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Environmentally Optimised Design of Low Volume Sealed Roads in Sub Tropical and Tropical Climates.

1 Introduction

There are many factors that determine the behaviour or performance of a road pavement. However, when traffic is heavy, it is traffic that has the most important effect. As a result, we find that most pavement design methods concentrate on the traffic aspect, recommending increasing thicknesses of pavement structure for higher levels of traffic. The design methods then deal with most of the other factors simply by specifying limiting values of the relevant pavement variables; in other words there is no full design process involved at all.

There are a few exceptions. The American design method, which is based on very comprehensive experimental data and which is, without doubt, the most commonly used design method worldwide, takes account of the effectiveness of drainage in the pavement layers and climatic conditions through scaling factors that modify the 'strength coefficients' of the materials of the individual pavement layers and thereby influences the thickness design. The method allows defective drainage to be taken into account by modifying these scaling factors. The strength of the subgrade, which has a very non linear effect on the design, is dealt with through a proper weighting of the subgrade strength estimated for each month or season of the year. This is probably the most comprehensive empirical method but was developed from data from just one site where the subgrade was all the same. These scaling factors were never evaluated as part of the Road Test and are, essentially, local calibration factors. This is perfectly legitimate but it would be far more satisfactory to disaggregate all the effects contained within it and deal with them separately. This would make the method much more transferable from place to place. Other design methods also take account of climatic differences in a similar way.

Performance models such as those described by the algorithms incorporated in HDM III, and now also in HDM 4, consider many different forms of deterioration and are so structured that they can be calibrated for local conditions. HDM 4 relies on similar structural principles to the AASHTO design method namely a structural number approach to represent the potential strength of the pavement. This is reasonably flexible, and the performance models are quite sophisticated because they allow each form of deterioration to be predicted separately.

It was during the analysis of the field data on which the HDM models depend that the importance of the environmental contribution to pavement performance and behaviour was fully appreciated. The analysis showed that the environmental contribution was at least as great as the traffic contribution and a specific environmental factor had to be introduced to modify the basic deterioration models to cope with the range of climates required. The estimation of this factor is still relatively crude. Models such as those in HDM III and HDM 4 can only be calibrated for the different materials, climates and so on if adequate data are available and they cannot necessarily cope with the range required to deal adequately with all the design choices available. This is particularly true at low traffic levels because not only does the environment play an even larger part in the performance of the pavement, a part that is far more difficult to model successfully with a set of equations, but also the number of design choices becomes much greater because many aspects of the standard specifications designed for high and heavy traffic can be relaxed.

The relative effect of environment and traffic on the behaviour of road pavements is illustrated in Figure 1. At high traffic, traffic is the dominant factor and its effect on the road structure is moderately well understood (e.g. the AASHO Road Test and many other full-scale road experiments). At low traffic levels the environment dominates behaviour and here the effects are far less well understood, especially in quantitative terms. This is because there are simply so many effects to consider and many of them, from an experimental point of view, are difficult, if not impossible, to control. In comparison with traffic, for example, climatic events are unpredictable and experiments need to be very carefully designed and of a long-term nature if definitive conclusions are to be drawn. Thus one of the principal reasons why engineers have not taken full advantage of the opportunities for reducing the cost or for improving the quality of roads where traffic does little damage, is simply lack of knowledge or confidence to design the roads specifically for particular environments.

The implications of this are shown in the Figures below. With appropriate design considerations to mitigate these environmental factors, low volume sealed roads can be provided at a low cost and as an attractive alternative to gravel roads with their associated problems of sustainability and passability.

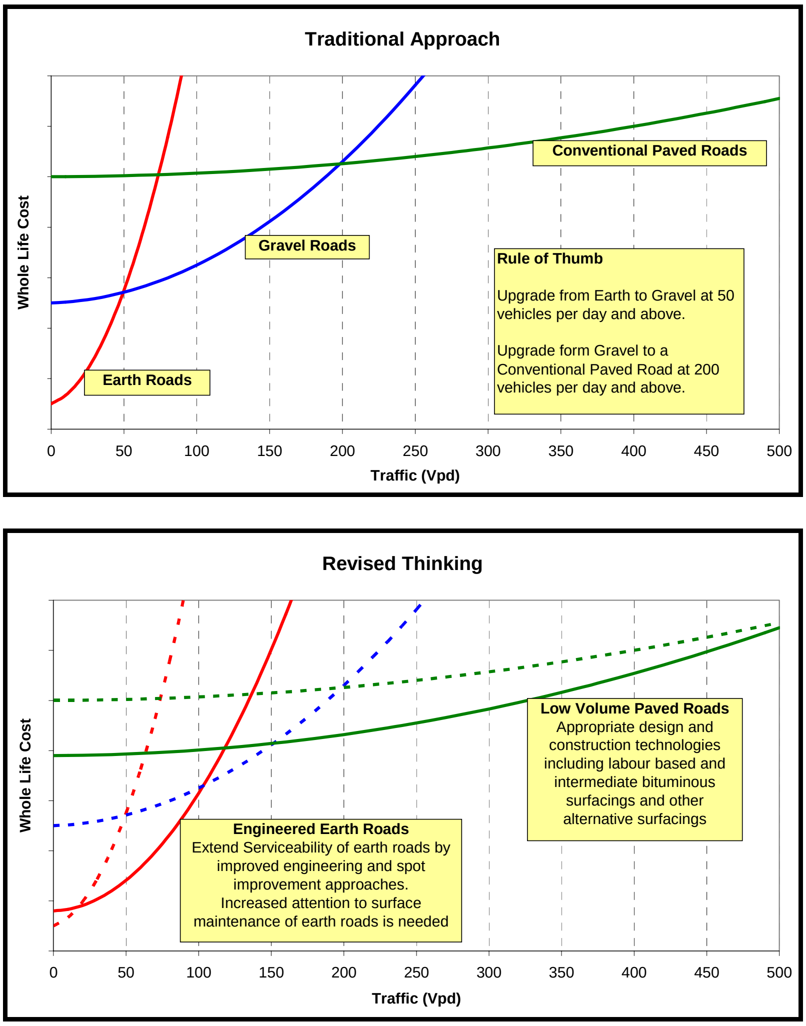


Figure 1. The implications for choice of road surfacings

2 Methodology

The approach was to formulate improved design charts for low volume roads, which recognise the importance of designing for the road environment first and foremost. The methodology was to gather information from existing low volume sealed roads across Southern Africa which were performing well and yet did not conform to existing specifications. The condition of these roads would then be monitored over time to arrive at deterioration models and ultimately the desired design charts. Existing roads were chosen as opposed to the construction of new trial sites for reasons of economy. However, by using existing in service roads for the study, an assessment of their performance since construction could be made, acting as a means of accelerated testing.

2.1 Site selection

2.1.1 Basis of selection

Base specifications for natural gravels usually set limits on grading, plasticity index, and strength determined by the soaked California Beating Ratio (CBR) test. The selection of test sections involved a desk study in Zimbabwe, Malawi, and Botswana to identify sites for monitoring. The selection process placed considerable reliance on the accuracy of the as-built records and, in some cases, subsequent sampling and laboratory testing of the materials revealed significant differences to results recorded at the time of construction. However, using the test results, it was possible to select sections which were outside the current specifications for roadbase materials. Some sections with crushed stone roadbase, or a natural gravel meeting specifications, were selected as control sections.

Natural gravel materials occurring in the region, which can be used for roadbase construction, fall essentially into four main groups: quartzitic and lateritic gravels; gravels resulting from weathering of rocks, including weathered granitic and basaltic gravels; calcretes and other pedogenic materials; and sands. These have different engineering properties, and most were represented in the study.

It was possible to select sites with a reasonably wide regional spread covering a range of the climatic conditions found in Southern Africa. The region has been mapped using the Weinert (1980) climatic N-value and this information was used, in addition to other local climatic records, to categorise and classify the sites on this basis.

Other information was also considered during the final site selection process. This included the pavement structural design, geometry, age of the road and surfacing, condition of the surfacing, prevailing drainage, standard of maintenance, construction quality, type and volume of traffic.

2.1.2 Sites selected

Test sections on the regional trunk and secondary road networks were then established in Malawi, Zimbabwe and Botswana. During site selection, care was taken to select sites which were representative of the longer sections constructed to the same design and with similar materials. Where possible, sections with unrepaired potholes were avoided because part of the study involved investigating moisture ingress from sources other than through permeable surfacings. However, even this could not be avoided completely as some of the oldest roads in the study had not been re- surfaced since construction and the surfacings were cracked due to age hardening of the bitumen.

The road sections selected in Malawi were exposed to the wettest climatic and drainage conditions. They also had some of the highest traffic levels and poorest quality roadbase materials. The driest climatic area was in Botswana, where it was possible to assess a range of poor quality roadbase materials, including sands. The materials in Zimbabwe were generally good, although a number of roads were incorporated where pavement standards and specifications had been relaxed. Most of the sites in Zimbabwe were on sealed secondary roads, which were often less than five years old. Here the traffic was much lighter than on the sections selected in the other countries.

2.2 Monitoring programme

2.2.1 Basis of the design

The monitoring programme was designed to provide data on a range of materials and conditions being investigated by the study. The main variables were the material properties, moisture profile, strength profile, and shoulder width and type (sealed or unsealed). The duration and degree of moisture change, and the effect of this on pavement strength, requires frequent monitoring. Moisture and strength information was also required to investigate the impact of sealed shoulders. It was particularly important to monitor the test sections at the end of each of the dry seasons, in the period October-November, and at the end of the wet season in the period March-April.

Some of the selected roads were relatively old in terms of their design life. It was therefore anticipated that, after such a long period of trafficking, it would be possible to draw firm conclusions on the performance of the pavement materials, and particularly on that of the roadbases. The main variables investigated were traffic, pavement age, material properties and pavement condition. This approach also meant that the performance data consisted essentially of just two points: the measurements made, or implied, at the time of construction and the current measurements. Some small changes were observed during the monitoring period mainly on the older sections with poor surfacings.

Pavement condition was monitored in terms of moisture, strength (in situ CBR measured with a dynamic cone penetrometer, described in detail in section 2.2.2), density, riding quality (roughness), deformation (rutting) and deflection at the end of

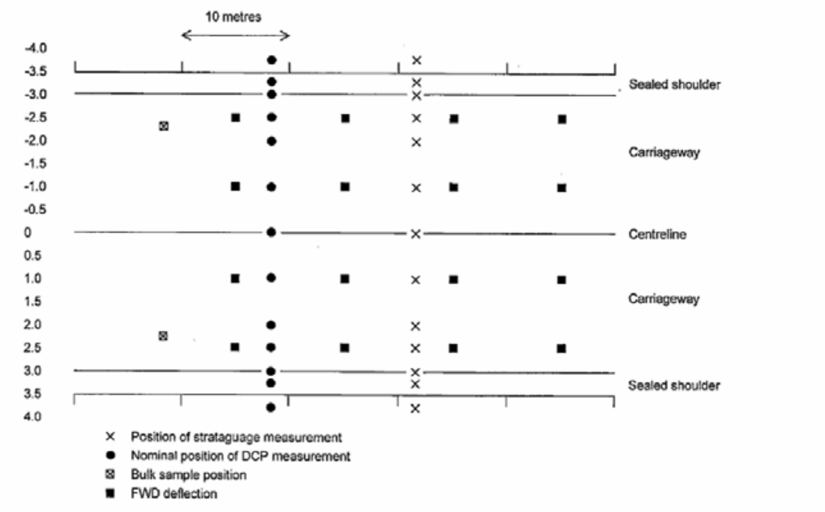


Figure 2 Layout of test section

each wet and dry seasons as described above. Visual inspections were also carded out to assess surface condition. The layout of a typical test section with measurement positions is shown in Figure 2.

2.2.2 In situ strength

The strength of the pavement layers on the test sections was assessed using a dynamic cone penetrometer (DCP). The DCP is an instrument designed for the rapid in situ measurement of the strength of road pavements constructed with unbound materials. It consists of a small steel cone mounted on a rod connected to an anvil. The cone is driven vertically into the road using the constant force provided by a weight falling through a fixed distance onto the anvil. The weight is guided by a rod connected above the anvil. The distance penetrated by the cone for each blow is recorded. Continuous assessments can be made to a depth of 800mm. Where pavement layers have different strengths, the boundaries can be identified and the strengths of the individual layers can be found.

Correlations between measurements with the DCP and CBR have been established by several authors, so that results can be interpreted for pavement design purposes in terms of CBR. A typical test takes only a few minutes, and the instrument provides a very efficient method of obtaining sub-surface information.

Cross-sections within each test section were tested with the DCP. The number of measurement positions chosen depended on the width of the road, but always included the outer and inner wheel-tracks (OWT and IWT, respectively) and the centre-line (CL). Further measurement positions were concentrated between the outer wheel-track and the shoulder. The longitudinal measurement position was relocated about one metre further along the road in each successive • survey. Thus, over time, there were only relatively small variations in the measurement position, and results from successive surveys are comparable. The transverse measurements at these locations were always made at the same offset positions.

2.2.3 Traffic and axle loading

Cumulative equivalent standard axle loading was derived for each test section, based on 12-hour and 24-hour classified counts of traffic and axle loading data collected from the roads departments during the project. These data were supplemented and verified by collection of further data at the sites.

The impact of traffic loading on an individual road will be influenced by the road width. If the carriageway is less than about six metres wide, then larger vehicles tend to drift towards the centre of the road rather than driving in their lane. These phenomenon needs to be taken into account when analysing the data.

2.2.4 Rainfall and climate

Data on rainfall and climate were collected from various sources, including meteorological offices and agricultural stations that were close to the research sites. Existing climatological maps for the region using climatic indices, such as the Thomthwaite 'Im' value and the Weinert N-value, were also used. Both of these indices have been found to relate well to the moisture conditions in pavements in the region, and relate well to the location and performance of materials. The wide geographic distribution of the sites covered a range of N-values, from less than 2 to greater than 5. Typically, N-values of less than 4 imply a climate that is seasonally wet; whereas N-values of greater than 4 imply a climate that is arid, semi-arid, or dry.

3 Development of Specifications and Design Charts

3.1 Basic principles of the approach

The data obtained from the roads in Botswana, Malawi and Zimbabwe covers a reasonably wide range of climates, classified broadly as arid to semi-arid, seasonally wet, and wet.

Two approaches can be followed when developing structural design charts:

a. A single design chart developed on the basis of actual field experience
   The chart is based on in situ subgrade strength, with the onus on the user to predict the in situ strength based on soil type, climate, drainage conditions and any other risk factors.

b. Several design charts based on a subgrade classification test
   Different charts are provided to suit the different climate, drainage conditions and so on.

3.2 Predicting in situ conditions

Sufficient examples were found in the region to enable the relationship between laboratory and in situ conditions to be determined. Some of the weaker roads investigated had deteriorated to a poor condition, but the majority of the roads were still performing well with little signs of normal traffic related deterioration.

Examination of the data shows that, in wet climates with poor drainage, the most adverse site conditions gave in situ CBR values equal to or stronger than the laboratory soaked values when tested at the same density.

In arid and semi-add areas, the in situ CBR was found to be at least twice the value in wet areas, as shown. Where exceptions occurred, these could be explained by the quality of the drainage or by the construction standards. Some subgrades were surprisingly weak. These tended to occur under pavements of roads that had previously been gravel, such as KIBA, and where soil densities were very low. The analysis underlined the value of preparing and compacting the subgrade properly when upgrading from an unpaved to a paved road to take full advantage of the cost savings possible in arid and semi-add areas.

Drainage conditions also influence road performance. This can be measured in terms of the height of the crown of the road above the invert of the drainage ditch, referred to as the 'crown height', and the distance of the outer wheel-track from the edge of the sealed area. The results show that the provision of a sealed shoulder at least one metre wide increases subgrade strength under the wheel-tracks to about twice that of the worst case value in wet and poorly drained conditions, at least in arid and moderately wet climatic areas. However, strengths are affected only marginally by the addition of sealed shoulders less than one metre in width.

The results show that pavement structures which work well under wet and poorly drained conditions have an in situ subgrade strength, at the seasonally worst condition, similar to that obtained in the standard laboratory soaked CBR test. These structures behave in a similar way on a subgrade of half this strength in arid and semi-add conditions provided the subgrade has been prepared to the density standard used in the design test. Therefore, as a first approximation, the same design chart can be used in arid and semi arid climates as in wet climates, except that the subgrade strength values in the standard soaked CBR classification test will be halved. This is equivalent to a shift of one subgrade category in the chart because each category represents a CBR range where the highest value in the range is twice the lowest. For example: S2 covers a CBR range of 3 to 4 per cent; S3 covers a range of 5 to 7 per cent; S5 covers a range of 8 to 14 per cent, etc.

Further shifts in subgrade class are possible in situations where a particularly dry environment can be assured. This may require that the shoulders of the road are sealed to a minimum width of one metre, that the outer wheel-track is more than 1.5 metres from the edge of the sealed area, and that the drainage is ensured by maintaining the crown height greater than one metre above the ditch.

3.3 Traffic induced deterioration

Traditional design principles for the traffic factor rely on two assumptions:

- The thickness design is sufficient to protect the subgrade from a 'fatigue' type of failure brought about by repetitive loads; this implies that higher levels of traffic will require thicker structures.

- The strength of the roadbase is sufficient to prevent failures of any sort; this implies that the roadbase specification is a 'zero risk' design.

The evidence from this and other studies in the region indicates that roadbase materials, which would be considered of 'marginal' quality using traditional specifications, can give satisfactory performance on low volume rural roads carrying typical rural traffic. In general, this does not include vehicles with excessive axle loads. As traffic levels increase, the specification for roadbases should approach those of the traditional design charts. The experience gained during the study indicates that this change of function occurs at traffic levels around 500,000 esa. ORN 31 (TRL 1993), or other relevant design guides, can be used at higher traffic levels. In the proposed design charts, the transition between the new designs and those given in ORN 31 have been smoothed to provide an appropriate transition. The studies have shown that roads built with laterites and calcretes can carry particularly heavy traffic loadings, and these provide important exceptions to the above principle.

Low volume roads serving functions where particularly heavy flows result need to be considered differently. For example, roads serving a specific 'heavy' industry, such as a mining operation, may require that the roadbase specifications are tightened, or that the next higher traffic category can be used for design to reduce risks.

It was noted earlier that deterioration on low volume sealed roads is controlled mainly by the environmental factors rather than traffic. Thus, the thickness designs and material specifications have been devised to mitigate this. A standard sub-base layer has been provided for all designs to protect the weaker subgrades from environmental deterioration, even for low traffic levels. A gradual increase in pavement thickness has been used to provide a transition to the thickness required at the higher traffic levels.

3.4 Specific materials issues

3.4.1 Laterites

Lateritic gravels are the product of intensive tropical weathering of the parent rock and continued leaching of the initial weathering products of the rock (clays). This continual weathering and leaching results in the solution, residual accumulation and precipitation of iron and aluminum rich weathering products in distinct horizons. To develop a concretionary (hardened) deposit of laterite, chemical precipitation and loss of water of crystallisation is required. These conditions generally arise in areas of fluctuating groundwater level. Lowering of the groundwater leads to oxidising conditions, whereby both precipitation of the hydrated oxides and dehydration occur.

Lateritic gravels are widespread throughout the northem reaches of the region. True laterites self-harden irreversibility on exposure to air, but the vast majority of the lateritic gravels, and certainly all of those occurring in Southern Africa, do not possess this capability. They do however seem to perform extremely well as roadbase materials, even though the majority of the deposits fail to meet at least one of the normal design criteria required in the specifications.

Only sporadic use has been made of lateritic gravels as roadbase materials for sealed roads in the region. This is mainly because they exhibit tremendous variability in their engineering characteristics, both between deposits and within the same deposit. The lateritic gravels found in the region commonly exhibit gaps in the grading curve, such as in the sand fraction. They also tend to have high plasticity, with plasticity indices greater than 15, and soaked CBR values lower than the minimum of 80 per cent normally specified. Most lateritic gravels are therefore considered sub-standard, and are generally precluded from use as roadbase materials even for low volume roads. Other more expensive options are normally used to provide roadbase layers in these areas. These options include hauling other natural gravels, which meet the specifications, over long distances; stabilising the lateritic gravels with cement and lime, which is the preferred option in Zambia and Zimbabwe; or using crushed stone for the base, which is the preferred option in Malawi. All of these options can be prohibitively expensive, particularly for low volume roads.

However, the study has shown that some of these 'sub-standard' lateritic gravels can be successfully used as roadbase materials for low to medium traffic levels.

3.5 Pavement materials specifications

3.5.1 Information sources

The materials design characteristics recommended for use with the design chart have been developed using a number of information sources in addition to the data from the road sections investigated in this study. These include:

- TRL's ORN31
- AASHTO specifications for natural gravels
- Experimental pavements investigated by TRL and others in the region
- Other sources of information such as the C1RIA (1988) report on laterites
- Many other world wide specifications, most importantly from Australia, South Africa and Brazil

Material properties used in the design charts are assigned based on traffic level and climate.

3.5.2 Roadbase specifications

The requirements for roadbase have been developed using the natural gravel groups which are most predominant in the region. These include quartzitic gravels, weathered rocks, lateritic gravels, sands and calcrete. Some materials, such as calcretes and laterites, are identified as special cases where special recommendations can be made. Weathered basalt materials are also subject to special treatment.

Roadbase properties have been set at values which are more conservative than those observed during the study. This is because there were insufficient combinations of subgrade and traffic in the test sections to enable an approach based on percentile values to be used. The design values therefore offer a low risk approach. As further data become available, it may be possible to relax these guidelines further in the future.

The principles of the roadbase selection are based on the following:

- Traffic and climate

- Roadbase strength
- Grading envelopes
- Plasticity

Traffic and climate

The strength, plasticity and grading requirement varies depending on the traffic level and climate.

Roadbase strength

The soaked CBR test has been used to specify the minimum base material strength. This has assumed a test compaction requirement of 98 per cent BS 4.5kg rammer compaction, or equivalent, with a minimum soaking time of four days or until zero swell is recorded.

Grading envelopes

Four grading envelopes (A, B, C and D) are used which depend on the traffic and subgrade design class.

Envelope A varies depending on the nominal maximum particle sizes of 37.5, 20 and 10mm. It has been derived using ORN31, AASHTO M147-65 and the MoTE (Zimbabwe) recommended grading envelopes.

The lower limit for Envelope B is the same as the lower limit of the Envelope A with a 37.5mm maximum particle size, and the upper limit corresponds to the upper boundary of the Envelope A with a 10mm maximum particle size. This wider envelope allows use of a much wider range of natural gravels including the more commonly gap-graded materials such as laterites and ferricretes. A requirement for 5 to 10 per cent retention on successive sieves may be specified to prevent excessive loss in stability.

Envelope C applies only to dry (N>4) climates, and extends the upper limit of Envelope B to allow the use of calcareous and Kalahari sands.

Envelope D provides a basic gravel wearing course specification. This is specified in terms of grading modulus (GM) with a range of 1.5-2.5.

Plasticity

The maximum plasticity index of the roadbase also depends on the traffic and subgrade design class. A maximum plasticity index of 6 has been retained for higher traffic levels and where the road is to be constructed over a weak subgrade. For arid and semi-arid environments, the plasticity index can be increased by three units, and the plasticity modulus increased by 40 per cent.

The limit of the plasticity index for laterite and calerete gravels may be increased by 40 per cent up to a limit of 18 for wet areas and 21 for arid and semi-arid areas.

3.5.3 Sub-base materials

Insufficient data were available from the study to confirm whether or not the sub-base requirements could be relaxed. There is a particular need to ensure that the subgrade has adequate protection because of the important impact on deterioration of the environment. The normal quality standards for sub-base were therefore retained. These are to use a soaked CBR of 30 per cent at 95 per cent BS 4.5kg rammer compaction, or equivalent maximum dry density, and the normal grading requirements.

3.5.4 Selected fill

The requirement for selected fill is a soaked CBR of 15 per cent, using 95 per cent BS 4.5kg rammer compaction, or equivalent maximum dry density, or a minimum CBR of 15 per cent at the highest anticipated field moisture condition at the specified field density.

3.6 Environment and maintenance

The purpose of a pavement is to protect the natural ground, or subgrade, from the high and concentrated load stresses applied to the subgrade by the wheels of vehicles. Layers of material are provided to reduce these stresses and to distribute them evenly throughout the pavement so that traffic can be supported for as long as required. The principal elements in the design process are the choice of materials and their thickness for each pavement layer. The design engineer also needs to understand all other external impacts on the design, and to recognise the influence exerted by these other parameters.

An aim of pavement design is, therefore, to limit the level of pavement distress caused by environment or traffic to predetermined values. These values are set with reference to a suitable remedial treatment being provided at the end of the design period. It is assumed that strengthening is carried out at this time. It is also assumed that adequate maintenance is carried out during the design period of the road.

The road environment will also influence this interaction, as discussed earlier, and the

pavement design process must therefore recognise and deal with this in the context of any particular road design project. Experience in the region on low volume roads is that, where a timely re-seal has been earned out, this will arrest environmental deterioration. Also, as the surfacing becomes thicker as a result of re-sealing, it will start to act as a semi-structural layer, thus reducing stresses lower in the pavement. This can prolong the serviceability of the pavement well beyond its normal design life. Clearly, this observation requires more research, but it is considered at this stage that the benefits resulting could become an important component of the whole life costing of low volume roads.

4 Results

Since these studies were completed a major effort has been made to draw together and synthesise *all* the good research that has been carried out in the region on low volume sealed roads and to identify best practice. This has resulted in the publication by SATCC (Southern Africa Transport and Communications Commission) of a key document entitled ‘*Guideline: Low volume sealed roads*’ which, for the conditions found in southern Africa, describes the current state of the art. The design specifications described herein form part of that Guideline.

4.1 Pavement Thickness Design

The approach developed for pavement design is summarised in Figure 3. Comments on the key factors are given below.

Climate.
Climatic zones are characterised by the Weinert N-values (Weinert, 1974). N-values less than 4 imply a seasonally wet tropical or sub tropical climate. Values greater than 4 indicate a tropical or sub tropical arid or semi-arid climate. The pavement design chart for $N > 4$ is reproduced below as Chart 1 and Table 1. Almost 60% of the region falls within the $N>4$ category. Chart 2 for $N < 4$ is also shown below.

Traffic and environmental effects.
For a correctly constructed pavement carrying low levels of traffic, there is a low risk of a pavement failure being induced by traffic, and deterioration is controlled mainly by environmental factors. This is consistent with the finding that materials that are of marginal quality, in the traditional sense, perform well at low traffic levels. However, as traffic levels increase, the specification for road bases should approach those of traditional design charts. Experience suggests that this transition is in the range of design traffic classes of 0.3M to 0.5M.

Sealed width.
On total sealed widths of 7 metres or less, the outer wheelpath is within one metre of the edge of the seal. This affects pavement performance adversely, so relatively stronger pavements are necessary in these situations. If the road width is sufficient for the outer wheelpath to be more than 1.5 metres from the pavement edge, and good drainage is ensured by maintaining the crown height at least 700 mm above the ditch, a further improvement in performance results which is reflected in the charts. The different sealed surface widths are, therefore, treated separately in the design charts.

Embankments.
When a road is on an embankment of more than 1.2 m in height, the material in the road base and sub-base stays relatively dry, even in the wet season. In this case, the design category can be relaxed, and a pavement with a 7 m total sealed width can be designed to the same criteria as an 8 m seal.

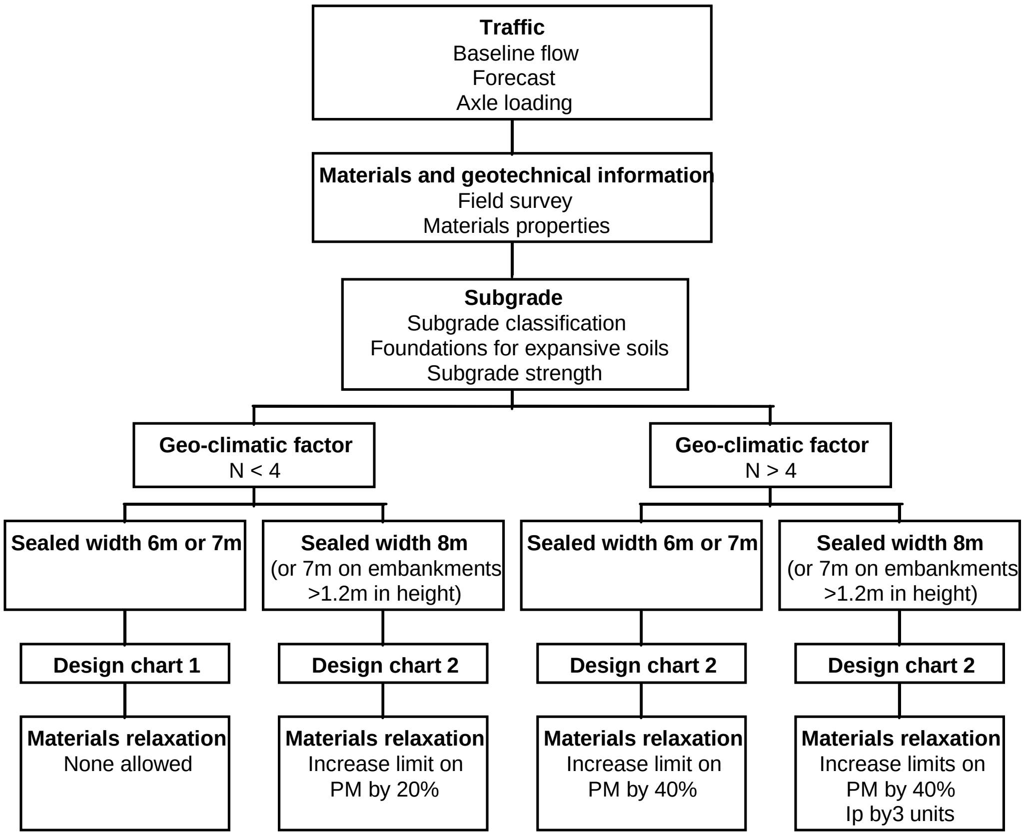


Figure 3. Flow chart for sealed road pavement design process.

4.2 Materials Design

The specification is based on the following principles:

- The strength, plasticity and grading requirement varies depending on the traffic level and climate.

- The soaked CBR test has been used to specify the minimum base material strength, with a compaction requirement for the test of 98% mod AASHTO, and with a minimum soaking time of four days or to zero swell.

- Four grading envelopes (A, B, C and D) are used, which depend on the traffic and subgrade design class.

Guidance on the selection of natural gravel roadbase materials are given in Table 2.

Plasticity.

The maximum plasticity index of the roadbase also depends on the subgrade classification and traffic design class. A maximum plasticity index of 6 has been retained for higher traffic levels and weak subgrades. For designs in dry environments, the index can be increased to a value of 3, and the plasticity modulus by 20 and 40 per cent, depending on whether unsealed or sealed shoulders are to be used.

Particle size distribution.
The grading envelopes used are shown in Table 3. Envelopes A-D are used for road bases, and envelope E for sub-bases. Envelope C extends the upper limit of envelope B to allow the use of calcareous and Kalahari sands, but is not for use in wet climates. Envelope D is used for very low traffic volumes (0.01M) in wet or dry climates.

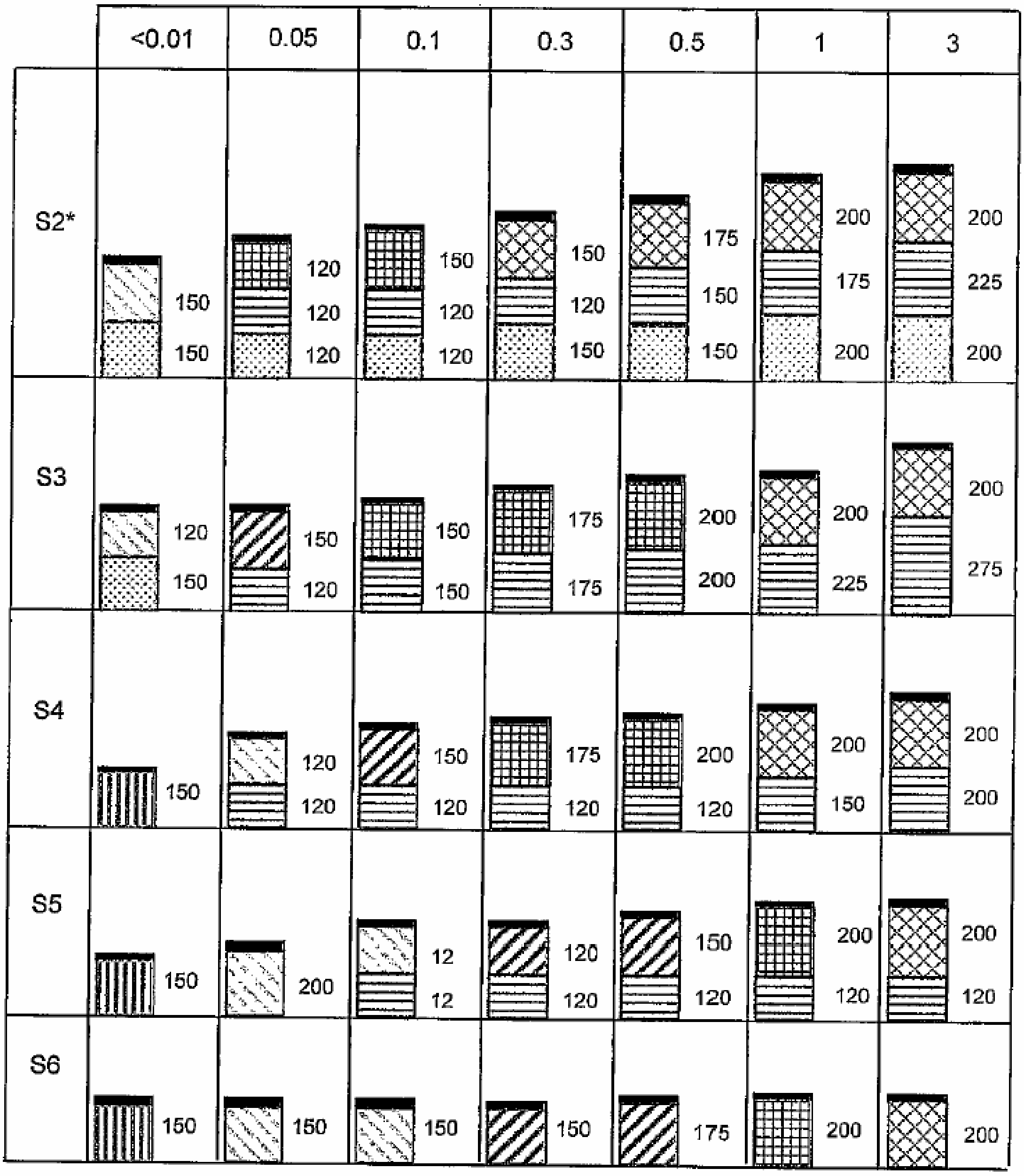
Table 1 Key to structural catalogue

Traffic classes (10^6 esa)		Subgrade strength classes (CBR%)	
<0.01	= < 0.01	S2 =	3 , 4
0.05	= 0.01 - 0.05	S3 =	5 - 7
0.1	= 0.05 - 0.1	S4 =	8 - 14
0.3	= 0.1 - 0.3	S5 =	15 - 29
0.5	= 0.3 - 0.5	S6 =	30 +
1	= 0.5 - 1		
3	= 1 - 3		

Material Definitions

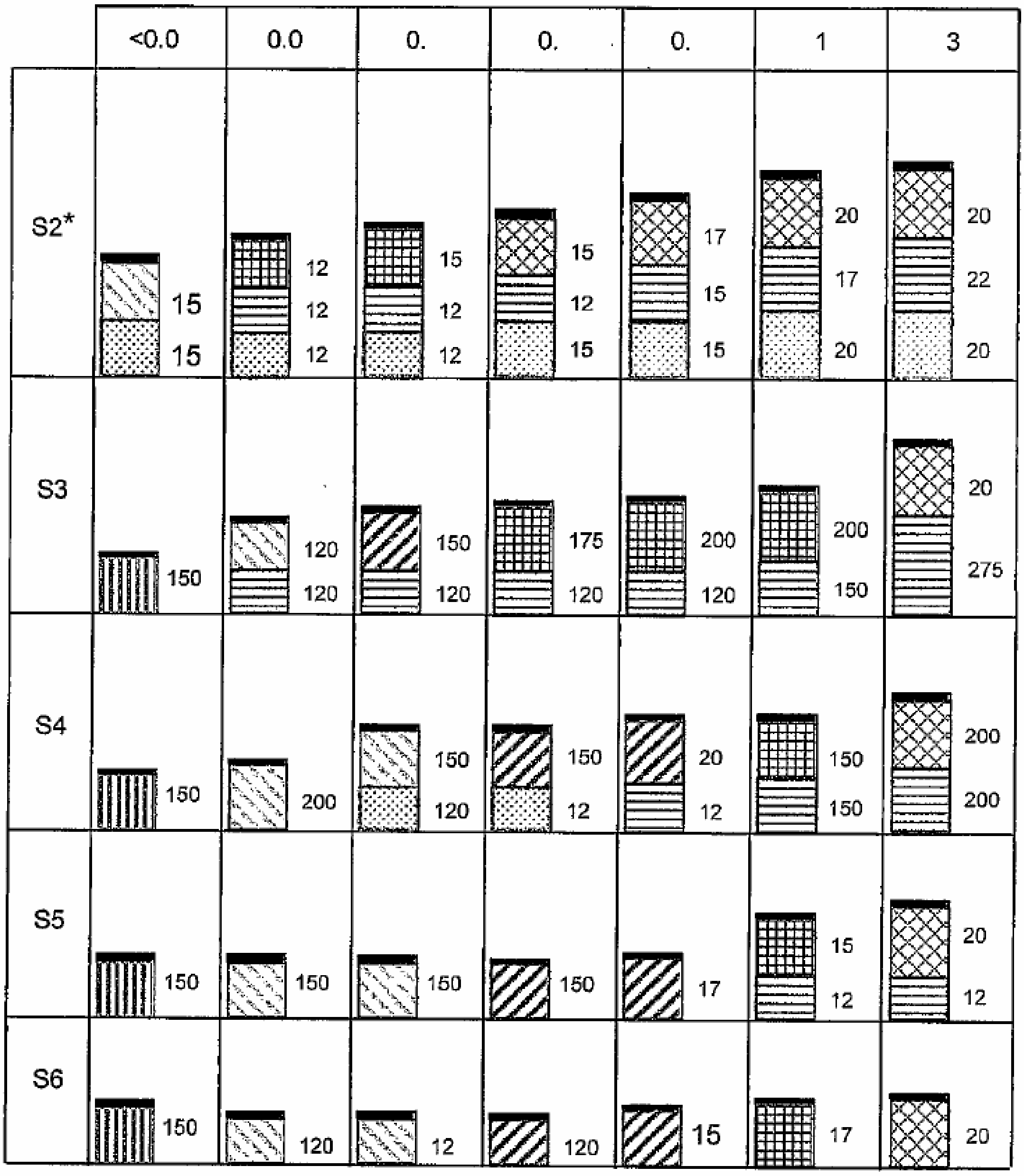
- Bituminous surfacing
- Base, CBR 80
- Base, CBR 65
- Base, CBR 55
- Base, CBR 45
- Gravel wearing course quality
- Sub-base, CBR 30
- Selected subgrade fill, CBR 15

Chart 1 for climate zones N< 4



Note: * Non-expansive subgrade

Chart 2 for climate zones N < 4



Note: * Non-expansive subgrade

Table 2. Selection of natural gravel road base materials

Subgrade class	Materia lpropert y	Upper limit of design traffic class						
		0.01M	**0.05M**	**0.1M**	**0.3M**	**0.5M**	**1M**	**3M**
S2	Ip	≤12	≤12	≤9	≤6	≤6	≤6	≤6
	PM	400	250	150	120	90	90	90
	Grading	B	B	B	A	A	A	A
S3	Ip	≤15	≤12	≤12	≤9	≤6	≤6	≤6
	PM	550	320	250	180	90	90	90
	Grading	C(1)	B	B	B	A	A	A
S4	Ip	Note (2)	≤15	≤12	≤12	≤9	≤9	≤6
	PM	800	450	320	300	200	90	90
	Grading	D(3)	B	B	B	B	A	A
S5	Ip	Note (2)	≤15	≤15	≤12	≤12	≤9	≤6
	PM	n/s	550	400	350	250	150	90
	Grading	D(3)	C(1)	B	B	B	A	A
S6	Ip	Note (2)	≤18	≤15	≤15	≤12	≤9	≤6
	PM	n/s	650	550	500	300	180	90
	Grading	D(3)	C(1)	C(1)	B	B	A	A

Roadbase CBR	Maximum swell (%)
45	0.5
55	0.3
65- 80	0.2

Notes:

(1) Grading 'C' is not permitted in wet climates; grading 'B' is the minimum requirement
(2) Maximum Ip = 8 x GM
(3) Grading 'D' is based on the grading modulus 1.65 < GM < 2.65

- All base materials are natural gravels
- Subgrades are non-expansive
- Further relaxation applicable for the use of laterites and calcretes
- Ip Plasticity index
- PM Plasticity modulus = % passing 0.425 mm sieve x Ip
- n/s Not specified

Table 3 Particle size distributions for natural gravel road bases and sub-bases

Test sieve size	Per cent by mass of total road aggregate passing test sieve					
	Envelope A			Envelope B	Envelope C	Envelope E
	Nominal maximum particle size					
	37.5 mm	20 mm	10 mm			
50 mm	100	-	-	100	-	100
37.5 mm	80 – 100	100	-	80 - 100	-	80 - 100
20 mm	55 – 95	80 - 100	100	55 - 100	-	60 - 100
10 mm	40 – 80	55 - 85	60 - 100	40 - 100	-	-
5 mm	30 – 65	40 - 70	45 - 80	30 - 80	-	30 – 100
2.36 mm	20 – 50	30 - 55	35 - 75	20 - 70	20 - 100	-
1.18 mm	-	-	-	-	-	17 – 75
425 µm	8 – 30	12 - 30	12 - 45	8 - 45	8 - 80	-
300 µm	-	-	-	-	-	9 – 50
75 µm	5 – 20	5 - 20	5 - 20	5 - 20	5 - 30	5 – 25
Envelope D 1.65 < GM < 2.65						

5 Dynamic Cone Penetrometer

Utilising the new design charts a computer programme was written to assist road engineers with overlay design for existing gravel and earth roads. Data from the Dynamic Cone Penetrometer (DCP) – described in section 2.2.2 is fed into the software, which determines the pavement layers and calculates the corresponding CBR values and structural numbers.

By analysing a number of DCP measurements taken along the length of the road using the software, it is possible to divide the road up into sections with similar properties. Environment data is then entered into the package and a costed thickness design for each section of road is outputted (provided unit cost information has been previously inputted).

6 Summary and Conclusions

The programme of research in southern Africa, successfully demonstrated that the existing pavement design methods are too conservative for low volume road design in the region. The study proved that the road environment is the overriding factor in the deterioration of these roads.

A number of sites in Botswana, Zimbabwe and Malawi were investigated and monitored. The data collected afforded a clear understanding of the link between material strength and the moisture regime for a number of naturally occurring road building materials commonly used in the region.

The findings of the trial were used to formulate design charts suitable for low volume sealed roads. These findings have subsequently been published in a guideline document for southern Africa and the relationships developed have been used as the basis of a design tool, enabling engineers to design low cost upgrades to existing unsealed roads. This in turn reduces the dependence on gravel as a suitable wearing, with it's associated sustainability problems.

7 References

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