and the environment that may be affected and the manner in which the biological, social, economic and cultural environment may be affected by the proposed activity;
- a description of the environmental issues and potential impacts, including cumulative impacts that have been identified, and details of the public participation process undertaken.

In addition, the Scoping Report must contain a plan for the Environmental Impact Assessment, specifying the methodology to be used to assess the potential impacts, and the reports that will be required. The EIA may only commence once the Scoping Report and the Plan of Study for the EIA have been approved by the relevant authorities.

The EIA will normally be carried out by a specialist in the field, who would identify and assess each potential impact and identify mitigating measures or practical alternative activities that would reduce or eliminate such impacts.

Only once this EIA has been submitted and approved will an Environmental Authorisation be issued. The works can then commence.

2.13 *Subgrade preparation*

Many unsealed roads, however lightly trafficked at the time of construction, will with the passage of time capture more traffic and increase in use (and importance) as the local population increases. They may eventually be upgraded to higher standard unsealed roads or even lightly trafficked sealed roads. **Good preparation of the subgrade for a new unsealed road is therefore extremely important as this will often be the subgrade for much of the future improved road**.

Initially the subgrade should be cleared of bush and trees over the full width of the road prism. All vegetable matter and organic soil should be removed by grader or bulldozer from the road prism. Following the shaping of the intended cross section (refer Figure 6), the moisture content of the road bed should be brought to Optimum Moisture Content (OMC), the moist material thoroughly mixed and then compacted to a density of at least 90% Mod AASHTO maximum dry density. Nuclear density techniques (with gravimetric moisture correction) or a rapid sand replacement test (eg, Cernica, 1980) are recommended for density testing of unsealed roads although DCP testing based on trial sections that have been rolled and tested is a rapid low cost alternative. Because of the natural variability of subgrade (and wearing course) materials, the normal time-consuming sand-replacement density tests are seldom cost-effective. It is thus recommended that a number of quick tests are carried out and the average density considered. Where large variations in the subgrade material properties are present the use of high energy impact compaction could be considered.

Adequate subgrade compaction reduces the possibility of subgrade deformation, reduces the material permeability and strengthens the subgrade. The subgrade should then be smoothed and shaped with a suitable camber (at least 4%).

Material of at least subgrade quality (CBR ≥ 5 %) should be used to build up the formation to a height of not less than 300 mm above the natural ground level in flat terrain. Suitable material can often be obtained during the construction of side drains parallel and on each side of the road and mitre drains to remove water from the side drains. If this material is unsuitable, a higher quality material must be imported. The drains should be deep and wide enough to remove all of the expected surface water during wet periods from the road and its adjacent areas without ponding or excessive erosion. In flat areas, the formation should be high enough to allow the placement of drainage structures (usually pipes) at adequate depths beneath the wearing course. It is important that construction of the formation does not interfere with the natural drainage of the surrounding area and cause ponding. The material used for the formation should be slightly plastic with a plasticity index of about 4 in order to provide a stable platform for construction of the wearing course.

Other material from a borrow pit may be required to build up the formation. Once adequate material has been dumped on the subgrade, the formation should be compacted at about OMC to a density of at least 93% Mod AASHTO (or preferably refusal density) and smoothed and shaped as for the subgrade. It is important that the formation level is smooth and has an adequate camber to ensure that any water that soaks through the wearing course does not pond at formation level, should a permeability differential exist.

Proof rolling (ie, observation of the behaviour of the layer during the passage of a loaded water tanker or tipper truck) should be carried out on the prepared subgrade after compaction. There should be no evidence of movement, shearing or compaction of the layer under this applied load.

During preparation of the formation, subgrade (or subbase, where necessary), the finished surfaces should have a camber at least equal to or preferably slightly greater than the final designed camber of the wearing course. The surfaces of these layers should also be lightly scarified before the following layer is placed on them to assist with bonding of the layers.

The wearing course is placed directly on the formation in most unsealed roads, although "subbases" may be used to increase the structural capacity of the support if the subgrade is poor or large numbers of heavy vehicles are likely to use the road (refer Section 2.7).

2.14 ***Material operations***

4.2.1 General

The location, winning and transportation of wearing course gravels are the most expensive operations associated with the development of unsealed roads. It is important therefore that the optimum material is located as close to the project as possible and it is used to maximum advantage.

Materials location should follow the logical process described earlier (section 2.11) and not the random exploration that is often the case (Netterberg, 1985). Materials that comply with the appropriate specifications recommended in Section 2.9) should only be used. These specifications, like most material specifications (eg, COLTO, 1998; TRH 14 (NITRR, 1985)) **apply to the materials after processing and compaction**.

Once a potential borrow pit has been located, an adequate source of suitable material proved and the administrative requirements for use of the material finalised (ie, the expropriation or rights for material removal, the Environmental Management Project Report (EMPR) prepared and approved, etc.), the borrow pit can be commissioned.

4.2.2 Demarcate and excavate

It is important to demarcate the extent of the suitable materials in the borrow pit clearly and ensure that the material is only obtained from this area. Similarly, the depth of excavation should be carefully controlled so as not to excavate into less weathered or different material (often with significantly different properties) at greater depths. It is essential to cut the face being worked downwards through the entire depth of usable material and then to move the material parallel to the face to facilitate mixing. The floor of the borrow pit should be sloped away from the face to ensure that precipitation drains away and does not overly disrupt the material preparation process.

4.2.3 Mix and stockpile

Because of the inherent variability of natural construction materials, particularly those in a relatively advanced state of weathering or disintegration, it is strongly recommended that material is won using bulldozers and then stockpiled, as an alternative to loading it directly from the borrow pit to the site. Stockpiling allows improved mixing and reduction of variability and allows better quality control testing of the material prior to use, an essential part of the construction process.

Stockpiles in the borrow pit should be kept as low as possible to reduce segregation of the material (Ferry, 1986). Regular visual observation of the stockpiles should be carried out by an experienced material technician in order to ensure that segregation of materials in the stockpiles does not occur. Should segregation be observed, the loading and removal of the material for dumping needs to be closely supervised to ensure that the material is properly mixed. **The gravel operations should be carried out in a manner that ensures delivery to the road of a consistent gravel of the required quality**.

Optimally, the material should be processed to remove or reduce oversize in the borrow pit as far as possible. Such a device for doing this is a "Grizzly" which is a cheap, portable method of sieving out oversize material using a frame supporting a screen of the required aperture that can be used in the borrow pit. Although it may slow down material production in the borrow pit, it is capable of a high production rate (Ferry, 1986) and should be used wherever possible. Care should be taken to ensure that excessive oversized but elongated particles are not included in the material – such particles will pass through the aperture of a Grizzly screen, but would not pass through a conventional square mesh screen. The material should be excavated and processed in the borrow pit before removal of the gravel to the construction site commences. When the materials consist of rounded alluvial particles, it is recommended that oversized material is crushed instead of being screened, in order to produce as many rough and fractured faces as possible. In this way the constructability and shear strength of the material are considerably improved.

4.2.4 Breaking down oversize

The use of a grid roller to break down oversize material on the road is not always successful. Adequate supervision and the correct use of the roller are essential for satisfactory results. Rolling trials should be carried out where the process is applied to ensure that effective comminution of the material does occur. Certain materials such as decomposed acid and basic crystalline materials (eg, dolerite and andesite) may disintegrate adequately, but often corestones of hard unweathered material (particularly granite and dolerites in drier areas) and pedocrete boulders survive the grid rolling and lead to excessive roughness of the completed road as they become exposed on the road surface after some time. The use of the Treton Impact Value test result in the specification allows the quantification of the material hardness. Investigations have shown that a Treton Impact value of less than 20 is indicative of materials that are too hard to be broken down using conventional grid rolling (Paige-Green and Bam, 1995) and would require crushing (or scalping).

If a significant portion of the material is oversized, a **two-phased** mobile crusher should be used to reduce this to the maximum size specified. This process could also improve the grading significantly. It may be economic in some cases to windrow the oversize materials in, or next to the borrow pit, and reduce them with a mobile hammer-mill (eg, Rockbuster). Although mobile hammermills can be used on the material dumped on the road, it is recommended that they are used at the borrow pit in order to reduce the transportation of oversized material, which will not be broken down by the hammermill. It has been shown elsewhere (Beaven at al, 1987) that for roads carrying over 50 vehicles per day it is cost-effective (in terms of the vehicle operating and maintenance costs) to crush oversize material to pass a 37.5 mm sieve. The most economic means of removing oversize material in borrow pits with only a limited quantity of large stones is manually by hand picking. For effective results, however, this requires a conscientious team of labourers working under good supervision.

If blending of two or more materials is necessary to achieve the required shrinkage product or to alter the particle-size distribution of the gravel, this can be done in the borrow pit if the sources of gravel are in close proximity, but is usually more effective on the road. Careful supervision over the dumping and mixing of the materials is necessary to ensure that the correct proportions are combined and mixing is complete. The process must be carried out by dumping and spreading the material comprising the largest proportion over the entire road area and then dumping the other materials at the correct spacing, and spreading of these in even layers over the first layer. Once all of the materials have been spread as individual layers, thorough mixing of the layers through their full depth can be carried out.

Where possible, the material should be moistened in the borrow pit before being hauled to the road. This reduces segregation during hauling and fines (dust) loss during transportation and assists with the compaction of the material. If the material is unlikely to be spread and compacted within 24 hours of dumping on the road, it is better to moisten the material on the road just prior to compaction in order to avoid an uneven moisture distribution resulting from surface drying of the pre-moistened material on the road.

Some materials such as mudrocks and highly weathered basic igneous rocks which slake on exposure to the atmosphere often require stockpiling for a period varying from a few days to a few weeks to achieve the required breakdown. These materials should be allowed to break down in the borrow pit and must not be left on the side of the road being regravelled while they disintegrate (for obvious safety reasons). Materials which slake to fine powdery materials are undesirable for use as wearing courses and should be avoided.

4.2.5 Compaction

Compaction plant is available in various configurations and masses. In general, the heavier the plant, the better the compaction obtained. However, certain plant is best used for certain activities as discussed below.

High Energy Impact compactors – These usually consist of 3, 4 or 5 sided "rollers, which develop their energy by falling freely off their centre of gravity. The energy imparted by the impact of the falling mass to the soil is much higher than conventional plant and the depth affected is significantly greater. In addition, compaction can be effectively carried out at moisture contents considerably lower than optimum. The action of these rollers, however, results in disturbance of the upper portion of the layer, but they are highly effective for compacting **sandy and potentially collapsible** subgrades, to high densities.

Sheepsfoot rollers – Sheepsfoot (or padfoot) rollers have protuberances on the rolling drum that exert high stresses and also provide a kneading action to the soil. They are most effective on **cohesive soils** where voids and pore pressures are effectively expelled. They are seldom used for wearing course compaction, but are highly effective for the compaction of cohesive subgrades. Their effective mass can be increased by applying vibration to the drum.

Sheepsfoot rollers should be used until the rollers (protuberances) “walk out” of the layer, ie, change from compressing the points of contact only to travelling on the layer surface with minimal embedment.

Grid rollers – Grid rollers are widely used for the compaction of gravel wearing courses with a wide range of gradings but particularly where it is necessary to **break down larger particles**. They typically require ballasting to in excess of 12 or 15 tonnes and should be towed at a relatively high speed (8 to 10 km/h) by a tractor. Grid rollers tend to leave impressions of the grids on the layer surface and should not be used for final compaction of a wearing course. When grid rollers are used to break material particles down, they should be mixed with a grader to ensure separation of the broken fragments from each other. It is important that the condition of the “grids” is carefully controlled to ensure effective breakdown of coarse materials.

Smooth steel-wheeled rollers – These are probably the most widely used roller in gravel road compaction, being particularly effective on **well-graded low to medium plasticity gravels**. They generally have a vibration mode (with variable amplitude and wavelength) and are highly effective in compacting gravel wearing course layers of 150 to 200 mm to a smooth surface finish. Care needs to be taken not to over-vibrate the layer, as delamination or crumbling of the surface will result. Excessive vibration of relatively low cohesion materials can also result in the development of shear planes within the layer.

Pneumatic tyred rollers – Pneumatic tyred rollers consist of a number of rubber-tyred wheels on a frame and are particularly useful for providing a final smooth surface finish on **good selected gravels**. They should always from part of the compaction “team”. They can be very heavy static rollers commonly up to 27 or 30 tonnes, and do not have a vibrating mode. They have a slight advantage over smooth steel rollers when compacting material containing larger particles, as the individual tyres knead these particles into the layer, where steel rollers tend to bridge areas of the road across larger particles with poor compaction in the finer grained areas between these particles. These rollers are also best for the slushing process described previously.

4.2.6 Traffic management

The direction of transportation of the gravel should be such that the newly constructed road is not trafficked by the construction traffic. If the road is compacted as previously recommended, trafficking by construction vehicles results in more damage to the road (ravelling and potholing) than the benefits gained from further compaction. If the compaction is minimal (not recommended), controlled passage of the construction traffic can, however, be beneficial.

4.2.7 Supervision and control

One of the main problems with the construction of unsealed roads is the lack of adequate supervision and control testing. Greatly improved unsealed roads would result from close supervision and control by experienced personnel during the borrow-pit working and actual construction. In view of this, a simplified procedure has been developed (ILO/ASIST, 1998). Although it was developed specifically for labour-intensive projects, it is equally applicable to conventional gravelling projects. A portable field test kit has been developed to provide the necessary equipment for this material and construction control (http://asphalt.csir.co.za/graveltestkit.pdf).

The techniques described in this section apply equally to the regravelling operation.

2.15 *Wearing course construction*

Good construction practices for gravel wearing courses will:

- provide the correct thickness of material;
- provide adequate compaction, and
- provide a smooth finish with a good cross-sectional shape

Conventional construction will entail the use of tipper trucks, graders and large self-propelled or towed rollers. It is also possible to construct unsealed roads using labour-intensive techniques (ILO/ASIST, 1998).

4.3.1 Thickness

The appropriate wearing course thickness is dependent on the expected annual gravel loss and the strategy of the authority regarding the minimum frequency of regravelling operations. Typically, roads are regravelled with a layer of between 100 and 150 mm with exceptions, in case of high volume traffic, up to 200 mm. Generally, the minimum regravel frequency is taken as once every 7 to 10 years.

It is important that the material be dumped on the road at the correct spacings to provide for the desired thickness of gravel after spreading and compaction. If the constructed thickness is incorrect the management of the maintenance of the road network will be disrupted as premature regravelling may be necessary or the road may need a thinner layer of gravel when being regravelled. Both of these variations affect the budgeting requirements. The thickness must be as consistent as possible over the length of the link to avoid total loss of gravel over limited portions of the link only. The thickness of recently compacted (ie, still moist) wearing course layers can be reasonably well estimated using a Dynamic Cone Penetrometer (DCP): the depth at which the penetration rate shows a marked reduction defines the interface between the drier underlying layer and the newly compacted wearing course.

4.3.2 Compaction

Good compaction produces a tightly bound gravel with optimum particle interlock, minimum permeability and porosity and significantly increased strength.

The importance of adequate moist compaction has been clearly shown (Poolman and Paige-Green, 1990) who found that a high degree of moist compaction resulted in a road with a lower roughness than similar materials which were poorly compacted in a dry condition. The roughness deterioration was much slower and gravel loss and dust emission were significantly reduced. Significant savings in road user costs were also obtained. Although dry compaction can be effectively carried out (O'Connell, 1997), experience has shown that the lack of suction in such materials compared with that developed during the drying out of moist compacted material results in a weakly bonded material. As such, dry compaction is not recommended for unsealed roads.

A poor degree of compaction results in a low density, permeable material which ravels easily and is highly moisture sensitive. Deep rutting, compaction under traffic, potholing, corrugations and passability problems in the soaked condition are common results of poorly compacted material. The initial traffic-induced compaction and increased gravel loss again interfere with the maintenance management strategy for the road.

In order to take advantage of the moisture added to the material before hauling, the material should be dumped, spread and compacted before a significant quantity of the water has evaporated. This requires careful project planning and management. Construction during the wet season results in additional moisture being available (from rain) and often lower evaporation.

It is recommended that compaction should be carried out until refusal, ie, the maximum density that can be obtained with the plant available, subject to a minimum of 95% Mod AASHTO density being achieved, but ensuring that overcompaction/de-densification and material breakdown do not occur. This can be monitored using compaction meters attached to the rollers. The practice of slushing gravel wearing courses after final compaction has proved to be beneficial in many cases. This involves saturating the compacted gravel surface with water and repeatedly passing a pneumatic tyred roller (PTR) over the surface to pump excess fines to the surface. This produces a smooth surface with a thin layer of fines which gradually wears down to expose a tightly bound gravel matrix.

Numerous commercial proprietary compaction aids are available. Many of these appear to be suitable for certain types of material while others have little benefit or are not cost-effective. The use of these should be preceded by their application on trial sections with controlled proof rolling to ensure that they are beneficial.

Typically, compaction of a gravel road would require initial grid or sheepsfoot rolling followed by smooth steel rolling (with vibration) and ending with a PTR to provide a smooth finish.

4.3.3 Finish and shape

The roughness of a road is one of the most important factors influencing vehicle operating costs, affecting every contributor except depreciation (Harral et al, 1975). It is important therefore to make use of competent grader operators who can provide a smooth, well-finished riding surface. A good surface after construction can be maintained to a much better standard than a poorly finished surface.

The cross-section and shape of the road should ensure an adequate crossfall (4 to 5% minimum) with a definite crown (except on horizontal curves). Large stones (greater than 37.5 mm) which have found their way into the gravel should be removed (manually if necessary) and discarded away from the road to ensure that they are not bladed onto the road during routine blading or drain clearing. Good plant operators will usually be able to break oversize material down and remove large particles.
A common problem is the use of oversized material which is repeatedly rolled (usually with a grid roller) until it is embedded well into the layer and often, even the subgrade. In a short time these stones and boulders protrude from the surface and cause a rapid deterioration in the roughness and significant maintenance problems. Construction crews should be trained to refrain from this practice.

2.16 *Quality control and quality assurance*

Unsealed roads are often seen as a low cost solution to providing access and traditional activities considered obligatory on sealed roads are relaxed or even neglected on unsealed roads. One of these is routine quality control by the Contractor and the follow-up assurance of quality by inspection and testing by the Engineer or Client. **The importance of appropriate quality control in unsealed road construction cannot be underestimated and neglect of this is often the reason for poor performance of newly constructed unsealed roads**. Recent work has indicated that unsealed roads that are built to a specified requirement, which is confirmed using appropriate quality management procedures, perform much better than those built in the past with minimal, if any quality control.

The properties that require routine control during construction include:

- Material quality
- Stoniness
- Compaction/density
- Layer thickness

The wearing course material placed on unsealed roads usually consists of natural weathered gravels excavated from relatively shallow borrow pits. These materials require the efficient removal of the top-soil and then extraction of the specified thickness of gravel that has been previously identified and tested. In addition to the natural variation of weathered materials, the effects of poor stripping of the top-soil and/or uneven working of the material depth results in the potential for a highly variable material. Proper stockpiling and mixing (Section 2.14) can reduce this variation. Material quality must be controlled on a continual basis, using the necessary test techniques. **The cost of material testing is usually negligible compared with the cost of obtaining and placing the material and should not be compromised**.

The presence of excessive oversized material has been discussed earlier. It is essential that this property is assessed continually during construction and when the supervisor judges the large particles to be excessive in either number or dimension, the supply of material should be halted until the problem has been resolved. **Too frequently, it is seen that large particles are “buried” in the layer only to appear or be exposed at the surface a year or two later**. Apart from the severe impact such stones have on the riding quality of the road, the maintenance operation is severely hampered and it is almost impossible to maintain the road to an acceptable standard.

Although the standard specifications generally specify a minimum density for the compaction of wearing course materials (usually 95% mod AASHTO), the compaction of the layer to refusal with the available plant is recommended, subject to the density being at least 95% Mod AASHTO. The benefits of applying one or two additional roller passes to increase the density and stiffness far outweigh the additional cost of the extra rolling. The use of a rolling trial in which the density/strength of the layer after each roller pass is determined and plotted to determine the number of passes after which no additional benefit is obtained allows both a method specification to be employed (exact number of roller passes necessary) as well as identifying the achievable density or strength. This is best controlled using a nuclear density gauge, but can also be controlled using a DCP.

Success has been achieved on a number of new gravel road and regravelling projects using the DCP for quality control. The required DCP penetration rate for the gravel layer at compaction moisture content must be determined (usually by rolling trials) and then this can be tested for each lot using the standard random sampling and number of tests specified in COLTO (1998) under Clause 8200.

It is also important that the layer thickness be controlled and this can be done by excavating small holes, by using a DCP or by pressing a calibrated probe (Figure 15) into the layer immediately after compaction and before the layer has dried. When a DCP or such a probe contacts the drier underlying layer, it is usually clearly felt and the layer thickness can then be accurately determined. It is often useful to carry out testing with the probe before and after compaction and the degree of reduction in volume assist with estimating the compaction achieved (typically it should be at least 25 to 30%). A similar statistical method of assessing the results as for using the DCP for compaction control should be employed.

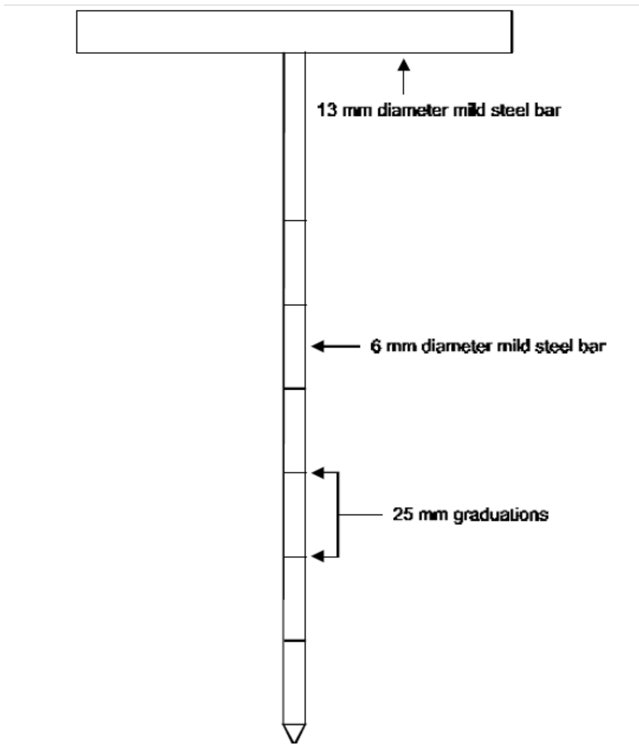


Figure 15 Probe for determining gravel wearing course thickness before and after compaction

2.17 ***Labour Intensive Construction***

The construction of conventional unsealed roads is essentially a machine intensive operation. The volumes of material required and their spreading and compaction requirements make the use of labour for many operations neither time nor cost-effective.

Despite this and particularly in line with the Expanded Public Works Programme (EPWP) being implemented in South Africa (GDPTRW, 2008), the potential for labour intensive construction, particularly in remote areas should not be ignored. Many rural access roads have been successfully constructed using labour primarily, but the need to obtain conventional quality standards should not be neglected in order to avoid excessively rapid deterioration of the road. It is essential that trial sections are initially constructed to ensure that the required standards can be cost-effectively achieved.

Labour intensive methods, particularly on relatively narrow roads (less than about 6 m) can generate significant employment opportunities in rural communities, increase the income in these areas and establish contractors for various maintenance operations. It may, however, be necessary to use conventional compaction plant to achieve the specified densities.

2.18 ***Drainage***

Unsealed roads are totally exposed to the elements and rainfall can result in significant maintenance problems. The importance of good drainage cannot be overemphasised. The moisture content of an unsealed road is one of the few potential problems which can be controlled by the road maintenance team.

The water in an unsealed road can only come from two sources:

- Surface water from precipitation (including flooding) and adjacent high ground;
- Subsurface water from high water tables, seepage, springs and capillary suction.

4.6.1 Surface water

Surface water is generated predominantly from local rainfall (although in the case of flooding it may have fallen some distance away) but may also arise from snow and hail to a lesser extent. **Infiltration of this water into the pavement structure can be limited by ensuring a compact, tightly-bound wearing course with an adequate camber or cross-fall, which removes the water rapidly from the road surface into the side drains without causing scouring. Material that is poorly compacted, porous (ie, poorly graded uniformly sized or excessive oversize material) or highly absorbent (eg, clays) will not shed surface water from the road effectively or sufficiently rapidly**. This will result in weakening of the road surface, with shear failures and consequent trafficability problems.

The side drains should collect the water and at the necessary intervals lead the water through mitre drains far enough away from the road so that it is unlikely to influence the road structure.

The side drains should run parallel to the road collecting the surface water from the pavement and shoulders, and removing it through mitre drains (or turnouts) as far from the road as is practically possible, where it can soak into the ground or flow into a natural drainage course without influencing the road structure. The distance between the mitre drains (which need not necessarily always be associated with side drains) depends on their grade. The principle is to place the mitre drains at distances which avoid ponding adjacent to the road but not so distant as to allow the build-up of high flow velocities and consequent scouring. Flow velocities can also be decreased by using mitre drains constructed with a grader with widths of 1 to 1.5 metres. In urban areas widths of 0.6 metres are recommended. Mitre drains in areas with dispersive soils should generally be spaced at approximately 50 m intervals in flat ground, decreasing to about 10 m as the slope increases to 1:10. In clayey areas the spacing could be largely increased if the side drain capacity is sufficient. **Table 17** gives a rough indication of the minimum and maximum spacing recommended by practitioners in South Africa. Each situation, however, needs to be assessed on its own merits.

Table 17 Minimum and maximum distance between mitre drains (m)

ROAD GRADIENT %	**2**	**4**	**6**	**8**	**10**	**12**	**14**
Erodible material (Minimum Spacing)	50	40	30	20	10	10	10
Clayey material (Maximum Spacing)	300	150	100	75	60	50	40

The importance of the road surface being raised above the surrounding area is obvious. When the surrounding area is higher than the road surface, the road becomes the drain during periods of heavy rainfall and rapidly becomes deformed or even impassable if the water soaks in.

Drains should be deep and wide enough to contain the expected water and avoid flooding of the carriageway. Their dimensions should be such that the velocity of flow is not excessive (which results in scouring and erosion) and the intended maintenance is practical (i.e. wide enough for graders if grader clearing is anticipated). Flat-bottomed drains are less susceptible to erosion than V-shaped ones and where graders are to be used for maintenance it should be ensured that the drains are wide enough to accommodate the graders. On steeper grades some form of erosion protection of the drains is usually necessary.

If the prevailing topography allows runoff water to disperse naturally, the construction of drains can be minimised, significant cost savings can be made and potential erosion, scouring and sedimentation problems can be avoided. It is important that the road structure does not interfere with natural cross drainage of the area. Adequate provision for cross drainage must be made using culverts with careful attention being paid to their size, inlet and outlet control and maintenance. *If the natural dispersion of water is not disrupted by the road structure, side drains need not be constructed as the concentration of water resulting from these structures exacerbates any potential erosion problem.*

4.6.2 Subsurface water

Subsurface water is derived from high ground-water levels (temporary or permanent). Occasionally springs may be encountered beneath the road, especially in cuttings. Capillary rise of water from relatively high ground-water levels may occur in clayey and silty soils. Subsurface drainage problems are usually manifested as continuously damp areas on the road surface which result in the constant presence of potholes. The remedial actions may require the installation of subsurface drains if the water is due to high water tables or capillary suction or cut-off side drains when the water seeps from areas adjacent to the road. **These are, however, not recommended as they are expensive and require regular and careful maintenance**. The use of shallow rock-fill embankments (usually together with geosynthetic separation layers) beneath the road structure is a possible alternative, but geotechnical assistance should be obtained to identify the source of the water and propose the most appropriate remedial measures in these cases – poor design could result in the rock-fill being compacted into the soft saturated soils and the problem re-occurring.

Many of the drainage construction techniques are particularly conducive to the use of labour, which should be considered where appropriate.

The maintenance of unsealed road is an essential part of their successful operation. The exposed nature of the wearing course makes them highly susceptible to damage from the environment and traffic. Various maintenance activities are required to ensure that the desired Level of Serviceability is provided over as much time as possible.

2.19 ***Routine maintenance***

Despite all the programming and time spent on maintenance, it is not worth doing if it is not done cost-effectively and to a high standard. **The importance of sufficient maintenance carried out by experienced and conscientious machine operators and back-up staff cannot be overemphasised**. Once the condition of a road deteriorates beyond a certain point, restoration of the road to an acceptable condition can seldom be achieved with routine maintenance and requires a considerable mechanical and labour input.

The major categories of routine maintenance covered in this document are:

- roadside maintenance;
- drainage maintenance, and
- surface maintenance.

5.1.1 Roadside maintenance

The roadside is defined (Hudson et al, 1987) as the first three metres adjacent to the edge of the shoulder or pavement. For local conditions it is considered prudent to define the roadside as the full road reserve (National Research Council, 1979).

The main maintenance activity affecting the roadside is bush clearing and grass cutting. This procedure is carried out mainly for safety reasons but also to avoid damage to vehicles from vegetation overhanging the pavement edge and to reduce the fire hazard in some areas. The frequency of this maintenance depends on the relevant Level of Serviceability and should be adapted for the district under consideration. Areas with a high rainfall and short radius horizontal and vertical curves (ie, short sight distances) will require considerably more vegetation control than long straight roads in arid areas.

Vegetation control on unsealed road reserves is best carried out manually although mechanised control may be cost-effective in some areas. This activity provides a good opportunity for the establishment of SMMEs and local contractors.

Collection of litter should also be programmed periodically especially near built-up areas and on more heavily trafficked and tourist routes. Debris from car accidents, discarded car parts (eg, tyre remains, exhaust pipes and silencers) which periodically end up on the road and dead animals should be removed as soon as possible.

Another roadside maintenance activity which should not be neglected is the repair and prevention of erosion affecting cut and fill slopes, side drains and ditches. The most cost-effective way of preventing this erosion is the establishment of vegetation. Cuts and fills should be constructed at suitable batters to allow the establishment of vegetation (preferably less than 1 vertical :2 horizontal) with a cut-off drain or catchwater bank just behind the crest of the cut or fill. Should erosion occur, the erosion channels should be back-filled with rocks and grouted if possible. The erosion of drains should also be prevented by a rock lining and some form of obstacle (eg, rock dams, vegetation) to retard the speed of water flow. Care should be taken with vegetation “drain liners” as the resulting increased siltation often leads to vigorous growth and filling of the drain.

Erosion of culvert inlets and outlets is a common problem and control structures, eg, rock rip-rap or concrete wing-walls, may be considered at problem sites. With time the erosion protection measures themselves may require significant maintenance.

Most of the roadside maintenance is labour intensive and great scope exists for the contracting of this type of work to local residents in developing rural areas.

5.1.2 Drainage maintenance

In both the wetter areas of southern Africa, where prolonged periods of rain occur and in the more arid areas where high intensity thunder-storms of short duration are common, drainage problems affecting unsealed roads are significant. Many of these can be overcome by improved drainage maintenance. Although the overall drainage systems are usually adequate, with time the drains become eroded and/or silted up and free drainage of water from the road is impeded.

The first significant problem is to remove the bulk of the rain-water from the road surface without causing erosion of the gravel wearing course. **For this to occur effectively the surface of the road should be well maintained with a good shape (definite crown), no potholes, deep corrugations or ruts and an adequate crossfall**. Local experience shows that a crossfall of about 4 or 5% is the optimum, which allows adequate run-off without erosion. Slopes and crossfalls steeper than about 5% are prone to erosion. On the steep slopes commonly encountered in the eastern areas of southern Africa erosion is a significant problem and no cost-effective way of avoiding this has been developed as yet.

The important drains which require maintenance are the side drains and mitre drains. These should be designed with widths (if possible 2 m wide) and side-slopes (1:2 to 1:4) which permit ready access of a motorised grader so that maintenance can be carried out during the routine pavement surface maintenance. Graders are, however, adaptable implements and the extension and angles of their blades can be adjusted for most purposes. The grader operators should ensure that all drains have an adequate fall with no low spots where water may accumulate. **It is important to ensure that routine grader blading does not leave windrows blocking the entrance to mitre drains**.

Deep V-shaped side drains are difficult to maintain (even manually), not always effective and are often unsafe, even for lightly trafficked roads. However, experience indicates that the construction and maintenance of V-shaped side drains in hard materials, e.g. shales, are easier and cheaper than flat bottomed drains.

In many cases it is cost-effective to clean drains of their silt and excessive vegetation manually. Drain maintenance should endeavour to retain the grass cover which reduces the erosion potential. This is especially necessary during manual clearing around culverts and drains. **It is important that silt excavated from drains is removed as far as possible from the drains and should under no circumstances be used to patch or repair the road surface as the material is usually uniformly graded (i.e. single sized particles) and the material is generally non-plastic**.

Excessive silting of drains is indicative of inadequate water flow velocities while erosion is indicative of excessive velocities. An ideal drain should be graded to provide the optimum velocity with no siltation or erosion.

The maintenance of culverts is necessarily a labour intensive operation and should be carried out regularly to avoid damage to the culvert and surroundings, should they become blocked and flooding occurs. It is important once again that the material removed from the culverts is not used to maintain the road and is disposed of as far as practically possible from the culvert. **Cleaning of the outlet of culverts to ensure free-flow conditions on the downstream side should not be neglected**.

5.1.3 Surface maintenance

The maintenance of the surface of unsealed roads is the major cost in the routine maintenance programme. Patching and blading are the main activities applied to maintain the road surface.

Patching

Patching of unsealed roads is done by filling potholes with suitable wearing course material. Patching can only be effective if the pothole is properly prepared and the material is moistened and properly compacted.

Patching should make use of the same material as the wearing course gravel (excluding material larger than 37.5 mm). Potholes should be cleaned out, the loose material removed from the sides, the bottom and sides of the hole moistened with water, and then the hole back-filled with moist gravel in 50 to 100 mm layers. Each layer should be compacted (a hand rammer is adequate) until the hole is filled to about 10 mm above the surrounding road.

Grader blading
The standard procedure for surface maintenance is grader blading. Grader blading may be carried out at anything from once a week to twelve monthly intervals depending on the climate, traffic and required Level of Serviceability.

A grader is run across the surface of the road (in no higher than 2nd gear and speed not exceeding 8 km/h) with the blade set to smooth and shape the surface. **After grading, no potholes, corrugations, excessive loose material, large boulders, ruts or erosion channels should be present and straight portions of the road should have a definite crown and crossfall while curves should have an adequate superelevation for safety**. Experience has, however, shown that crossfalls and superelevations greater than about 5% result in excessive erosion. A balance is required for the superelevation not to result in erosion but to be adequately safe.

Blading should preferably be carried out during periods of average moisture when the material is most easily cut, moved and compacted. Experience has, in fact, shown that during the dry season, the hard upper crust or "blad" should not be cut. If blading is deemed to be essential during the dry season, it is best to blade the loose material to windrow at the side of the road and wait until rain moistens it before re-spreading it. It is essential that drains are cut through the windrows to allow any rain that falls to flow away from the road. A significantly improved performance will be obtained if the material is graded in a moist condition and then compacted before opening to traffic. The use of a "free roller", a relatively lightweight roller attached to the back of the grader has been described from Australia (ARRB, 2000). Although light, the results of this rolling are described as being better than no rolling.

Different forms of grader blading are applied in southern Africa depending on:

- Condition of the road and in particular the shape, occurrence and depth of distress
- Material quality and oversize
- Availability of maintenance material

In general, blading can be classified as either light or heavy during wet or dry conditions. For purposes of communication the following definitions apply regarding "Wet" and "Dry" blading:

Dry blading
Two different opinions are held, namely:

- Blading (light or heavy) without any form of additional moisture and applied in areas where there is no water available and/ or extremely low rainfall areas.
- Blading (light or heavy) without a water bowser, generally during or after rainy periods.

For purposes of standardisation and communication, the latter strategy will be referred to as "Rain Blading".

Wet blading
Wet blading is generally referred to as any form of blading making use of a water bowser to moisten the surface material.

Light blading
Light blading refers to blading with a motor grader without disturbance to the existing hard crust. Light blading (smoothing) could consist of a light trimming of the road surface on a routine basis. Light blading is considered to be the appropriate routine maintenance activity during early life after regravelling operations when defects are less than 25 mm in depth and suitable "maintenance material" is still available.

<u>Approach A</u>
During the dry season, the loose surface material should be moved towards the side of the road, while during the wet season the loose material should be graded towards the centre of the road (TRRL, 1981). It must be remembered, however, that the fine material is slowly lost from the road surface in the form of dust and the repeated return of the loose surface material which is deficient in fines may lead to the formation of corrugations.

Approach B

This involves the removal of loose, cohesionless (often coarse) material from the road surface and the distribution of slightly plastic, fine and preferably moist material over the width of the surface to replace ravelled material. The source of spare material for this purpose varies from area to area, eg,

- During regravelling the surface width is increased slightly to “stock” maintenance material,
- Additional maintenance material is kept in windrows on the side of the road after regravelling for this particular purpose, or
- In situ material is brought in from side drains for this purpose.

Approach C (Sand cushioning)

Sand cushioning is a process whereby a thin layer of sand is spread onto a road surface in order to reduce gravel loss, to minimise the transmission of the underlying roughness of the road surface to traffic and to limit base deterioration. The process is generally only suited to very low traffic volumes and areas where there is an abundance of suitable sandy material adjacent to the road.

A layer of fine sand, preferably with 100% finer than 2.0 mm, is spread to a thickness of approximately 40 mm and maintained through regular light blading, or by dragging a set of 5 truck tyres. Specific requirements for the material used for sand cushioning have been identified (Jones, 1998)

Heavy blading/ Grading

Heavy blading should be carried out when inspection reports indicate defects up to 50 mm. The road surface is moistened, cut to the bottom of the deformations, reshaped and compacted (TRRL, 1981).

Heavy blading is often necessary when "fixed corrugations" have formed. These corrugations may need initial tining or deeper cutting to break them up before being graded and recompacted. The use of carbide tips fitted to the grader blade improves the ability to scarify and loosen the upper 50 mm or so of the layer,

Labour-intensive maintenance

For labour intensive maintenance, and in developing areas, use of simple devices such as "camber boards" should be encouraged to raise the overall standard of the maintenance.

Common problems

A common problem caused by poor grading practices is damming of water on the roads by windrows left at the edge of the road. Often the material deposited at the end of the grader blade during the last run forms a bank which retains water. This should not be permitted and should either be removed by the grader, or manually after grading. As a minimum, openings should be made in the windrow at strategic positions to allow surface water to flow through it and escape from the road. Some grader operators keep the windrow at the edge of the road prism and blade it onto the road when it is damp and will bind with the existing surface, ie, it will not create a loose layer. Excessive grader maintenance with the production of banks often results in the level of the road being below the adjacent shoulders. Heavy grading and reshaping should be carried out in this case to avoid canalisation of the water along the road surface.

Grading can make some roads rougher, especially those which are slightly "self¬-cementing" and form a crust or "blad" or those with large stones as they often tend to be torn up under the grader. Spot-regravelling is usually required to patch these (TRRL, 1981). Excessive large stones cause problems with grader blading, as the stones are plucked out and dragged along the road causing long, deep gouges. They also cause excessive wear to the grader blades.

Loose material is a significant problem on unsealed roads. Many single vehicle accidents on unsealed roads are caused by windrows ("sandwalletjies") of loose material on the roads. These windrows interfere with the directional stability of the vehicles (the higher the vehicle speed, the greater the interference) which may eventually overturn; the higher the vehicle speed, the greater the interference. It is important that these windrows are not permitted to become higher than 75 mm. In addition to the vehicle handling aspect, high windrows often conceal large stones which can cause extensive damage to the under parts of vehicles (especially modern compact cars with ground clearances of less than 150 mm).

Some grader operators place a thick layer of mixed material (sand, gravel and boulders) over the entire road. This results in damage to vehicles (windscreens in particular), decreased safety, increased rolling resistance of the vehicles (and hence fuel consumption), the quicker development of corrugations (as the fine material has usually been removed) and an overall poorer riding quality. The use of these thick "sand blankets" or "sand duvets" should be avoided. If "sand blankets" are used, the maintenance gang should ensure that no loose stones larger than 25 mm are incorporated in the "sand blanket" or obscured by it. If such stones are obscured by the “sand blanket”, it is too thick.

The development of ruts should be controlled during grader maintenance. Grading should occur before ruts have become deeper than about 25 mm, with the ruts being filled with loose material. Prolonged rut development results in channelling of run-off and subsequent erosion and loss of shape of the road. **On excessively wide roads (more than 8 m) the vehicles tend to hollow out the centre of the road and the crown is totally destroyed**. Particular care should be taken to restore and maintain this crown during grader blading.

The use of selective maintenance of certain links or even sections of a link is often appropriate and economically justifiable.

Instances have been observed where permanent corrugations with a 2.5 to 3 m wave-length occur in the road. These have been caused by bouncing of the grader during blading and once formed cannot be removed by the same grader without tining, as their wave-length is the same as the distance between the front wheels of the grader and the blade. A grader with a different wheel-blade length can be used to cut them, but ripping is preferable. Excessive speed of the grader is also a contributory factor in the formation of such corrugations.

A less expensive, but equally effective, method of blading is to use underbody blades mounted beneath trucks or towed graders.

The lowest class of surface maintenance is dragging. This has not been used to any significant extent in southern Africa but is recommended in developing areas for sandy roads carrying less than about 50 vehicles per day. Many different types of drag are available, ranging from steel bars, branches or small trees, tyre drags, or custom-made drags. Dragging in association with sand cushioning has proved to be highly cost-effective (Jones, 1998).

Proper training of grader operators is the basis of good grader maintenance practice. Although experience is extremely important, it is recommended that all grader operators are given high quality training in the theoretical and practical aspects of unsealed road maintenance and regular refresher courses. Bad maintenance habits (eg "sand duvets", windrows along the edge of the road, etc) should be explicitly addressed.

The use of compaction after grader blading is usually highly beneficial. This benefit, is however, only achieved if the material is moist before compaction and must thus be done either after rainfall or after water spraying of the material.

2.20 ***Periodic maintenance***

5.2.1 Reshaping

This activity is carried out when **defects are typically more than 50 mm in depth and only when sufficient material thickness of appropriate quality exists, and the road level is still adequate relative to the adjacent ground level and/or side drainage is adequate**.

Reshaping generally consists of:

- Loosening material to a depth of 50 – 100 mm,
- Removal of oversize material,
- Moistening,
- Reshaping of the road surface, and
- Compaction using grid rollers or vibratory rollers and pneumatic rollers..

5.2.2 Reworking

Reworking is generally referred to as the activity carried out to break down oversize material in an existing layer of adequate thickness, re-shaping and compaction. Breaking down the existing layer material may be done by:

- Loosening the layer to full depth and windrowing it,
- Extensive grid rolling, or
- Using specialised equipment, e.g., a "Rockbuster".

5.2.3 Forming

Forming refers to shaping of the road-bed to ensure adequate road levels, proper side drainage, camber and crossfall. Additional material is often imported or obtained from shallow cuttings to improve drainage and alignment. The term "construction" is also used by some practitioners for this activity.

Notes

- This activity would normally be the first upgrade from a track to a "minimum standard" formed road.
- Due to good quality subgrade materials, often found in southern Africa, materials obtained from constructing the side drains are utilised to form the road bed on which a suitable wearing course may be constructed.

5.2.4 Spot gravelling

Spot (or patch) gravelling refers, for purposes of this document, to the regravelling of short sections on a road, typically only on curves, steep gradients, isolated rock outcrops, etc, where extensive gravel loss has occurred or areas have been damaged due to washaways. The purpose, therefore, is to ensure similar performance over the entire road

It is useful during the regravelling process to stockpile supplies of wearing course aggregate in the borrow pit, at the maintenance camp or along the road at strategic places for future localised maintenance purposes.

5.2.5 Regravelling

Regravelling generally refers to the addition of a suitable wearing course layer, typically 100 mm to 150 mm in thickness over the entire length or substantial lengths of the road. Regravelling is the most expensive single maintenance procedure for unsealed roads. It is carried out when the imported gravel on the road has been almost totally lost through erosion by rain and wind or abrasion by traffic or when inappropriate material exists on the road. **Regravelling should take place before the subgrade is exposed in order to avoid deformation which will necessitate reconstruction, and loss of the strength which has been built up in the subgrade by traffic moulding over time**.

Improvements to any drainage deficiencies should be made prior to regravelling. The quality of the new gravel should comply with the required specifications (Section 2.9).

The regravelling process should follow the same procedure as the construction process with respect to the winning, hauling, spreading and compaction of the material as discussed in sections 2.14 and 2.15.

Due to the cost of regravelling and the availability of construction equipment, a special effort is made to:

- Improve drainage through forming and/or installation of culverts,
- Reduce accident risks through small changes in the alignment and camber, and
- Obtain sufficient pavement strength through proper roadbed preparation, suitable materials and sufficient thickness.

2.21 *Emergency maintenance*

After unusually heavy precipitation or abnormal use of the road (eg, many large timber trucks following clearing of a forest or plantation), unsealed roads often show excessive damage or wear. Emergency maintenance would be provided to ensure that the road was returned to an acceptable condition for the traffic that it normally caters for.

2.22 *Labour intensive maintenance*

Other than grader blading, most maintenance activities can be effectively carried out using labour intensive methods. This has the advantages of creating sustainable employment in rural areas, developing small contractors and effectively improving the condition of many very lightly trafficked unsealed roads. Activities such as the repair of distinct potholes and the loosening of fixed corrugations can be very effectively done using labour (GDPTRW, 2008).

These activities can be contracted on a lengthman basis, which is highly conducive to the creation of local employment and development of local contractors and has been successfully utilised in South Africa, eg, the Zibambele Programme in KwaZulu Natal. It is important that the required Levels of Serviceability, activities to be carried out and employment conditions are clearly understood by all parties and effective contractual arrangements are entered into for each contractor.

3 GRAVEL ROAD MANAGEMENT

3.1 *Management Systems*

The annual expenditure on maintenance of unpaved roads in southern Africa is of the same order as that of paved roads. The management of maintenance is therefore necessary to maximise the benefit from the available finance. Gravel Road Management Systems should provide answers to questions such as the following (Visser, 1986):

- What budget is required?
- How many graders and staff are required?
- How often should each road be bladed?
- What is the resultant Level of Serviceability?
- What volume of gravel needs to be replaced annually?
- Which roads should be upgraded to bituminous standard?

6.1.1 Gravel road management systems (GRMS)

Over the last decade many road authorities in southern Africa have established Gravel Roads Management Systems (GRMS), mostly to assist with strategic and tactical planning of gravel road networks. Their aim is to:

- Define the current condition, trends of deterioration and backlog
- Identify and prioritise periodic maintenance projects
- Identify and prioritise “upgrading to surfaced standard” projects
- Provide general guidance regarding optimal blading frequencies
- Determine optimal budget requirements and impact of funding constraints at a strategic level

The input data for these systems is, however, frequently inaccurate, scarce or outdated and only a few of the schemes currently implemented in southern Africa are actually functioning efficiently. Some authorities have integrated Gravel Road Management Systems into their Integrated Road Management Systems to allow total road network optimisation and allocation of funding to upgrading, periodic maintenance and routine maintenance budget votes. Typical models for estimating the gravel loss and inputs for the determination of blading frequency are provided in Appendix A.

In order to provide a consistent rating of the condition of unsealed roads within a jurisdiction, TMH 12 (Jones and Paige-Green, 2000) was developed in a similar manner to TMH 9 (1992) for the rating of paved roads. This allows a uniform description of various defects and conditions affecting the performance of unsealed roads by different evaluators. These can then be used in a GRMS to quantify the condition of the elements of the road network and produce various forms of comparative ratings, eg, discrete levels such as poor to good or an actual continuous series of values between 0 and 100.

6.1.2 Maintenance Management Systems (MMS)

Maintenance Management Systems (MMS) are typically more operational level systems, dealing with the day-to-day routine maintenance activities such as blading programming. Although maintenance management could involve numerous activities including materials, costing and project management components, this section will focus mainly on the management of grader maintenance.

6.1.3 Borrow Pit Management Systems (BPMS)

Large investments are made in the location and testing of materials for any gravel location or regravelling project. It is essential that this data is captured for future use in a system that facilitates the use of available data and test results in material location exercises.

Comprehensive Material Information Systems have been developed and implemented in southern Africa and incorporate borrow pits, commercial sources and potential water sources.

3.2 *Levels of Serviceability*

Maintenance requirements and costs are based almost entirely on the required Level of Serviceability which should be appropriate to the traffic. A Level of Serviceability acceptable for a remote, rural unsealed road with low traffic would generally be unacceptable for an unsealed feeder road to a densely populated developing area. The following guidelines for Levels of Serviceability for unsealed roads based on local performance criteria should be taken as a basis in southern Africa (Table 18):

Table 18 Guidelines for Levels of Serviceability

	Required standards		
Level of Serviceability	Max Roughness[a]	Dustiness[b]	Impassability
5	15	5	Frequently
4	11	3	< 5 days/yr
3	9	3	Never
2	8	3	Never
1	6	1	Never

a International Roughness Index (IRI) in m/km
b See Jones and Paige-Green (2000)

The maximum roughness is generally used to determine the grader blading frequency in maintenance management systems and can be programmed into the maintenance management system.

The Level of Serviceability should be adapted to the primary use of the road. For example, Important tourist routes or a farm access road over which a product sensitive to extremely rough roads, such as eggs, may be maintained at a Level of Serviceability higher than that which the traffic dictates, for obvious reasons.

As the availability of road roughness measuring equipment is limited in South Africa, it is not usually possible to routinely measure the International Roughness Index (IRI). An approximate indication of the approximate speed at which various degrees of road roughness can be comfortably travelled in a typical small pick-up or saloon car is provided to assist in estimating road roughness (Table 19). The results depend to some extent on the cause of the roughness, eg, corrugations would have a different effect on comfortable travel speed to transverse erosion.

Table 19 Estimation of IRI on the basis of comfortable travel speed

Roughness (IRI)	Approximate comfortable travel speed (km/h)*
15	<35
12.5	45
10	60
7.5	80
5	>100

* - This is a function of the type and condition of the vehicle but provides a reasonable estimate

It is also important that the classification of any specific road being designed allows compatibility between the geometric design, the materials used and the expected level of serviceability. An example of this compatibility is discussed in Appendix B.

3.3 *Performance modelling*

Performance models developed for southern African conditions are provided and are described in Appendix A and can be simply calculated using conventional Spreadsheet software.

Three aspects of performance modelling addressed are:

- Roughness deterioration
- Roughness improvement due to blading
- Gravel loss

It can be seen from the models in Appendix A that the main factors influencing performance are:

- Traffic volume
- Material properties
- Climate

Implementing improved methods for material selection, drainage, compaction and maintenance as described in this document in the Western Cape since 2000 has resulted in much better performance than predicted by these models. These models, however, give reasonable indications of wearing course deterioration for roads constructed conventionally.

3.4 *Optimisation of blading programming*

6.4.1 Blading frequency

The appropriate blading frequency is a function of:

- The Level of Serviceability selected for each road section (refer Section 3.2)
- The rate of deterioration due to traffic, materials, climate, environment (Appendix A)
- Improvement due to blading (Appendix A)
- Type/ method of blading applied (refer Section 2.19)
- Maintenance strategy of the authority and current condition

Maintenance strategy of the authority
Two basic maintenance strategies are defined namely

- Heavy blading only
  This is the current practice in most authorities after construction or regravelling and allows deterioration to a level of user complaint (Approximate IRI = ± 6 m/km) before blading
- Light blading, heavy blading and reshaping
  A strategy resulting in huge savings in vehicle operation costs is to maintain the gravel road surface by regular light blading, heavy blading when required and reshaping.

Additional effort during design and construction of a gravel road could result in only light blading required for up to five years. Although the effect of light blading is not modelled with current models, experience indicates:

- That double the frequency of heavy blading is required
- Only single blade passes are required
- The speed of blading is double that of heavy blading

Although this strategy is considered far more cost-effective than less frequent heavy blading, it can only be applied when the condition of the gravel road is still good, climatic conditions are favourable and sufficient maintenance material is available to replace lost fines.

6.4.2 Optimising grader maintenance

The purpose of this exercise is to plan and execute blading activities on a road network to maintain the required Level of Serviceability.

The number of graders required (also type of graders) is dependent on:

- Required blading frequency as discussed above
- Number of blade passes required due to the road width, availability of spreading material, condition of the surface, strategy of the authority
- Effectiveness (blade km per day) due to type of blading, topography, traffic accommodation, distance to site, available working hours, skill of operator

Number of blade passes required

The number of blade passes required is typically calculated as follows:

1. Travel-way width divided by 1.9 (rounded) to the next even number (2, 4,or 6)
2. Additional blade pass to accumulate maintenance material from a windrow, shoulder or side drain
3. Double the above summed number in case of heavy blading strategy or need
4. Multiply the number of blade passes calculated by the required blading frequency

Example 1

The strategy on a specific road of 7m width with coarse shale wearing course is to apply heavy wet blading 8 times per year:

1. 7 / 1.9 = 3.7 = 4
2. 4 + 1 = 5
3. 5 x 2 = 10
4. 10 x 8 = 80

Therefore 80 blade passes would be required per year.

Effectiveness

The effectiveness of blading for this purpose is defined as the blade km that one grader can do in a year. Factors governing the effectiveness are:

- Hours available due to distance to site, policy regarding "returning to base", grader availability, due to condition and emergency repairs
- Speed of blading due to type of blading, topography, material, operator experience, traffic accommodation, availability of water

The effectiveness of blading typically varies between 16 blade km/ day (difficult conditions) to 70 blade km/day (easy conditions).

Planning

Effective planning of blading operations and managing a grader fleet requires an iterative process, starting off with an estimated programme based on experience, required level of service and the expected blading frequency required per blading section. Blading sections refer to road sections that are managed as a unit and could be combinations of different road sections or even roads. The initial programme and budget requirement is often referred to as a "maintenance business plan". Steps towards such a business plan are as follows:

- Define/ Verify the road network to be maintained
- Define uniform maintenance sections
- Define/ Confirm appropriate level of service
- Estimate/ determine required blading frequency
- Determine appropriate type of blading
- Determine required blade kilometers per year
- Allocate grader productivity per maintenance section
- Define practical maintenance areas
- Determine required grader fleet
- Balance grader requirement per maintenance area
- Devise overall District strategy
- Compile blading schedules (Work programmes)

Note: Situations often occur where an area is defined on the basis of natural boundaries such as mountain ranges and rivers, resulting in under-utilisation of a grader. A strategy often applied is to "lend" such graders to a neighbouring ward for short periods e.g., one month, or to first utilise such a grader for emergency repairs/ washaways in other wards.

Should insufficient funds be available for the initial business plan, the required Level of Serviceability for each blading section has to be adjusted. This will result in a higher average roughness and consequently in higher vehicle operating costs.

Once the business plan matches the available funding level, the next step would be to define periods of compulsory blading on specific sections, eg:

- Harvesting periods
- Holiday periods

In addition, efforts should be made to optimise the use of natural moisture in the wearing course as a result of rain.

Typically eleven cycles are defined (based on 11 months work) and the timing of bladings allocated to balance the total eleven-cycle programme.

Regular district inspections are required (at least inspecting the sections to be bladed during the next cycle) to:

- Verify deterioration/ adherence to required level of service and, therefore, the required blading frequency
- verify the type of blading required
- need for additional plant/ equipment e.g. water bowser

Note: This information, per blading section, is used to update the "business plan" half-way" through the year, as well as for the next year.

3.5 *Simplified maintenance frequencies*

In small areas or where an authority (eg, mine or forest) has only a limited length of unsealed roads, it is not practicable to operate a GRMS. In these cases, simple guidelines for the optimum grading and regravelling frequencies are useful. Bearing in mind that these will typically depend on the type and nature of the traffic, the environmental conditions and most importantly, the quality of the wearing course materials, the following are only rough guides.

It has been proposed that grading is usually required after the passage of about 4000 to 8000 vehicles (Fossberg *et al*, 1988 in ARRB, 2000). This would typically equate to grading the road about once every 3 months for traffic between 50 and 100 vpd. Gravel loss for an average road carrying similar traffic would be about 20 - 25 mm per year, indicating a regravelling frequency of once every 6 or 7 years. Gravel losses significantly higher than this indicate either that much higher traffic is carried than expected, a poor material is being used as a wearing course or the blading frequency is too high.

3.6 *Cost effectiveness of maintenance*

6.6.1 Maintenance Costs

Typical costs of gravel road maintenance activities (2008 prices) are provided in Table 20.

Table 20 Typical costs of gravel maintenance activities (2008 prices)

Activity	Unit	Cost (2008)
Blading (based on 25km dry/ rain blade km/day)	Blade km	R 120
Blading (based on 25km "Wet" blade km/day)	Blade km	R 240
Reshape (Wearing course 50 – 100mm) – 7 m	km	R 40 000 – R 60 000
Rework (Break down and reshape) – 7 m	km	R 80 000 – R100 000
Regravel only (125 mm) 7m wide	km	R 100 000 – R160 000
Spot gravelling		R 180 000 – R 250 000
Forming and road bed preparation (Excluding imported material)	km	R 80 000 – R 120 000
Reforming, roadbed preparation, side drainage and regravel	km	R 200 000 – R 280 000

Notes:

- Costs exclude establishment, traffic accommodation, CPA , contingencies and VAT
- Cost provided are only estimates as information obtained for this purpose show high variability

6.6.2 Effectiveness of maintenance

The roughness of a road is the major controllable factor affecting the vehicle operating costs on that road. Maintenance is the only means of reducing the roughness and is therefore directly related to the vehicle operating cost.

The vehicle operating cost (VOC) on an unsealed road based purely on the roughness can be determined from various operating costs models (eg, HDM 4)). This does not take into account the effect of dust on the vehicle occupants or surroundings or the safety aspects of the road. The safety issue is difficult to take into account as on rough roads the vehicles normally travel at slower speeds and although the directional stability of the vehicles is decreased the lower speed results in a reduced chance of an accident and lesser consequences. On smooth roads, however, the higher speeds may result in an increased chance of accidents with more sever consequences as a result of poor driving ability.

Figure 16 shows the typical relationship between road roughness and vehicle operating costs for a range of vehicles travelling at typical speeds (60 to 80 km/h).

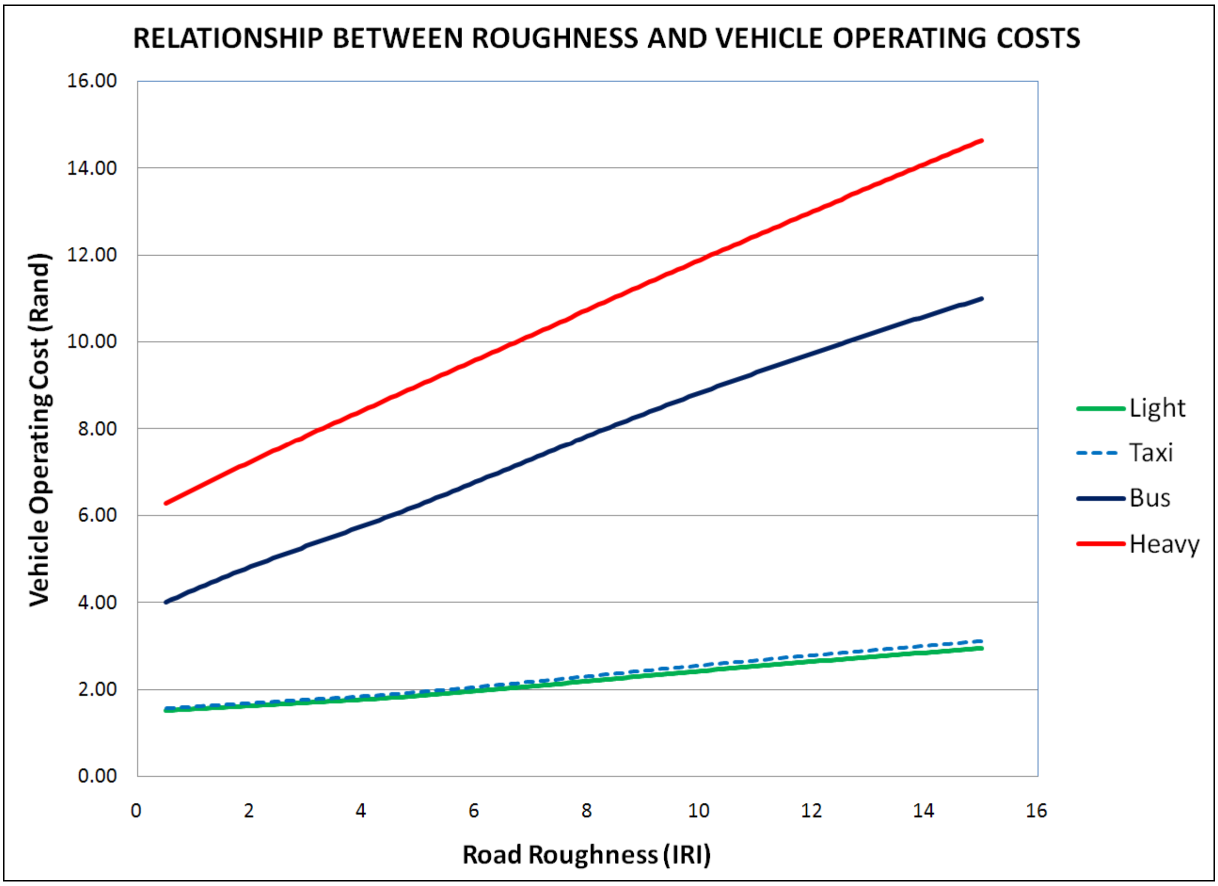


Figure 16 Relationship between road roughness (IRI) and vehicle operating costs (2007 R/km) for light vehicles, taxis, buses and heavy vehicles (Reference WCPA)

3.7 *Maintenance records*

It is essential that the records of all maintenance activities are kept up to date and filed for later reference. Maintenance activities are typically recorded daily in diaries and standard report format as well as being electronically stored.

Documents such as blading records (date and length graded), regravelling records (dates, material sources and properties, procurement and delivery documents, payment records, etc) need be retained for various uses. They are obviously of immense value in determining plant and labour productivity as well as cross checking the predictions of Gravel Road Management Systems. However, such maintenance records can prove invaluable in accident litigation cases, should these occur.

Electronic records should be properly backed up and stored in easily readable formats under adequately secure conditions.

4 INVESTIGATION AND MAINTENANCE MEASURE SELECTION

4.1 *General*

The purpose of this section is to assist practitioners in selecting appropriate maintenance/ remedial measures. Due to the variability of conditions along unsurfaced roads, several maintenance measures might be necessary along a periodic maintenance project, the detail of which should be provided to the contractor or in-house construction team on typical “line diagrams”.

4.2 *Principles*

7.2.1. Minimum standards

Given the low traffic volumes on gravel roads in southern Africa and the cost of maintenance measures, activities such as regravelling can often not be warranted from an economic perspective. Cognisance is, however, taken that longer term economic benefits, resulting from maintenance/ improvement, are often difficult to quantify and therefore, not necessarily taken into account in benefit/cost calculations.

A road authority still has the obligation to ensure all-weather access on all proclaimed roads as safely as possible. Although minimum standards for safety and accessibility have not been defined, the majority of proclaimed roads, except for minor roads, are passable throughout the year. However, extraordinarily heavy rainfall and resultant flooding of roads does occur from time to time. Inaccessibility due to such occurrences cannot be addressed through periodic maintenance activities. In most known cases of frequent flooding, alternative routes are available.

7.2.2. Maintainability

The emphasis should be to keep unsurfaced low volume roads in a safe, accessible and maintainable condition at least cost. **This implies that even if a road has been gravelled with an imported gravel before, it does not necessarily mean that if the wearing course is less than 25mm thick, it must be regravelled. The in-situ subgrade material of numerous roads in southern Africa is of adequate quality to effectively carry reasonable traffic volumes**.

Should routine maintenance become ineffective or not possible, leading to impassibility/inaccessibility or unsafe situations, more costly measures are inevitable. **It should be noted that even though several low volume roads could be described, in terms of the current visual assessment methodology as poor, and even if the effect of blading only temporarily improves the riding comfort, the road could still be safe and accessible**. Cognisance should be taken of the traffic volumes, geometry, climate, the purpose of the road and the distance travelled.

7.2.3. Minimise development of new borrow pits

Due to the environmental impact as well as the time constraints and costs related to approval and development of borrow pits, development of new borrow pits should be minimised

4.3 *Investigation*

7.3.1. General

Investigations for periodic maintenance projects normally include:

- Road and condition survey
- Obtaining additional information from local residents, road managers and maintenance foremen
- Material investigation and borrow pit approval
- Selecting appropriate maintenance activities
- Design, specifications and presentation

4.4 *Road and condition survey*

The main purpose of this activity is to **identify uniform sections along the road, requiring different treatments to rectify**:
- Unsafe geometric situations
- Pavement structure
- Wearing course
- Side and cross drainage

Specific attention is given to rectify situations that impact on safety, accessibility, mobility, maintainability and material performance.

It is considered good practice and often a requirement by road authorities to check and to report:
- Existing wearing course thickness and quality along the road
- Structural capacity along suspect areas (using DCP)
- Positions of frequent drainage problems/ washaways
- Accident red spots
- Unsafe geometric situations
- Illegal services and access roads

TMH 12 (Jones and Paige-Green, 2000) is a useful document to assist with obtaining onsistent ratings of the wearing course condition during such road surveys.

4.5 *Additional information*

Useful information could be obtained from residents, maintenance foremen and even grader operators regarding:
- Performance of the road, materials and drainage problems at specific positions
- Traffic type, distribution and seasonal variation

In addition, cognisance should be taken that good information might be available from Gravel Road Management Systems

4.6 *Material investigation and borrow pit approval*

Material investigation processes are fully described in this document (Section 2.9 and2.11). However, it is often important to conduct a centre line survey and testing of existing materials as their properties might be ideal for mixing with borrow pit material (Section 2.10) or treatment with of chemical additives (Section 6.2).

4.7 *Selecting appropriate maintenance activities*

7.7.1. General

Any periodic maintenance project could comprise a combination of several activities. Although an activity could be identified for a project and budgeting purposes, the compilation of final activities occurs during the detailed investigation and design phase.

The design process comprises visual assessment of road shape and drainage, sampling and testing of centre line materials, measurement of layer thickness and identification of obvious safety hazards. Based on the information obtained the road is subdivided into uniform sections, each requiring a specific activity. The standard periodic maintenance activities serve as guidelines for activity selection.

7.7.2. Reshaping

Purpose

The main purpose is to restore a road with poor crossfall to a hard, smooth road with a good crossfall and crust (Figure 17).

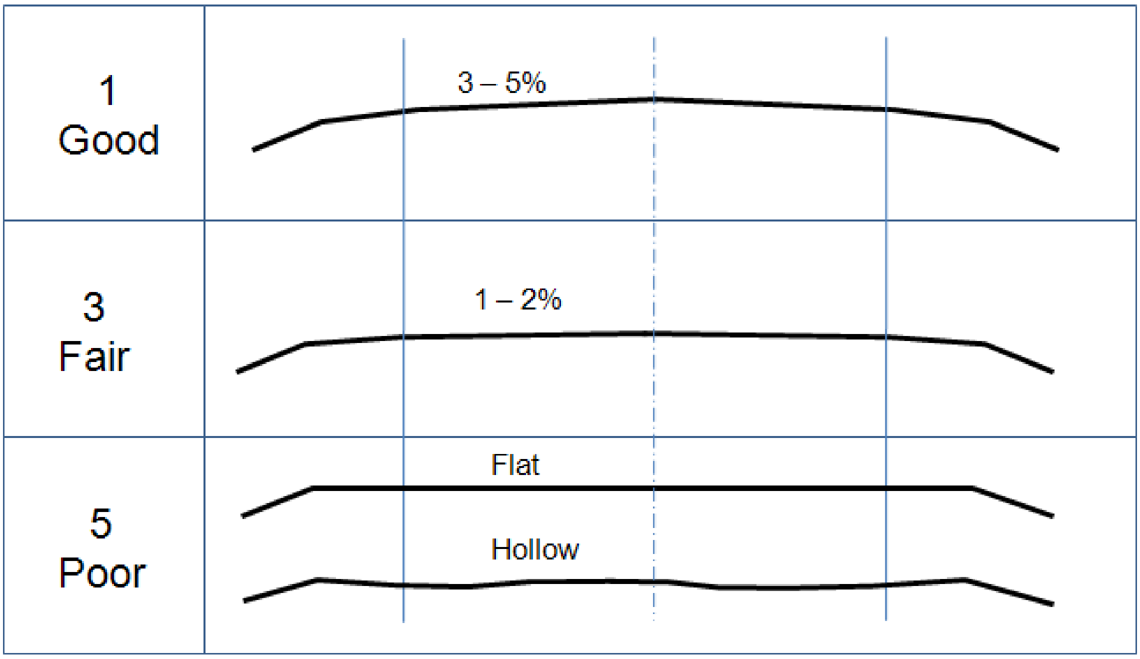


Figure 17 Description of existing road shape

Activity

Reshaping generally consists of:

- Loosening material to a depth of 50 mm – 100 mm (mixing of the remaining wearing course and in-situ materials could be considered),
- Removal of oversize material,
- Moistening,
- Reshaping of the road surface, and
- Compaction using grid rollers/vibratory rollers and pneumatic rollers.

When appropriate

The activity is carried out when defects are typically more than 50 mm in depth and only when sufficient material thickness of appropriate quality exists and the road level is still adequate, relative to the adjacent ground level, and/or the side drainage is adequate.

When not appropriate

The activity is not effective when:

- Rock outcrops occur frequently
- High percentage of oversize material exists in the layer,
- Material is of poor quality e.g., loose sand, clay

Typical cost

Refer Table 20.

Notes:

- Reshaping is considered by several practitioners as an essential activity to optimise performance of the road surface between regravelling operations.

- An assessment must be made of the quality of the remaining wearing course material and the in-situ material quality if mixing of the two material types will occur during the reshaping exercise.
- Limited quantities of additional material could be imported from borrow pits or preferably from excavations with the road reserve.
- Raising the road level is not always required as sufficient side drainage can often be obtained through cutting of side drains.
- Earth roads with suitable quality materials could be reshaped

7.7.3. Reworking

<u>Purpose</u>
The main purpose of “reworking” is to break down excessive oversize material within the existing wearing course to obtain a better performing material, when mechanical modification of the material is to be carried out, to reshape the prism and to improve effective maintainability through blading.

<u>Activity</u>
Reworking generally comprises the following activities:

- Loosening the layer to full depth and windrow,
- Extensive grid rolling, or
- Using specialised equipment, e.g., a “Rockbuster”,
- Re-mixing
- Moistening
- Shaping of the road surface, and
- Compaction using grid rollers/vibratory rollers and pneumatic rollers.

Note:
Re-mixing after grid rolling or processing with the "Rockbuster" must be done to ensure a uniform grading throughout the layer.

<u>When appropriate</u>
The activity is normally only selected when:

- A high percentage of oversize material exists, hampering effective improvement through blading
- When sufficient strength in the compacted sub-grade could be obtained to apply effective grid rolling (in case where other measures e.g. rock busting are not available)

<u>When not appropriate</u>

- Reshaping could be applied
- Rock outcrops occur frequently

<u>Typical cost</u>
The cost of reworking is a function of the measure selected to break down the material and the number of grid roller passes required. Typical costs are provided in Table 20.

Breaking down oversize material using the “Rockbuster” is usually more expensive and could increase the cost of “Reworking” by 20 to 50%.

Note: Although experimentation with the “Rockbuster” could improve the performance of materials, grid rolling is usually cheaper and is often equally effective with softer materials, correct speed and ballast and proper maintenance of the grid itself.
Also note that several roads have been constructed initially by placing large rocks/ oversize material as a “pioneer layer” on a poor subgrade, after which the wearing course was imported

7.7.4. Regravel

<u>Purpose</u>
The decision to regravel the full road section should only be made if the road can no longer be maintained with a grader alone.

Activity

Regravelling generally consists of:

- Forming if necessary
- Importing of suitable wearing course material
- Removal of oversize material if necessary,
- Moistening,
- Shaping of the road surface, and
- Compaction using grid rollers/vibratory rollers and pneumatic rollers.

When appropriate

The decision to regravel is considered inevitable when:

- Subgrade strength is/ will be inadequate to carry the traffic load within two years
- The rate of gravel loss would necessitate strengthening and/or the addition of better performing material within two years

When not appropriate

Regravelling under current financial circumstances is not considered appropriate if less costly maintenance measures could be applied to ensure accessibility, adequate safety and maintainability.

Notes:

- The thickness of regravel is dependent on the expected gravel loss and therefore highly dependent on the traffic volume, material, climate and construction quality.
- Minimum recommended thickness is 100 mm and the maximum 150 mm
- The width of regravel is dependent on the purpose of the road and traffic volumes to ensure safety and maintainability. Although guidelines are provided in the Gravel Manual, the effectiveness of the existing cross section should be evaluated and, if possible, be maintained.

Typical cost

Typical costs for regravelling are provided in **Table 20**.

7.7.5. Spot gravelling

Purpose

Spot gravelling refers, for purposes of this document, to the regravelling of short sections on a road, typically only on curves, steep gradients, isolated rock outcrops, etc., where extensive gravel loss has occurred or where areas have been damaged due to washaways.

Note:

Experience indicates that roads are often regravelled with a standard material thickness, regardless of the variation in the remaining wearing course thickness.

Activity

The activity comprises the same activities as normal regravelling, the only difference being the treatment of shorter distances at one time.

When appropriate

Spot gravelling is considered appropriate when:

- Occurrences of exposed poor subgrade and/or rock outcrops are isolated
- Remainder of the section is still maintainable and has an adequate thickness of good material

When not appropriate

Cognisance should be taken of the traffic volumes, rate of gravel loss on the entire section and the frequency of exposed poor subgrade/rock outcrops. Due to the higher unit cost, compared with regravelling, it may be more cost-effective to regravel the entire road section.

Note:

During the investigation and design phase, provision must be made for increased gravel thickness at localised positions of excessive gravel loss.

Typical cost

The cost of spot gravelling is highly dependent on the distance of and between work zones and could be double the cost per km when compared with full scale regravelling (Refer **Table 20**).

7.7.6. Forming / road bed preparation

Purpose

Forming refers to shaping of the roadbed to ensure adequate road levels, proper side drainage, camber and cross fall. Additional material is often imported or obtained from shallow cuttings to improve drainage and alignment.

For purposes of this document "forming" does not incorporate the importation of wearing course material. The activity of "side drainage improvement" and "reshaping" could have the same principle in mind. However, it could imply moving a substantial volume of material transversely across the formation.

Note:

On low volume roads it would be still more acceptable for the crown to be lower than the surrounding ground level (provided that the side-drains are effective) than the current situation as shown in Figure 18.

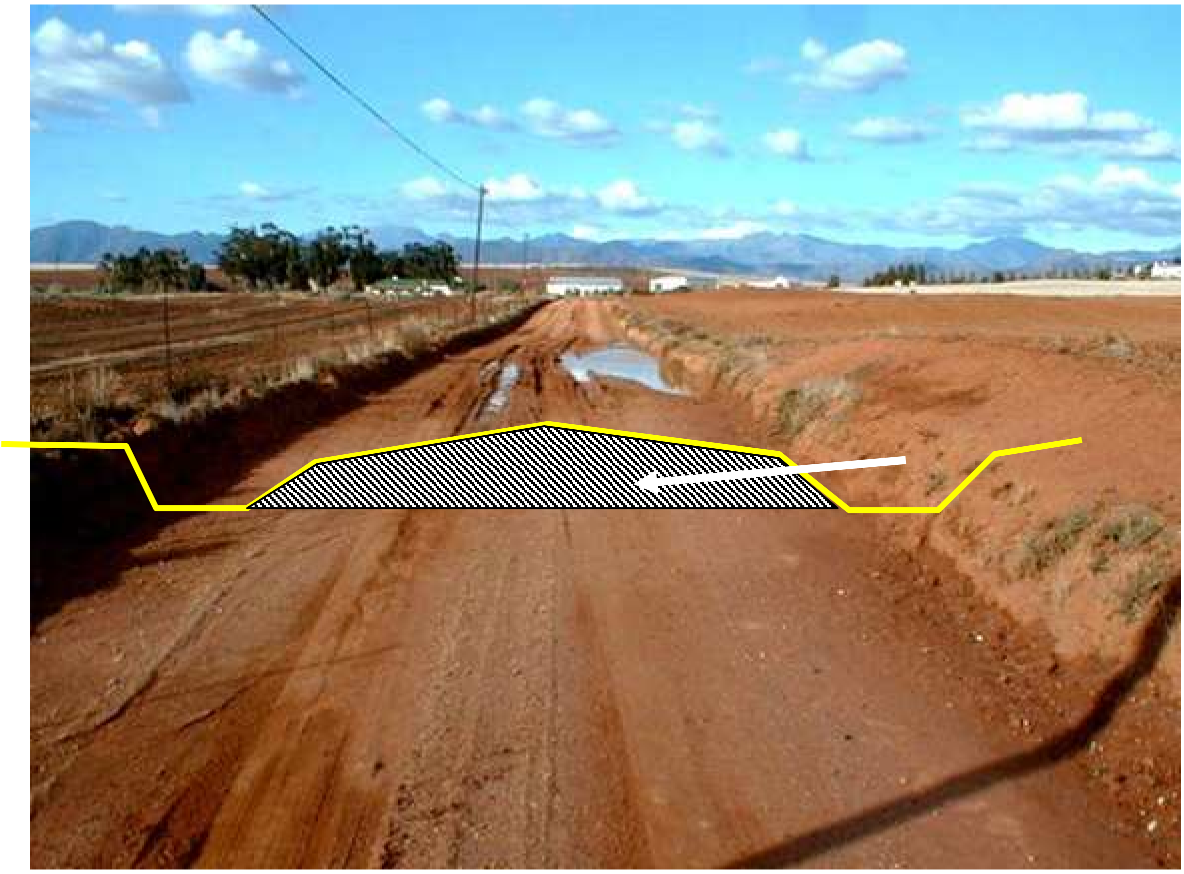


Figure 18 Forming to improve drainage

Activities

Activities include:

- Forming of the total road prism, utilising adjacent material or material excavated from side drains
- Compaction using grid rollers/vibratory rollers and pneumatic rolling

When appropriate

This activity would normally be the first upgrade from a track to a "Minimum standard" formed road. Forming is appropriate at any time that the side drainage and road prism or cross-section need improvement.

Notes

- Forming/ road bed preparation is an important activity as part of any periodic maintenance activity
- “Forming only” could be considered a maintenance measure which includes proper compaction of the roadbed after shaping of the road prism with material from the side drains of adequate quality

When not appropriate

Forming, which includes side drainage improvement, is seldom considered not appropriate. However, the level of work required to achieve an acceptable drainage system could vary dramatically from one road to the other.

The only time that the measure is considered inappropriate is when routine maintenance has been carried out to a high degree.

Notes

- Forming/ road bed preparation is seen an important activity as part of any periodic maintenance activity
- Due to good quality subgrade materials, often found in southern Africa, materials obtained from constructing the side drains are utilised to form the road bed on which a suitable wearing course may be constructed.

Typical cost

(Refer **Table 20**).

7.7.7. Drainage improvement

Surface drainage

Sufficient drainage of water from the road surface should be addressed by all periodic maintenance activities and routine blading.

Notes

- Experience indicates that the crossfall after construction should be 5 to 6 %. However, if the road carries large vehicles and the road width is less than 7m or winding, the maximum crossfall should be 4%.
- Effort should be made during routine blading to maintain a crossfall of at least 4%

Side drainage

Maintenance of side drainage is a continuous process and should be addressed during all routine and periodic maintenance activities. Rating of side drainage is illustrated in Figure 19.

Notes

- Table drains are more suitable in areas with sandy or erodible materials
- V-drains with frequent mitre drains are considered suitable in areas with hard in-situ materials

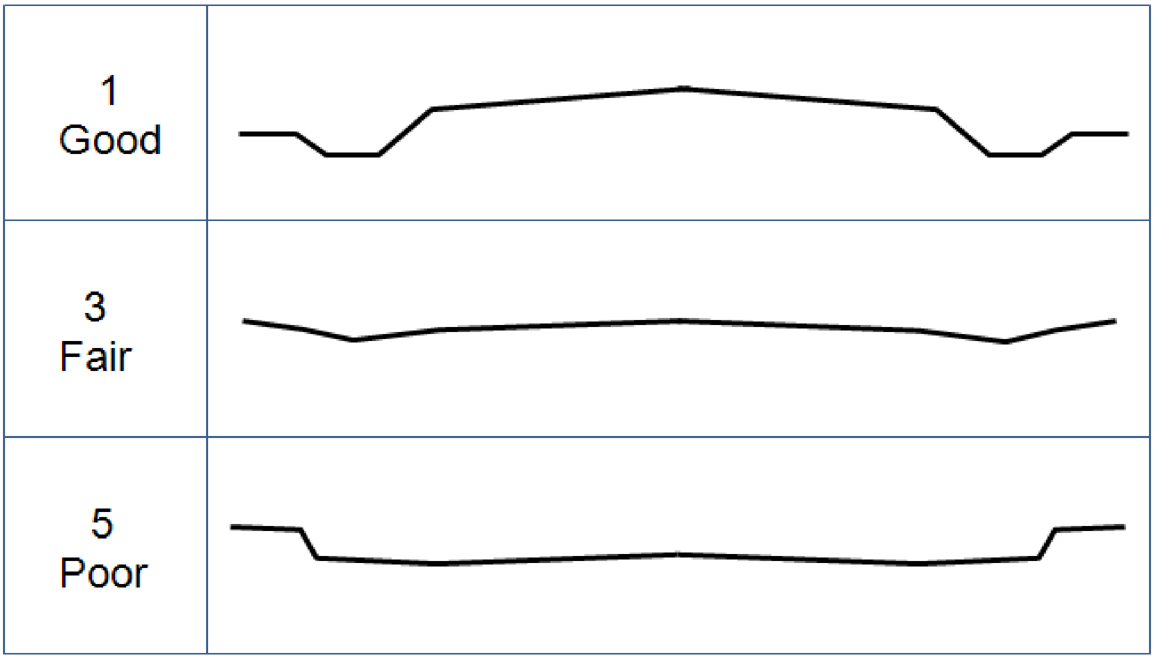


Figure 19 Guideline for rating side drainage effectiveness

Cross drainage

The decision to provide additional cross drainage structures and the type of such drainage depends on factors such as the minimum standards required for accessibility, availability of alternative routes, appropriateness for the situation, frequency of washaways, cost, etc.

Practitioners are referred to Section 2.6 of this document for appropriate solutions.

7.7.8. Simplified guidelines for measure selection

Figure 20 and Figure 21 assist with quick decision making for the selection of appropriate maintenance measures.

Notes

- The decision whether the threshold level of any criterion has been reached is a function of the road importance and traffic level. Therefore, the decision of the panel or design team is still subjective
- The term "construct" refers to substantial work to ensure acceptable levels of accessibility and/ or safety
- Providing adequate warning signs at unsafe positions along a road could reduce the need for substantial work dramatically

.

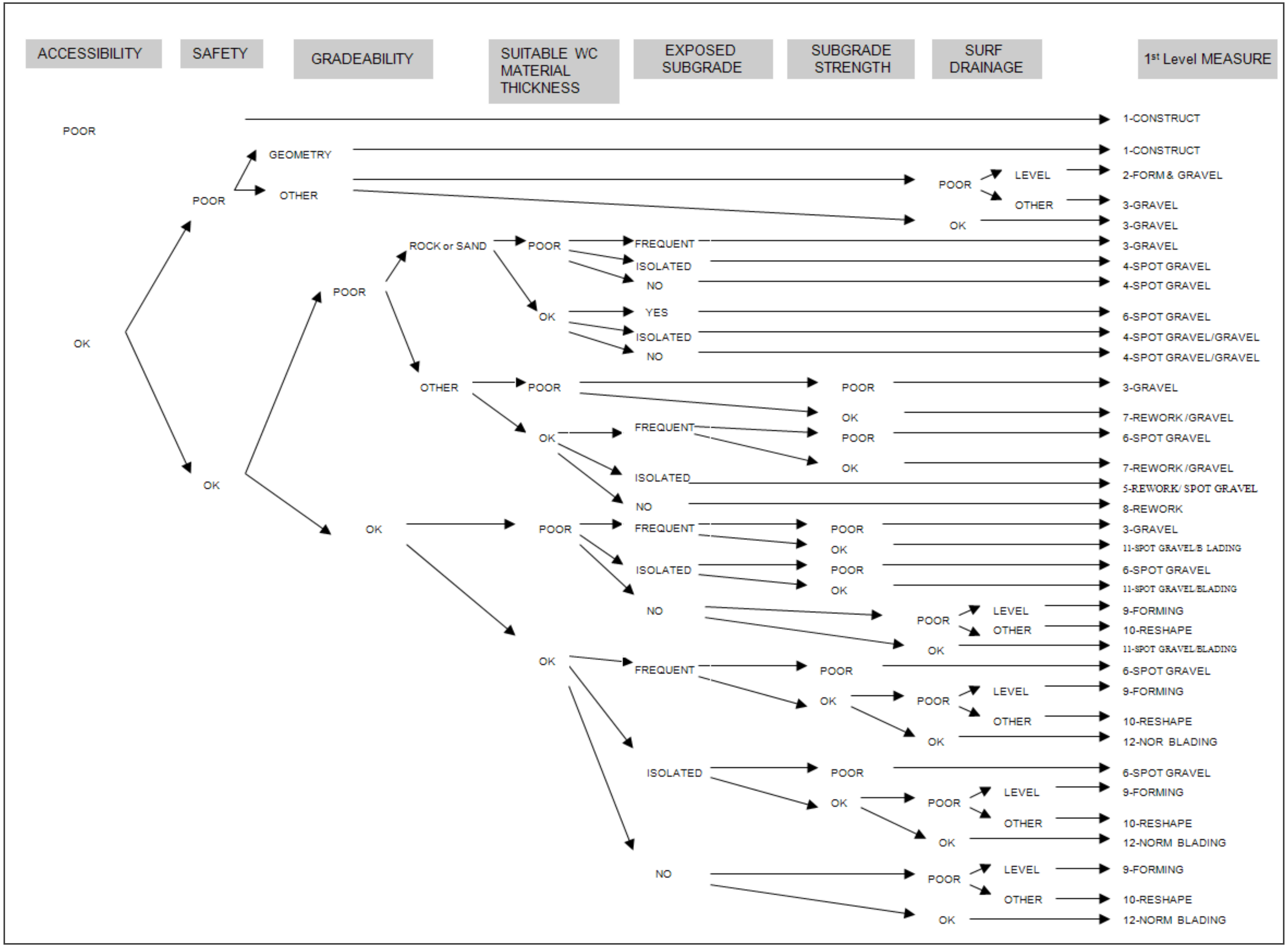


Figure 20 *Simplified Decision tree*

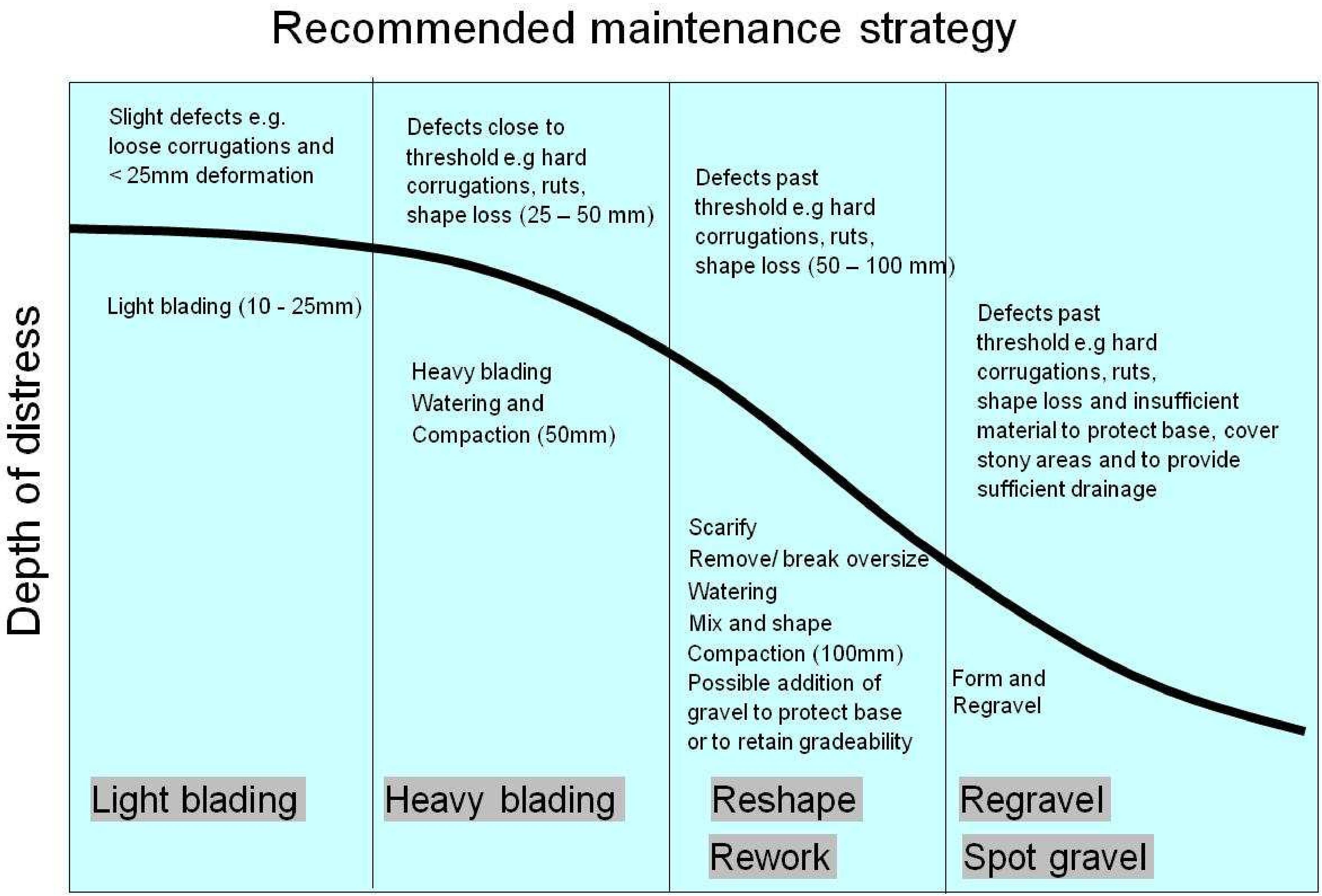


Figure 21 Maintenance measure based on distress depth

4.8 *Design, Specifications and presentation*

Design requirements regarding periodic maintenance vary for different road authorities in South Africa. However, it is considered essential to provide all necessary details to allow contractors or in-house construction teams to properly plan and execute the required activities within specification.

Information provided would include:

- Start and end position of each specified activity
- Cross-sectional details including super elevation, camber
- Road bed preparation
- Layer thicknesses and density requirements
- Drainage details e.g. culvert sizes, slope,
- Material utilisation e.g. borrow pit reference and horizon to be used for a specific layer from start to end position

Presentation of situations and required activities on line diagrams prevent confusion and greatly assist in the planning of operations. Information summarised from a detailed "Line Diagram" is shown in Figure 22 provides a holistic view of a periodic maintenance project

PROVINCIAL ADMINISTRATION: WESTERN CAPE

DEPARTMENT OF TRANSPORT & PUBLIC WORKS — ROAD INFRASTRUCTURE

GRAVEL ROADS PERIODIC MAINTENANCE DESIGN SHEET

Local Authority		Project Code					
Road Authority		Project Name		From km		to	
Road Number		DRE Area		Page		of	

Existing Situation																											
Landmarks																											
km		0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0
Landmarks																											
Traffic																											
Width																											
Shape																											
Gradient																											
Curves																											
Low level																											
Accident black spots																											
Subgrade deficiencies																											
Existing Material quality	Wearing Course																										
	Base																										
	Support/ In -situ																										
Existing Strength DCP (CBR)	0-150 mm																										
	150 - 300 mm																										
	300 - 450 mm																										
Recommended Actions																											
Borrow pits	Position																										
	Volume																										
	TRH 20 class																										
Geometric & level improvement	Horizontal																										
	Vertical																										
	Width																										
	Cross fall																										
	Raise level																										
Drainage improvement	Culverts																										
	Entrance pipes																										
	Other																										
Pavement structure	Road bed prep																										
	Support layer																										
	Wearing course																										
	Mix in																										
	Reshape																										
	Special treatment																										
Road side furniture																											

Figure 22 Design summary: Example

5 SAFETY ASPECTS

The construction and maintenance of unsealed roads includes various operations defined as “construction work” under the Construction Regulations (2003) (Section 43) of the Occupational Health and Safety Act (1993). This includes references to the use of plant, labour resources, work in excavations and trenches, etc, all of which may be pertinent to obtaining material and the construction and maintenance of unsealed roads. It is essential that the necessary sections of the Act are fully complied with.

It is not the intention of this document to provide guidance on all aspects of safety during construction and maintenance, but a brief mention of certain safety requirements is made. Poor safety conditions are likely to occur on unsealed roads during construction and maintenance operations. The roads are dusty, a high windrow often exists along the road, labourers are on and off the road, the plant moves at low speeds, potholes often occur and large stones and boulders may lie on the road during the operations.

It is thus important that the section of road being constructed and maintained is fully signposted with the appropriate warning signs. Many of the signs used are often in a poor condition as they are used under fairly severe conditions of dust, “flying” stones and exposure to the elements. The quality and condition of the signs should therefore be closely controlled and the signs timeously repaired where possible or replaced. The grader should be clearly visible over adequate distances with a high quality rotating warning light which must be kept clean and operating.

Windrows left temporarily on the road should not be allowed to become too high (greater than 100 mm) and should be left for as short a time as possible. Under no circumstances should a road be left partly graded overnight. An effective way of improving safety with respect to the presence of windrows is for the graders to work in tandem or even "tridem" (three in line). With these techniques, caution should be exercised to ensure that the crown of the road is retained.

Labourers should all be supplied with high visibility safety vests and hats which should be kept in an acceptable state of cleanliness. Wearing of these during maintenance should be made compulsory.

It is not usual to delineate unsealed roads with slippery when wet or speed limit signs and these are normally only used under extremely unsafe conditions. They cannot account for periodic episodes of extreme weather.

It should be noted that the construction, operation and maintenance of unsealed roads have inherent effects on the environment, many in the realm of safety. Dust is generated by wind and traffic, run-off of water erodes the wearing course and can leach out natural or added chemicals within the wearing course layer. The silt generated by erosion and leached chemicals often find their way into water courses, many of which could supply water to rural villages.

6 REHABILITATION, IMPROVEMENT AND UPGRADING

6.1 *Rehabilitation*

Some confusion exists with the definition of rehabilitation when applied to unsealed roads. The process of rehabilitation of sealed flexible pavements is fully described in TRH 12 (DOT, 1997) and is essentially the "measures used to improve, strengthen or salvage existing deficient pavements so that these may continue, with routine maintenance, to carry traffic with adequate speed, safety and comfort". This process usually takes place towards the end of the design life of the road or earlier if premature failure occurred due to inadequate design or excessive traffic loading.

The routine maintenance of unsealed roads (usually grader blading) is carried out at an interval of anything between one week and twelve months (undesirably). However, this restores the riding surface to an improved condition and is generally necessary when the road surface has deteriorated to a condition that is excessively rough or unsafe. Conditions which may be described as failure, e.g. subgrade deformation, are often corrected by routine grader maintenance although this could be construed as rehabilitation from the work description in TRH 12 (DOT, 1998).

A loss of the imported wearing course gravel under the action of traffic and natural processes (erosion by wind and rain) necessitates periodic regravelling (about every six or seven years on average, depending on the traffic, material properties and environment). This is the most expensive maintenance procedure and probably compares with the overlaying of paved roads or strengthening of the existing structure. (Both processes theoretically protect the subgrade and provide an improved riding surface). The fundamental difference between the two types of roads is the dynamic thickness variation (and consequent variation in load supporting capacity) of unsealed roads and the static thickness (with dynamic load supporting capacity due to fatigue of the layer) in sealed roads. In unsealed road terms, this would normally be considered as periodic maintenance.

Rehabilitation and betterment of unsealed roads, although not really maintenance procedures are considered as maintenance functions (National Research Council, 1979) because the work is usually carried out by the same crews. This is, however, not always the case in southern Africa. Hudson et al (1987) consider maintenance as reactive work performed when a noticeable deterioration of the roadway has occurred which can be easily corrected. Rehabilitation on the other hand refers to a more extensive action which is taken to correct a roadway that has deteriorated to some minimum acceptable level (Hudson et al, 1987). In many cases in southern Africa, grader maintenance is carried out when the roughness reaches an unacceptable level but this cannot be considered rehabilitation.

For the purpose of this manual, grader maintenance, regravelling and labour intensive maintenance (drain clearing and spot regravelling) have been considered as maintenance (routine and periodic) activities and have been discussed in Sections 2.19 & 2.20. Upgrading (realignment, raising of the formation, improved drainage) or “betterment” is considered in this document as a rehabilitation procedure. This is usually a policy decision made at a regional level or higher and is thus not discussed in detail in this manual, but additional information can be obtained from DOT, 1993. The decision for upgrading is based on high traffic counts, improved safety requirements (bad accident histories) or political decisions.

6.2 *Improvement*

Despite the best materials being selected, the construction process being optimised and high quality maintenance being applied to unsealed roads, they are still subject to the vagaries of the environment and traffic. They will continue to deteriorate, generate dust and loose material, become eroded and lose gravel with time.

Numerous proprietary chemical stabilizers are currently available on the market, promising a wide range of benefits associated with reducing gravel loss and maintenance requirements, reducing dust and erosion potential and even providing roads structurally equivalent to conventional sealed roads at significantly lower costs. These can be separated into those that only retain surface fines (dust palliatives) and those that chemically treat and strengthen the wearing course materials. Each of these may have the added benefits of the other, but their primary purpose would normally be classified as one of these functions.

Research has shown that many of these products can improve the fines retention or strength properties of certain materials, but there seems to be no product that will consistently improve the performance of all wearing course gravels. For this reason, it is essential that any product considered for use should be tested with the materials to be treated and should the required properties be achieved, there is no reason not to use the product, provided that it is cost-effective for the particular application.

An Agrément certification process has been developed (Jones and Ventura, 2004), which determines whether any product fulfils certain basic requirements in terms of the following properties (depending on the intention of the product, ie, as a dust palliative or a soil stabilizer):

- Resistance to abrasion
- Resistance to water absorption
- Increased density for single compactive effort
- Sensitivity to moisture
- Increased shear strength
- Change in plasticity.

The effects of any potential product on various standard materials after treatment with the product are determined. The results need to comply with certain criteria for certification. The certification of a product indicates that it has the potential to perform as intended, but does not necessarily guarantee that it will perform effectively with all materials under all conditions.

Chemical stabilizers and dust palliatives can either be sprayed on or mixed into gravel wearing courses. Sprayed on treatments are generally less long-lasting and are more suitable for dust palliation., Mixing in is essential for most soil stabilizers but can also have benefits for certain dust palliatives, in terms of providing a “reservoir” for longer lasting treatment, although seasonal rejuvenation is usually still necessary. Details regarding a number of these products are provided in the Gautrans Stabilization Manual (GDPTRW, 2004).

9.2.1 Dust palliation

A number of dust palliatives are commercially available but each one has to be tested individually in order to identify its suitability and cost-effectiveness for the material under consideration. Common dust palliatives may be bitumen- or tar-based, inorganic compounds (magnesium and calcium chlorides being the most popular), ligno-sulphonate (a product of the sulphite timber pulping process) and various commercial products of variable effectiveness. A first indication of the potential application of various dust palliatives can be obtained from Table 21.

Table 21 Interim product selection matrix

PARAMETER/ PRODUCT	Comprehensive SA guidelines available	High PI materials (PI >10)	Medium PI materials (PI 3 - 10)	Sandy materials (PI < 3)	All weather passability	Steep gradients	Heavy vehicles (mine/quarry)	High traffic volumes (> 250 vpd)	Short term applications ((deviations)	Long term applications* (maintenance progs)	Spray-on application	Mix-in application	Grader maintenance
Wetting agents			✓			✓			✓		✓		✓
Calcium chloride	✓		✓				✓	✓	✓	✓	✓	✓	✓
Lignosulphonate	✓	✓	✓	✓			✓	✓	✓	✓		✓	✓
Modified waxes			✓						✓		✓		✓
Synthetic polymers		✓	✓	✓	✓	✓	✓			✓		✓	
Petroleum resins		✓	✓		✓	✓	✓		✓	✓	✓	✓	
Tars and bitumens	Dependent on characteristics of individual products												
* Other products can be applied as long term applications, but will require periodic rejuvenation													

9.2.2 Chemical stabilization

Many of these proprietary products can improve the strength of certain materials, but there seems to be no product that will consistently increase the strength of all wearing course gravels (Paige-Green, 2007). Any product considered for use as a soil stabilizer should be tested with the materials to be treated and should the required strength (ie, normal soaked CBR requirements for that layer) be achieved, the product could be used, provided that it is cost-effective for the particular application (Paige-Green & Bennett, 1993). It has also been noted that it is essential that ongoing testing during the project is carried out to ensure that the materials consistently "react" with the selected product.

The range of tests included in the Agrément certification process (Jones, 2003; Jones and Ventura, 2004) includes those that will indicate the potential suitability of chemical stabilizers for soil improvement.

Considerable work has been carried out on the generic sulphonated petroleum product group of chemicals. This information has been written up and published as a "Toolkit" and is available on request (TRL, 2007). Such products rely on cation exchange reactions for their effectiveness and thus require a specific clay component in order to be effective. Similar requirements appear to be necessary for the "enzyme" products, although little information on their use in South Africa has been published.

Bolander (1999) has also reported on work on non-traditional soil stabilizers carried out in the United States, with similar findings to those noted in South Africa.

6.3 *Upgrading*

Upgrading is generally considered to involve either the improvement of a track to a formed earth or gravelled road or improving the road, geometrically and/or structurally, to black-top standard. It should also include, however, any intermediate steps designed to prolong use of the road in an unsealed state while minimising deterioration and/or gravel loss, possibly in preparation for later sealing.

The upgrading of unsealed roads is one area where the use of stage construction can be beneficial. Unsealed roads that are likely to be upgraded in the near future should be regravelled ensuring that the new wearing course layer would be a suitable layer in the new pavement structure. Conventional stage construction is often uneconomic as the need for the contractor to mobilise twice increases the costs significantly. The conventional regravelling process, however, usually requires minimal site establishment, and by selecting the gravel such that it could become a potential subbase or even base course, the upgrading cost can be reduced significantly. Upgrading could be restricted to the provision of a base or seal at worst or simply reworking and shaping the wearing course followed by priming and sealing.

Techniques for cost-effectively providing low cost and appropriate sealed roads have been described (SADC, 2003). It should be remembered that the traffic breakeven point for cost-effective upgrading of an unsealed road depends to a significant extent on the cost of the sealed option. The lower this cost is, by using appropriate standards and techniques, the easier the economic justification of upgrading thee road at low traffic levels.

The use of modern in situ recycling machines for improving and upgrading roads has changed the way of many improvement projects. These machines, when used with appropriate stabilizers can assist greatly with reducing the traffic accommodation requirements and are particularly useful when upgrading relatively narrow roads with limited availability of suitable areas for the construction of deviations.

6.4 *Economic aspects*

The basis of economic analysis is not discussed in this document other than the introductory comments in Section 1.5.

The major savings possible in the vehicle operating costs by reducing the average roughness of unsealed roads are in favour of the road user (and the national economy to a certain extent). The cost of reducing the vehicle operating costs by improved construction (better materials, compaction, etc) and maintenance is borne by the road authorities or owners of the roads.

For privately-owned roads (e.g. forestry and mining roads) the vehicle operating costs are borne by the owners and any savings are clearly visible in their financial statements as reduced replacement parts, fuel, lubricants, tyres, maintenance costs and improved productivity. Road authorities on the other hand, although financed through taxes obtained from the road-user, only show construction and maintenance costs in their books. Savings in these areas show the authority to be efficient and productive.

Greater cognisance of road user cost savings has, however, been taken by certain road authorities in the last few years. The conflict, however, requires further resolution so that the benefits to the road user are reflected back on the road authority. This is especially true in developing areas where fuel and lubricants are costly and maintenance parts are often difficult to procure.

A simple program, SuperSurf (Sabita, 2005) allows the comparison of different maintenance and regravelling strategies in terms of the net present value over the required analysis period. This package includes the facility of incorporating environmental and social benefits into the overall economic analysis, as in many rural areas, these can have a significant impact on the overall economic analysis.

The final decision to upgrade unsealed roads to paved roads can be either for political or social reasons or, more appropriately, based on economic criteria (Visser, 1984). Political reasons are not discussed further in this manual. Social reasons are primarily defined as those which affect the quality of life, for example, in developing communities where dust may be an important factor. Full dust suppression with a suitable dust palliative is necessary to eliminate this variable and the cost of the dust palliation should then be included in the economic analysis. The benefits are more difficult to quantify.

Benefit-cost studies of the alternative strategies of retaining the unsealed road or upgrading to an appropriate paved road should be carried out. Aspects such as dust palliation and erosion protection in developing urban areas must be included in the costs. The full costs of these operations, although benefits occur in terms of the improved quality of life and reduced maintenance, are best analysed in terms of the cost of prevention, assuming that they overcome the problem fully.

Comparison of the total benefits of the two options should then be carried out. The benefits include reduced vehicle operating costs, safety improvements and time savings. Although the benefit-cost ratio will invariably be higher for the sealed option on many roads classified as low volume, the short-term (construction) cost of the sealed road is considerably higher.

REFERENCES

AASHTO. 2002. **Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)**, (1st Edition). Washington, DC: AASHTO.

ARRB. 2000. **Unsealed roads manual: guidelines to good practice**. Vermont, South Australia: Australian Road Research Board Ltd.

BEAVEN, P, Robinson, R. and Aklilu, K. 1987. Experimental use of weathered basalt gravels on roads in Ethiopia. **Transportation Research Record**, 1106, Washington, D.C., pp. 103-115.

BOLANDER, P. 1999. Laboratory Testing of Nontraditional Additives for Dust Abatement and Stabilization of Roads and Trails. **Transportation Research Record**, 1652 (2), Transportation Research Board, Washington, DC, pp 24-31.

CERNICA, J N. 1980. Proposed new method for the determination of density of soil in place. **Geotechnical Testing Journal**, Vol 3, 3, pp 120-123.

COLTO. 1998. **Standard specifications for road and bridge works for state road authorities**. Midrand: SAICE.

DEPARTMENT OF TRANSPORT (DOT). 1989. **The design, construction and maintenance of low volume rural roads and bridges in developing areas.** Pretoria: Department of Transport. (Synthesis S89/2).

DEPARTMENT OF TRANSPORT (DOT). 1990. **The structural design, construction and maintenance of unpaved roads.** Pretoria: Department of Transport. (Draft TRH 20).

DEPARTMENT OF TRANSPORT (DOT). 1993. **Guidelines for upgrading of low volume roads.** Pretoria: Department of Transport. (RR 92/466/2).

DEPARTMENT OF TRANSPORT (DOT). 1997. **Flexible pavement rehabilitation investigation and design.** Pretoria: Department of Transport. (Draft TRH 12).

DEPARTMENT OF TRANSPORT (DOT). 2006. **Road infrastructure Strategic Framework for South Africa (RISFSA)**. Pretoria: Department of Transport.

FERRY, A G. 1986. **Unsealed roads: a manual of repair and maintenance for pavements**. Wellington, New Zealand: Road Research Unit, National Roads Board. (Technical Recommendation TR8)

FOSSBERG, P E, Harrall, c G, Fiaz, A. 1988. Technical options and economic consequences for road construction and maintenance. **Proc 3rd Int Road federation Middle East Regional Meeting**, pp 3.57- 3.69.

GAUTENG DEPARTMENT OF PUBLIC TRANSPORT, ROADS AND WORKS (GDPTRW). 2004. **Stabilization Manual.** Pretoria: GDPTRW. (Manual L2/04)

GAUTENG DEPARTMENT OF PUBLIC TRANSPORT, ROADS AND WORKS (GDPTRW). 2008. **Job creation, skills development and empowerment in road construction, rehabilitation and maintenance.** Pretoria: GDPTRW.

HARRALL, C G. and Agarwal, S K. 1975. Highway design standards study. In: **TRB Special Report 160: Low volume roads**. Transportation Research Board, Washington, D.C., pp. 17-24.

HEATH, W, and Robinson, R. 1980. **Review of published research into the formation of corrugations on unsealed roads**. Crowthorne: Transportation and Road Research Laboratory. (Supplementary Report 610)

HOLTZ, R D, Christopher, B R and Berg, R R. 1998. **Geosynthetic design and construction details.** Washington, D.C.: Federal Highways Administration. (Report FHWA HI-95-038).

HUDSON, S W, McCullough, F. and Carmichael, R F. 1987. **Surface design and rehabilitation guidelines for low-volume roads**. Washington, D.C.: Federal Highways Authority, US Dept of Transportation. (Report FHWA/TS-87-225).

ILO/ASIST. 1998. **Material selection and quality assurance for labour-based unsealed road projects**. Nairobi: ILO/ASIST. (Technical Brief No 9).

JENNINGS, J E, Brink, A B A and Williams, A A B. 1973. Revised guide to soil profiling for civil engineering purposes in southern Africa. **The Civil Engineer in South Africa**. January 2003, pp 3-12.

JONES, D J. 1998. The use of sand cushioning for unsealed road maintenance in arid areas. **Proceedings of 19th Autralian Road Research Board Conference**, Sydney, Dec, 1998, pp 64-80.

JONES, D J. 2001. **Dust and dust control on unsealed roads**. PhD Thesis, University of the Witwatersrand, Johannesburg.

JONES, D. 2002. **Protocols for unsealed roads in KwaZulu Natal**. Pretoria: CSIR Transportek. (CR 2002-13).

JONES, D J. 2003. Toward fit-for-purpose certification of road additives. **Transportation Research Record,** 1819 (2), TRB, National research Council, Washington, DC, p 208.

JONES, D J. and Paige-Green, P. 2000. **Pavement management systems: Standard visual assessment manual for unsealed roads (TMH12)**. Pretoria: Transportek, CSIR. (CR-2000/66).

JONES, D J. and Ventura, D F C. 2004. **A procedure for fit-for-purpose certification of non-traditional road additives**. Pretoria: Transportek, CSIR. (CR-2004/45v2).

LARCOMBE, G. 1999. **Forest roading manual**. Rotorua, New Zealand: Liro Forestry Solutions.

LEA, J D. 1996. **A general functional classification system for roads.** Pretoria: Department of Transport. (COD Report CR-96/008).

LEA, J D and Jones, D J. 2007. Initial findings on the skid resistance of unpaved roads**. 86th TRB Annual Meeting**, Washington, January, 2007.

MINISTRY OF WORKS, TRANSPORT AND COMMUNICATIONS (MWTC). 2000. **Methods and procedures fro prospecting for road construction materials**. Gaborone: MWTC. (Guideline No 3).

NATIONAL INSTITUTE FOR TRANSPORT AND ROAD RESEARCH (NITRR).1977. **Statistical concepts of quality assurance and their application in road construction**. Pretoria: NITRR, CSIR. (Draft TRH 5).

NATIONAL INSTITUTE FOR TRANSPORT AND ROAD RESEARCH (NITRR). 1979. **Standard methods of testing road construction materials** (1st Edition). Pretoria: NITRR, CSIR (Technical Methods for Highways (TMH) No1).

NATIONAL INSTITUTE FOR TRANSPORT AND ROAD RESEARCH (NITRR).1981. **Sampling methods for road construction materials**. Pretoria: NITRR, CSIR. (Draft TMH 5).

NATIONAL INSTITUTE FOR TRANSPORT AND ROAD RESEARCH (NITRR). 1985. **Guidelines for road construction materials**. Pretoria: NITRR, CSIR, (TRH 14).

NATIONAL INSTITUTE FOR TRANSPORT AND ROAD RESEARCH (NITRR). 1986. **Standard methods for testing road construction materials**. Pretoria: NITRR, CSIR, (TMH 1).

NATIONAL RESEARCH COUNCIL. 1979. **Maintenance of unsealed roads.** Washington, D.C.: Transportation Research Board.

NETTERBERG, F. 1985. **Materials location**. Pretoria: NITRR, CSIR. (Technical Note TS/34/85).

NETTERBERG, F and Paige-Green, P. 1988. Wearing courses for unsealed roads in southern Africa: A review. **Proceedings of 8th Quinquennial Convention of South African Institute Civil Engineers and Annual Transportation Convention**, Vol 2D, Paper 5, Pretoria.

O'CONNELL, M J. 1997. **A new approach to compaction for road construction in arid areas**. MSc Thesis, University of Birmingham, UK.

PAIGE-GREEN, P. 1989a. **The influence of geotechnical properties on the performance of gravel wearing course materials**. Ph D thesis, University of Pretoria, Pretoria.

PAIGE-GREEN, P. 1989b. New performance-related specifications for unsealed roads. **Proceedings of Annual Transportation Convention**, Volume 3A, Paper 12, Pretoria.

PAIGE-GREEN, P. 1990. Recent developments concerning rhythmic corrugation of unpaved roads. **Proceedings of Annual Transportation Convention**, Volume 5B, Paper 4, Pretoria.

PAIGE-GREEN, P. 2007. New perspectives of unsealed roads in South Africa. **Road & Transport Research**, Vol 16 No 3 September 2007, pp 56-62.

PAIGE-GREEN, P. 2008. Dispersive and erodible soils. In: **Problem Soils in South Africa.** SAICE/SAIEG, Midrand, South Africa, pp 59-65.

PAIGE-GREEN, P and Bam, A. 1992. Passability criteria for unpaved roads. Pretoria: Department of Transport. (Project Report PR91/172).

PAIGE-GREEN, P, and Bennett, H. 1993. The use of sulphonated petroleum products in roads: State of the art. **Proceedings Annual Transportation Convention**, Vol 4C, Pretoria.

PAIGE-GREEN, P and Bam, A. 1995. The hardness of gravel aggregate as an indicator of performance in unpaved roads. In: **ATC Research Forum, 5**, pp 140-154, Annual Transportation Convention, Pretoria.

POOLMAN, S and Paige-Green, P. 1990. The effect of adequate compaction on the performance of unpaved roads in arid areas. **Proceedings Annual Transportation Convention**, Pretoria, Vol 4C.

SABITA. 2005. **SuperSurf: Economic warrants for surfacing unpaved roads**. Cape Town: Sabita. (Manual 7).

SADC. 2003. **Guideline on Low Volume Sealed Roads**. Gaborone, Botswana: SADC.

SANRAL. 2002. **Code of Procedure for the Planning and Design of Highway and Road Structures in South Africa**. Pretoria: SANRAL.

SKORSETH, K and Selim, AA. 2005. **Gravel roads: maintenance and design manual**. Washington, DC: Federal Highway Administration. (Report no LTAP-02-002)

THOMPSON, R J and Visser, A T. 2000. The functional design of surface mine haul roads. **J S A Inst Min & Metal**, 100 (3), pp169-180.

TRANSPORT AND ROAD RESEARCH LABORATORY (TRRL). 1981. **Maintenance techniques for district engineers**. Crowthorne: TRRL (Overseas Road Note 2).

TRANSPORT RESEARCH LABORATORY (TRL). 2007. The Sulfonated Petroleum Products Toolkit. TRL/gTKP. (available from info@gtkp.com)

VAN ZYL, GD, Henderson, MG and Fourie, HG. 2005. Gravel road specifications in South Africa and their impact on performance. **Proc 2nd African T2 Conference**, Pietermaritzburg, September 2003.

VAN ZYL, GD, Henderson, MG and Uys, R. 2007. Applicability of existing gravel road deterioration models questioned. **Proc 9th Low Volume Roads Conference**. Austin, Texas, June 2007. Transportation Research Board, Washington.

VENTER, J P. 1989. **Guidelines for the use of mudrock (shale and mudstone) in road construction in South Africa.** Pretoria: Division of Roads and Transport Technology, CSIR. (Report DPVT-C68.1).

VISSER, A T. 1981. **An evaluation of unsealed road performance and maintenance**. Ph.D Thesis, University of Texas, Austin, Texas.

VISSER, A T. 1984. Warrants for upgrading gravel roads to bituminous standard. **Proceedings 4th Conference on Asphalt Pavements for southern Africa**, Cape Town, Vol 1, pp 77-90.

VISSER, A T. 1986. A review of the use of the MDS for managing unpaved road networks. **Proceedings Annual Transportation Convention**, Pretoria, Vol 2B.

WEINERT, H H. 1980. **The natural road construction materials of Southern Africa**. Pretoria: H&R Academica.

Useful links:

A number of South African road authorities have useful information and guideline documents on their web-sites. The following links are specifically useful.

Western Cape Provincial Administration: http://tdr.wcape.gov.za/tdr/doc.user_manual_web.main
KwaZulu Natal : http://www.kzntransport.gov.za/
South African National Road Agency: http://nra.co.za

APPENDIX A: Wearing course performance prediction

Annual Gravel Loss (AGL): (Statistically valid ranges in parenthesis)

AGL = 3.65 [ADT (0.059 + 0.0027 N – 0.0006 P26) – 0.367 N – 0.0014 PF + 0.0474 P26]

where ADT = average daily traffic (10 – 350 vpd)
N = Weinert N-value (1 – 10: 11 if N > 10)
P26 = Percentage passing the 26.5 mm sieve* (70 -100%)
PF = product of PL and (P075) where
PL = Plastic Limit (13 – 32%: 10% if Non-Plastic)
P075 = Percentage passing 0.075 mm sieve* (10 – 75%)

* - all grading analyses to be normalised for 100% passing 37.5 mm.

Roughness progression: (Statistically valid ranges in parenthesis)

LnR = D[-13.8+0.00022PF+0.064S1+0.137P26 + 0.0003.N.ADT +GM(6.42-0.063P26)

where LnR = natural log of change in roughness
D = time since blading in days
PF = product of PL and P075 where
PL = Plastic Limit (13 – 32%: 10% if Non-plastic)
P075 = Percentage passing 0.075 mm sieve* (10 – 75%)
S1 = season coefficient (= 0 in wet season, 1 in dry season)
P26 = Percentage passing the 26.5 mm sieve* (87 – 100%)
N = Weinert N-value (1 – 10: 11 if N > 10)
GM = Grading modulus * (0.3 – 2.5)

* - all grading analyses to be normalised for 100% passing 37.5 mm.

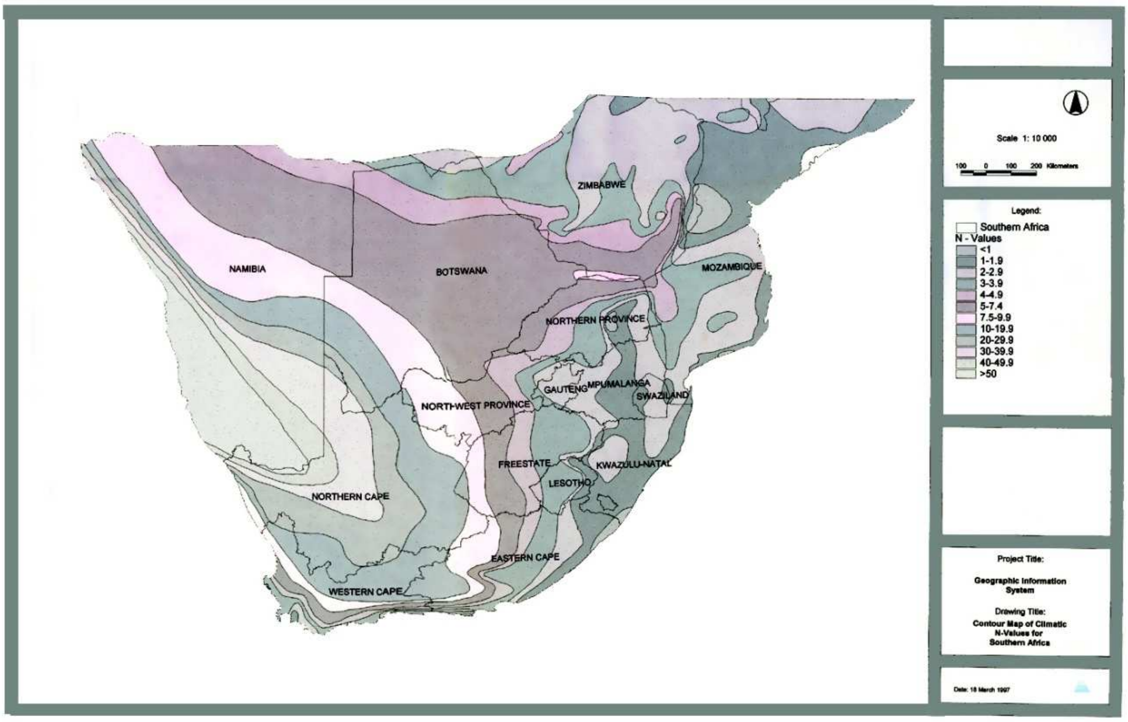
Roughness after blading: (Statistically valid ranges in parenthesis)

LRA = 1.07 + 0.699LRB+0.0004ADT-0.13DR + 0.0019LABMAX

where LRA = natural logarithm of roughness after blading
LRB = natural logarithm of roughness before blading
ADT = average daily traffic (10 – 350 vpd)
DR = dust ratio (P075/P425) * (0.24 – 0.92)
LABMAX = laboratory determined maximum particle size (6.7 – 58 mm)

* - all grading analyses to be normalised for 100% passing 37.5 mm.

Weinert N-value map



APPENDIX B: Example of compatibility between road classification, geometric design, material design and Level of Serviceability

Road Classification
As discussed in Section 1.3 the road classification could essentially be a functional one (DOT, 2006) or a hierarchical one. Based on the RISFSA classification (DOT, 2006) the following 5 classes are defined:

1 Primary distributor
2 Regional distributor
3 District distributor
4 District collector
5 Access

Although not explicitly stated, roads in Classes 1 to 3 would generally be of sealed standard, with a few roads in Class 3 and a large percentage in Class 4 being unsealed. Nearly every road classified as Class 5 is likely to be unsealed.

Geometrics and Levels of Serviceability
It should be noted that no road constructed properly using material specified in this document should become impassable unless this is the result of poor drainage conditions.

The Geometric standards related to Class 3 unsealed roads would be consistent with conventional standards (minimum width of 7.2 m), with the intention of upgrading such roads as soon as funding becomes available. Until such time the material selection, construction and maintenance standard should be such that the Level of Serviceability should be either 1 or 2 (Table 18) depending on the traffic (1 for more than 150 vpd and 2 for less than 150 vpd).

The geometric design of Class 4 roads (generally carrying less than about 100 vpd) could result in a reduction in width (to not less than 6 m). The Level of Serviceability in this case could be relaxed to 3 (Table 16).

Class 5 road would generally have traffic less than 50 vpd, consisting primarily of cars and taxis. The road width would be between 3 and 6 m and the minimum Level of Serviceability should be 4 (Table 16), although the impassability would generally be the result of flooding of drifts or low-lying portions of the road and not as a result of sub-standard material or construction. Only on roads carrying less than about 10 vpd or those carrying predominantly non-motorized traffic, can a Level of Serviceability of 5 be tolerated.