Guidelines for Structural Design of Low-Volume Rural Roads in Southern Africa

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An extensive project was recently completed in South Africa under the auspices of the Department of Transport to develop guidelines on the standards for roads that carry up to 400 vehicles per day. These guidelines were developed because traditional standards could not be justified. The guidelines encompass all aspects of road design, construction, and maintenance. The aim of this paper is to present the structural designs and material quality guidelines that were developed. In the structural design, special attention is given to evaluating the existing unpaved road since the economic construction costs do not provide for major realignment. The in situ conditions, monitored with a dynamic cone penetrometer, provide the input to the structural design, which is in a catalog format. A catalog of pavement thickness designs was developed using sophisticated analysis techniques, such as elastoplastic modeling, to allow the use of materials that fall outside the traditional specifications. The main emphasis is on using the existing road without disturbing the traffic compaction that was applied over many years and on adding the minimum amount of material. Of special interest is the approach that was adopted for selecting the asphalt surfacing, which is based on expected performance and maintenance and life-cycle costs. This paper contains the state of the art in low-volume road pavement design in South Africa and these guidelines are considered a major step in economically extending quality service to the sparsely populated rural areas. The guidelines should also be valuable to practitioners worldwide.

More than 70 percent of the road network in South Africa is still unpaved. The majority of these roads carry fewer than 400 vehicles per day (vpd). Using traditional standards, upgrading these roads would be warranted only if the traffic volumes exceed about 400 vehicles per day. The traditional approach has led to the perception of a huge gap between the standards of gravel or earth road facilities and surfaced road facilities.

In 1992 the Department of Transport in South Africa initiated a comprehensive research project to develop guidelines on standards for roads that carry up to 400 vpd for which upgrading is warranted (*1*). These guidelines are based on local research, performance of light pavement structures, and practical experience. They further encompass all aspects of road design, construction, and maintenance.

The purpose of this paper is to present the structural designs and material quality guidelines that were developed. The paper first discusses the design philosophy. Thereafter, the design catalog and application to existing gravel roads are presented. The choice of surfacing is briefly discussed and finally the applicability and conclusion and recommendations are presented.

DESIGN PHILOSOPHY

The upgrading referred to here is primarily the provision of a bituminous surfacing to keep water out of the pavement structure, to protect the underlying layers from the disruptive effects of traffic, and to provide an all-weather, dust-free riding surface. The roads in question are all considered to be short local-access roads; paved links shorter than the existing main routes should not be created because an unplanned through route would result.

The unpaved roads in the region vary from tracks to well-designed and -constructed gravel roads, resulting in a large variation in serviceability. In many cases, these roads have been in place for long periods, and problem areas have already been identified and improved. Through frequent regraveling, drainage improvements, and traffic compaction, some of these roads already have sufficient structural capacity to carry the expected traffic for more than 10 years, provided that a bituminous surface is applied.

The upgrading approach consists of the following steps, which will be discussed below:

- Determine the pavement strength required to ensure good performance and therefore low maintenance during the design period;
- Test the existing gravel road structure and determine what type of strengthening, if any, is required before surfacing; and
- Select an appropriate surfacing for the maintenance capability and environment.

DETERMINING REQUIRED PAVEMENT STRENGTH

Design Strategy

The economic analysis period is a realistic cost period, which is used to compare the cost of upgrading options. The analysis period recommended for low-volume roads is dependent on the existing geometrical standards and the likelihood for upgrading needed in this regard. A 20-year period is recommended where the alignment is fixed and 10 to 15 years where uncertainty exists.

Experience has shown that appropriate and properly constructed bituminous surfacings can be expected to last for 10 years. The cost of these surfacings can exceed 50 percent of the cost of upgrading; the pavement should therefore be able to carry the load for at least 10 years. However, in cases where it will be difficult or impractical to carry out structural rehabilitation, for example, in difficult terrain or because of financial constraints, a longer period of 15 to 20 years can be selected. The cost differential between 10 and 20 years can sometimes be surprisingly low and the consequences should be analyzed.

Design Traffic

Traffic Loading

For the structural design process, an estimate of the traffic loading (expressed as cumulative equivalent 80-kN axle loads over the structural design period) is required. At its simplest, this is derived from the average daily traffic in both directions and the percentage of heavy vehicles. Since heavy vehicles (trucks and buses) weigh so much more than cars, for all practical purposes it is sufficient to consider the loading from the heavy vehicles alone and ignore the cars. In addition, the growth rate over the structural design period is estimated. The simplest form of estimating the loading of heavy vehicles is to use tabulated values representing average conditions. A rough estimate is made of the type of heavy traffic, and the average number of equivalent 80-kN axles (E80s) per heavy vehicle is than read from a table such as Table 1 or Table 2. This factor is then multiplied by the number of heavy vehicles in both directions to obtain the average daily E80s.

Tables 1 and 2 reflect typical loads in South Africa. Because of the variation in the legal axle load limit and

TABLE 1 Average E80s per Heavy Vehicle (2)

LOADING OF HEAVY VEHICLES	E80/HEAVY VEHICLE
Mostly unladen	0,6
50 % of heavy vehicles laden and 50 % unladen	1,2
> 70 % of the heavy vehicles fully laden	2,0

TABLE 2 Average E80s for Different Heavy-Vehicle Configurations (2)

Vehicle type	Average E80s per vehicle	Range in average E80s per vehicle found at different sites
2-axle truck	0,70	0,30 - 1,10
2-axle bus*	0,73	0,41 - 1,52
3-axle truck	1,70	0,80 - 2,60
4-axle truck	1,80	0,80 - 3,00
5-axle truck	2,20	1,00 - 3,00
6-axle truck	3,50	1,60 - 5,20
7-axle truck	4,40	3,80 - 5,00

Note: * E80s of a fully laden 2-axle bus = 2.77

levels of control of overloading, these values might be unsuitable for other countries in the region.

E80 Growth Rate

The growth rate of heavy vehicle loading (E80s) can be different from the growth rate of heavy vehicles. This can be due to the growth rate of the number of axles per vehicle and the extent to which the vehicles are loaded on average. An increase in the permissible axle load will also lead to an increase in E80 growth rate. The E80 growth rate will further depend on whether the facility is used for tourism, farming, or industrialization and expected future developments. Therefore, where possible, the growth rate should be based on specific information. Generally the E80 growth rate is expected to range between 2 and 10 percent per annum.

Design Traffic

The design traffic (in terms of E80s) is calculated from the number of E80s at the start of the analysis period, the growth rate, and the structural analysis period. Care should be taken to allow for attracted traffic once the existing gravel road is surfaced.

Distribution per Lane

Low-volume roads (LVRs) typically consist of two lanes, one lane per direction. If the road has only one lane per direction, the cumulative E80s per direction constitute the design traffic. In some cases one lane may be carrying loaded vehicles, whereas the other is carrying empty vehicles. A distribution factor between lanes larger than 0.5 should be considered for the critical lane in such cases. If the road consists of only one lane carrying traffic in both directions, the cumulative E80s in both directions should be used.

Sensitivity of Traffic Class to Growth Rate, Loading, and Other Factors

The estimation of design E80s for LVRs should never be calculated as one number but should reflect a range of possible E80s. Therefore, an important design step is to conduct a sensitivity analysis. This will consider variations in factors, such as the E80 growth rate, E80 per vehicle or E80 per axle, initial E80 per day, and structural design period. Certain factors may be more uncertain or may have a larger influence than others for a specific design. By analyzing minimum and maximum scenarios, a range in design E80s can be obtained. The possible range in design E80s should be matched with the E80 ranges in Table 3 and the appropriate traffic class selected.

Pavement Structure

Material Classification

An understanding of the standard classification of road building materials in South Africa is essential to the following discussion. A description of codes, material types, and abbreviated specifications is given in Table 4.

Pavement Materials

The selection of materials for the pavement structure is based on a combination of structural requirements, availability, economic factors, and previous experience. These factors need to be evaluated during the design phase to select the materials that are most appropriate for the prevailing conditions. The selection criteria for materials for low-volume roads are similar to those for high-volume roads. Therefore, certain aspects must be satisfied with regard to the selection of materials:

TABLE 3 Catalog of Pavement Structures

TRAFFIC CLASS	TRAFFIC (E80's)	PROPOSED PAVEMENT STRUCTURES #					
		GRANULAR/GRANULAR		GRANULAR/ CEMENTED	CEMENTED/G RANULAR	CEMENTED/ CEMENTED	ASPHALT SURFACING/ GRANULAR
		DRY/ MODERATE	WET				
E0-1	< 5000	150 G6* 150 G8 150 G9 G10**	150 G5 150 G7 150 G9 G10	150 G5 125 C4 G10	100 C4*** 150 G9 G10	-	25 A^+ 150 G6 G10
E0-2	5 000 - 30 000	150 G5 150 G7 150 G9 G10	150 G4 150 G6 150 G8 G10	-	100 C4 150 G7 G10	-	25 A 150 G6 150 G7 G10
E0-3	30 000 100 000	150 G4 150 G6 150 G8 G10	150 G4 150 G5 150 G6 150 G7 G10	150 G4 125 C4 150 G7 G10	125 C4 150 G5 G10	100 C4$^{\phi}$ 100 C4 G10	25 A 150 G5 150 G9 G10
E0-4	100 000 - 200 000	150 G4 150 G5 150 G8 G10	150 G3 150 G6 150 G9 G10	150 G4 125 C4 150 G7 150 G9 G10	125 C4 150 G5 150 G7 G10	-	25 A 150 G4 150 G9 G10
E1-1	200 000 - 400 000	150 G4 150 G5 150 G7 150 G9 G10	150 G3 150 G6 150 G8 G10	125 G2 125 C4 150 G9 G10	125 C4 150 G4 150 G7 G10	100 C4$^{\phi}$ 100 C4 150 G7 150 G9 G10	25 A 150 G4 150 G8 G10
E1-2	400 000 - 800 000	125 G2 150 G6 150 G9 G10	125 G2 150 G5 150 G9 G10	150 G2 125 C4 150 G9 G10	$	125 C4 125 C4 150 G7 150 G9 G10	25 A 150 G4 150 G5 150 G8 G10

Double surface treatment assumed on all pavement structures unless otherwise indicated.

* Notation - 150 mm layer of G6 quality material. Layers are designated from top to bottom, with the lower being the roadbed material.

** **Pavement assumed to be supported by in-situ material having a CBR of not less than 3 (G10) and semi-infinite depth.**

*** C4 - cementation of G5, G6 material.

+ 25 mm asphalt

ϕ Can be combined into one layer of 200 mm thickness.

$ At present, reliable calculations of life expectancy cannot be made for this type of pavement structure.

TABLE 4 Summary of Material Classification (*3*)

CODE	MATERIAL	ABBREVIATED SPECIFICATIONS
G1	Graded crushed stone	Dense-graded unweathered crushed stone: max.size 37,5 mm 86-88 % of apparent density; fines PI < 4
G2	Graded crushed stone	Dense-graded unweathered crushed stone: max. size 37,5 mm 100-102 % mod. AASHTO; fines PI< 6.
G3	Graded crushed stone	Dense-graded stone + soil binder: max size 37,5 Minimum 98 % mod. AASHTO; fines PI < 6
G4	Natural gravel	CBR > 80 ; PI < 6
G5	Natural gravel	CBR > 45 ; PI < 10 ; max. size 63 mm
G6	Natural gravel	CBR > 25 ; max. size < 0,67 layer thickness
G7	Gravel-soil	CBR > 15 ; max. size < 0,67 layer thickness
G8	Gravel-soil	CBR > 10 ; at in-situ density
G9	Gravel-soil	CBR > 7 ; at in-situ density
G10	Gravel-soil	CBR > 3 ; at in-situ density
C3	Cemented natural gravel	UCS 1,5 to 3,0 MPa at 100% mod. AASHTO; max. size 63 mm
C4	Cemented natural gravel	UCS 0,75 to 1,5 MPa at 100% mod. AASHTO; max. size 63 mm

Note: All CBR values referred to in Table 4 are soaked CBRs.

- Adequate bearing capacity under any individual applied load;
- Adequate bearing capacity to resist progressive failure under repeated individual loads;
- Ability to retain that bearing capacity with time (durability); and
- Ability to retain bearing capacity under various environmental influences (which relates to material moisture content and in turn to the climate, drainage, and moisture regime).

Standards should be relaxed only in light of the relevant maintenance capabilities available in the area. If potholes or cracks occur and are not repaired speedily, water ingress could lead to substantial failures. Thus, if the local maintenance capability is poor, it is recommended that less moisture-sensitive materials, or the best material locally available, should be used. In areas with a very high maintenance capability, relaxation of traditional standards may be considered.

Relaxation of Atterberg limits is permitted for low-volume roads in drier climates, provided the material meets the appropriate bearing strength and durability requirements. No relaxation is permitted in wet environments unless the soaked California bearing ratio (CBR) exceeds the specified limits by at least 10 percent, the materials have low moisture sensitivity, and the pavement is well drained. Relaxation of the plasticity index (PI) up to 15 percent for calcretes and ferricretes is permitted.

The normal field compaction requirements for untreated layered materials apply. It is emphasized that the higher the density obtained, the stronger the compacted material will be and the lower the potential rut formation due to densification in service.

If no suitable materials are available locally for base or subbase layers, modification or stabilization with lime, cement, lime slag, or other pozzolanic stabilizers or combinations may be used to improve local materials. Tests such as the initial consumption of lime may show the need to increase the stabilizer content. However, there are both economic and engineering limits to the amount of stabilizer that should be added. For practical purposes, this limit is about 4 to 5 percent. Due to practical constraints with "on the road" mixing in of the stabilizer, minimum limits are usually set at 2 to 2.5 percent of stabilizer. In many cases, this can still result in very high layer strengths (exceeding that which is required); therefore, even if carbonation takes place, sufficient strength exists in the layer.

Pavement Structure

The catalog presented in Table 3 provides a range of structures appropriate to carry the relevant design E80s but does not exclude other possible pavement structures. This catalog was developed using characteristics of typical local materials, field testing and evaluation of existing light pavement structures, and elastoplastic modeling techniques and is described by Wolff et al. in a companion paper in these proceedings. Different pavement compositions consisting of granular layers, cemented layers, or combinations thereof are presented. Of specific importance is the variation of recommended granular pavement compositions in wet or dry to moderate environments. Due to the current unavailability of appropriate transfer functions for design purposes, pavement compositions with bitumen emulsion–treated layers have been excluded.

The most appropriate structure should be selected from an economic analysis based on conditions specific to the project. These conditions normally include aspects such as material availability, maintenance capabilities, construction skills, and established procedures.

Incorporating Existing Pavement in Design

Testing In Situ Strength of Existing Gravel Road

The existing gravel road strength should be used when the road is upgraded to a paved road. This is done by using the existing pavement as part of the new pavement and classifying the existing pavement material strengths in terms of the standard G1 (crushed stone) to G10 (subgrade soil) granular material classification as presented in Table 4. For example, if an existing low-volume gravel road had a wearing course of G4 material and a subbase of G5 material, those layers could be used as the base course and subbase of the paved road, creating a structure that is probably stronger than the catalog specifications. In this example, even if the catalog called for a new pavement of a G5 base course, a G8 subbase, and a G10 subgrade, it would be pointless to place those layers on top of the existing G4 and G5 material. There are parts of South Africa where the in situ subgrade is strong enough to be classified G5, and the bitumen surfacing could be laid on top of this without further layering (although attention would obviously be needed to levels, evenness, and drainage).

To use the existing gravel road strength, the materials in the pavement layers need to be tested for their actual bearing capacity using a dynamic cone penetrometer (DCP) (*4*), and their actual and theoretical bearing capacities need to be compared. For example, a G5 material may have been laid without proper compaction and will only perform as a G6 material. Alternatively, a G6 material may have been so well compacted by traffic over time that it can perform as a G5 material.

The materials in the catalog are classified by their soaked bearing strength (see companion paper by Wolff et al. in these proceedings), and the existing pavement materials need to be classified in terms of their soaked CBR to be related to the catalog. However, the CBR of a material in the field at different moisture contents and densities can vary significantly from its soaked CBR; in general, the drier it is, the higher the field CBR (*5*). Therefore, the DCP-CBR needs to be adjusted to the equivalent soaked CBR.

The preferred method for determining the soaked CBR of the existing gravel road materials is to take many samples and test them in the laboratory. At the same time, field density tests of all layers should be performed to ensure that their compaction is adequate. This can involve considerable testing and cost. However, a simpler, although less accurate, method is to use the DCP for most of the testing in conjunction with a limited number of laboratory soaked CBR tests. Then the design can be based on soaked CBRs estimated from the relationships between field DCP-CBR and soaked CBR (Table 5 for roads that are presently gravel) and cross-checked with the laboratory CBRs.

The compaction can be checked also. If the field DCP-CBRs estimated from the laboratory soaked CBR results are less than those actually found in the field, the existing gravel road has been well compacted (by traffic) and is suitable for incorporation in the design. If, however, the actual field DCP-CBRs are less than those from the laboratory, compaction is lacking and the existing gravel layer should be ripped and recompacted. Alternatively, compaction can be checked if sufficient field density tests have been performed, and the results compared to specified Mod. AASHTO densities.

Procedure for Using Existing Gravel Roads in Design

To ensure the cost-effective design of low-volume pavements, the following simple procedure is provided to optimize the in situ strength of gravel roads.

Step 1: Calculate Design Traffic and Select Traffic Class

Using the guidance above, a range of possible design E80s is obtained. By matching this range with the ranges given in Table 3 (second column), a suitable traffic class can be selected.

Step 2: Complete Tests Along the Road

DCP testing is performed along the length of road. The frequency of tests should generally follow the recommendations below, but a visual inspection may indicate adjustments to the frequency. If the road is uniform, the frequency can be reduced; if it is variable, the frequency should be increased. The basic frequency should be

- Test at the rate of five DCP tests per kilometer, with the tests staggered as outer wheel track–inner wheel track one side, outer wheel track–inner wheel track other side, center line, etc.;

TABLE 5 Approximate Relationship Between Soaked CBR and Field DCP-CBR for Gravel Road

Material classification	Soaked CBR	APPROXIMATE FIELD DCP-CBR : GRAVEL ROAD					
		Subgrade		Wearing course			
		wet climate	dry climate	very dry state	dry state	moderate state	damp state
G4	80			318	228	164	117
G5	45			244	175	126	90
G6	25	59	65	186	134	96	69
G7	15	45	50	147	106	76	54
G8	10	38	43				
G9	7	33	37				
G10	3	20	24				

Notes 1 The inter-relationship between soaked CBR and field DCP-CBR is approximate due to the variability of moisture contents, materials, test methods, and densities. It assumes that the density relates approximately to the field density expected for that layer. More research will give more confidence to this relationship.

2 The moisture contents that this table are based on are estimated moisture contents, based on various field studies and experience; they can vary in practice from the values assumed here. For the wearing course they are (expressed as the ratio of field moisture content to Mod AASHTO optimum moisture content): very dry state = 0,25; dry = 0,5; moderate = 0,75; damp = 1.0.

3 This table has been developed from Table 22 and equation 36 of Emery (1992) (5)

- Conduct an additional test at each significant location picked up in the visual survey, such as particular failure areas; and
- Ensure that at least eight DCP tests are performed per likely uniform section to provide adequate data for the statistical analysis.

It is recommended that at least two samples per kilometer be taken to check laboratory soaked CBR, Atterberg limits, and the in situ moisture content of each layer.

Step 3: Divide Road Into Uniform Sections for Upgrading

The results of the investigation, including the DCP testing and visual assessment, will enable the division of the length of road into relatively uniform sections for the purposes of upgrading. The minimum length of a section should be 0.1 km, but preferably 1 km. On long lengths of road with uniform conditions, the length of sections may be 10 km. Note that the construction of sections shorter than 0.5 km can be awkward. Low DCP results may occur in a spot that was identified in the visual survey as an isolated problem area; these are typical of an isolated drainage problem. Such section lengths should be repaired individually rather than regarded as being representative.

Step 4: Calculate Representative Layer Strengths for Each Section

The representative DCP layer strengths for each section are deemed to be those values below which only 20 percent of the measured DCP-CBRs lie. The easiest method for calculation is to analyze the field DCP results in uniform layer thicknesses, with each layer being, say, 150 mm thick. The actual rate of penetration is converted to the in situ DCP-CBR for each test (*4*). The representative DCP-CBR for each layer is then found statistically to provide a safety margin against the variability of material within the section. A normal distribution of data is assumed and Student's t distribution at the 80 percent level is used.

Step 5: Convert Layer Strengths to Material Classification

The representative DCP-CBR values must be converted to layer thicknesses and material types (i.e., 150 mm G5). The material type can be estimated from the soaked CBR that is obtained from the field DCP-CBR and moisture content during testing (Table 5 for roads that are presently unpaved) and cross-checked with the laboratory CBRs.

Step 6: Compare In Situ Structure With Required Pavement Structures

The in situ pavement structure (now expressed in terms of layer thickness and material classification) is compared with the catalog design (Table 3) for the relevant traffic class. This will indicate what new layers, if any, are required, and what layers need to be reworked or stabilized to improve their classification.

If additional layers are required, materials that meet the requirements must be located. In the case where suitable materials are available locally, the decision to modify and stabilize local materials or to import materials is made on economic grounds.

Choice of Surfacing Type

Materials

Materials used for surface seals consist mainly of a bituminous binder and aggregate (sand and/or crushed stone). The existing crushing strength requirement of 210 kN 10 percent fines aggregate crushing value (FACT) can be relaxed in light of the adequate performance of materials with lower crushing strength (120 kN 10% FACT) on low-volume roads, provided that construction with a steel-wheeled roller is restricted. [The 10% FACT is the load in kilonewtons required to crush a sample of −13.2 +9.5 mm aggregate so that 10 percent per mass of the total test sample will pass a 2.36-mm sieve (*6*).]

Polishing stone in the surfacing lowers the low-speed skid resistance of the surfacing under wet conditions and is particularly important when the texture depth of the surfacing is shallow. The rate of polishing, apart from the stone properties, is mainly dependent on the traffic volume. This implies that traffic volumes less than 400 vpd could take 10 times as long to polish stone to the same extent as 4,000 vpd. For low-volume roads, polishing is rarely a problem and the polishing stone value requirement can therefore be reduced for stone used for single and multiple seals and Cape seals.

For low-volume roads, the surfacing is important for good performance; therefore, choice must be made carefully. The choice of appropriate surfacing is based on performance, and then on cost.

The following discussion has been taken largely from South African Bitumen and Tar Association Manual 10 (*7*).

Performance

The performance of bituminous surfacings is determined by the environment, maintenance capability, and gradient. The restrictions on choice are progressive and sequential. Thus, a restriction in any one aspect is sufficient to limit the choice of surfacing.

Environment

The environment that the road traverses plays a major role in the choice of surfacing. Environment in this case includes climate, surroundings, topography, and institutional capability. From assessments on more than 100 low-volume roads, four different environments were identified:

- **First world, high pavement standards:** Pavements are generally well designed and constructed. In this environment any standard surfacing can perform.
- **First world, lower pavement standards:** This environment typically represents the roads of a small road authority with a restricted budget. Care should be taken in constructing thin surfacings, such as sand seals, thin slurries, and single stone seals.
- **Wet, hilly environments:** The maintenance capability and gradient of the road dictate the performance (see Tables 6 and 7).
- **Third-world environments:** Different stresses and low maintenance often result in loss of the complete investment (see Tables 6 and 7).

Maintenance

The maintenance capability of the road authority has a major effect on the performance of the surfacing. Light seals can give good performance provided they receive

TABLE 6 Choice of Surfacing for Rural Low-Volume Roads by Maintenance Capability

MAINTENANCE CAPABILITY	DEFINITION	SURFACING RECOMMENDATION
High	Can perform any type of maintenance	any
Medium	Routine maintenance, patching and crack sealing on a regular basis. Typically no maintenance management system[b]	asphalt, Cape Seal, slurry[a] double seal, single seal
Low	Patching done irregularly, no committed team, no inspection system	asphalt, Cape Seal, thick slurry, double seal[c]
None	No maintenance	asphalt

Notes a: thin slurries can lead to construction problems

b: it is not essential to have a maintenance management system, but its presence indicates a certain level of capability

c: this is sensitive to construction problems

adequate routine maintenance. Conversely, if there is no maintenance capability, only those surfacings that are inherently tough can survive. Maintenance capability varies widely because the capabilities of the authorities vary. The reasons for the variation include the level of expertise of the road authority, the funds available, security problems (risk, riots, etc.), and the quality of personnel. Lack of maintenance must be considered a part of the stresses on the surfacing, and the appropriate surfacing must be selected to cope.

Gradient

Gradient limits are important to minimize the damage caused by water running along the surfacing (parallel to the center line), as opposed to water running off the surfacing. Water flowing over the bituminous surfacing causes damage on roads with steep gradients, particularly those with curbs, such as are found in hilly areas. There is a maximum water velocity for each type of surfacing above which the surfacing is damaged by stone plucking and scour. Water velocity is related to gradient; therefore, gradient is used to select appropriate surfacings that will be able to resist this type of stress.

Gradient limits also apply to minimizing damage caused by shoving. Shoving occurs when the bituminous surfacing slips across the base course. For this reason, shoving limits are applicable only to an initial seal. It is much less common to find shoving of a reseal; in such cases, either a built-in construction defect exists (e.g., lack of tack coat) or the underlying surfacing is already

TABLE 7 Choice of Surfacing for Rural Low-Volume Roads by Gradient

GRADIENT	SURFACING RECOMMENDATION FOR INITIAL SURFACING
< 6%	any surfacing
6 - 8%	asphalt, Cape Seal, thick slurry[a], double seal[b], single seal[b], sand seal[b]
8 - 12%	asphalt, Cape Seal, double seal[b], single seal[ab], sand seal[ab]
12 - 16%	asphalt, Cape Seal[ab], double seal[ab]
> 16%	concrete block/concrete

Notes: a: not on stabilised base course

b: not if water flow is being channelled by kerbs or berms shoving and the reseal merely compounds the problem. The gradient limit to guard against shoving depends partially on the base course; a rough base course is more resistant to shoving than a smooth one. A stabilized base course is sensitive to shoving, and this sensitivity is accentuated on small-radius curves carrying many heavy vehicles. A base course with a thin layer of fines at the top may lead to shoving.

Intersections

Where the road is subject to turning vehicles (such as mine or industrial entrances and intersections), thin seals are generally not recommended. In general, the heavier the vehicles, the stronger the surfacing should be. The application of a fog spray and a blinding layer of sand or a thin slurry over a stone seal at intersections will reduce stone loss and subsequent potholing. In cases of many heavy vehicles turning, only asphalt concrete, epoxy asphalt, concrete, or concrete blocks are recommended.

Choice of Most Cost-Effective Surfacing

Once the appropriate surfacing types have been chosen from the performance viewpoint, their life-cycle cost should be determined to enable the selection of the most cost-effective and affordable surfacing type.

Conclusion and Recommendations

Road authorities' persistence in using surfaced roads of a high standard has led to a huge gap in quality between unpaved and paved roads, rendering it difficult to economically justify the upgrading of unpaved roads that carry fewer than 400 vpd. Cheaper solutions that still provide acceptable facilities for road users can be provided by changing the philosophy of design so that shorter structural design lives are used in the analysis and by making optimum use of the existing strength of gravel roads.

Procedures to investigate the existing gravel road structure with a dynamic cone penetrometer have been tested over a period of more than 10 years and have resulted in substantial savings to both road authorities and road users.

Investigations into the variability of moisture content in pavement structures (6) improved the understanding and use of the DCP in adjusting the measured in situ CBR to the expected in situ CBR of the pavement layers of a surfaced road, after equilibrium is reached. However, Table 5 will have to be refined as more information becomes available.

Bituminous surfacing seals and thin asphalt surfacings can perform well in southern Africa provided that the environment, maintenance capabilities, gradients, and the actions of traffic are properly taken into account. Understanding the limitations of different surfacing strategies will ensure appropriate, and therefore cost-effective, road networks.

The guidelines presented in this paper are the result of extensive research and practical experience in South Africa over the last decade and should be applicable to other countries in the region and elsewhere in the world where climates and environments are similar.

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