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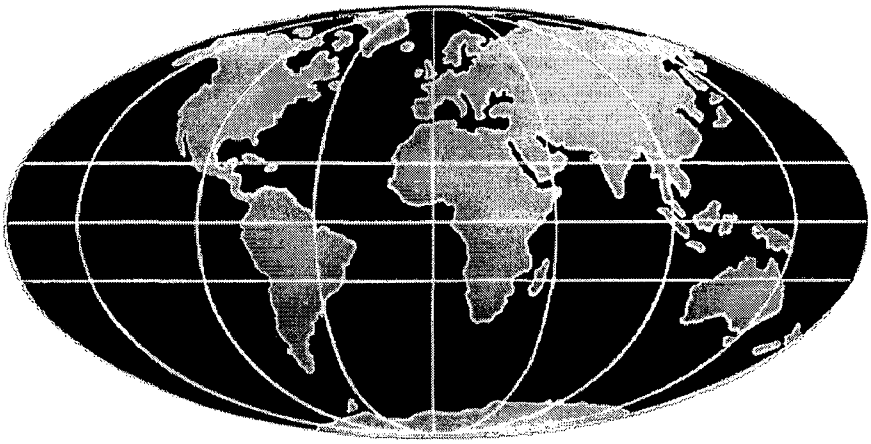

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A STRUCTURAL DESIGN GUIDE FOR LOW VOLUME SECONDARY AND FEEDER ROADS IN ZIMBABWE

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1. INTRODUCTION

Transport and its associated infrastructure is a key component in the development process. In rural areas, provision of roads, especially surfaced roads, is always high on the list of the priorities requested by local communities. One of the benefits of road provision for rural communities is that operators more readily provide public and commercial transport services. This in turn offers the communities greater mobility, better access to education and medical services, generates greater economic activity, improves employment opportunities and ultimately offers local communities a better quality of life. This improvement in access is extremely important as a high proportion of the agricultural capacity of the country is carried out in these areas by small scale farmers. Transport provision is also needed to enable movement and exploitation of the countries natural resources such as mining, timber, etc as well as opening up improved access to attract tourist traffic. At present just over 70 percent of the MOT secondary and feeder road network is unpaved. There is therefore considerable scope for improving the well-being of the rural communities if ways can be found of surfacing these roads at an economic cost.

In recognition of this the Department of Roads in Zimbabwe has in recent years been involved in a number of research programmes specifically aimed at addressing the needs of the secondary and feeder road network. The Sida funded Secondary and Feeder Road Development Programme and the DFID-Sida funded TRL-SADC Regional Research Programme both comprised sizable components aimed at deriving solutions to particular pavement materials, design and construction problems so that costs for provision of these lower volume roads could be reduced.

In some countries, there has been a tendency to construct many secondary and feeder roads to the structural design standards which emanated from studies in developed countries or to design standards which are similar to the trunk road network. Zimbabwe, which has a long history of development behind its current standard pavement and materials design procedures and has always recognised that low volume rural roads need not be designed and constructed to the standards demanded of the trunk road network. Examples of this include the use of strip roads and narrow mats, provision of design classes at very low traffic levels e.g. 50,000 esa's, stage construction techniques, and the use of relaxed materials specifications as traffic levels reduce. In recent years further innovation has been shown by adoption of low cost sealing techniques, flexibility in geometric designs and the use of experimental surfacings, such as the Otta seal.

The evidence of the recent research programmes shows that a further general relaxation in the specifications for rural roads is achievable and that there are still further very large savings that can be made on rural road projects.

2. RESEARCH PROGRAMMES

The strategy to develop and test revised design standards is usually achieved by construction of full-scale trials where the number of variables is strictly controlled. Measurements of the performance of these sections are made over a number of years through the design life by assessing the deterioration that occurs in the road as a result of traffic or environment. Trials constructed at different locations enables a range of typical environmental conditions to be included. This approach was adopted on the SFRDP programme in Zimbabwe where 15 experimental trial sections, shown in Table 1, were established on short sections of four secondary roads. All of these roads comprised natural gravel bases with thin surfacings and were monitored regularly to evaluate the pavement deterioration. The performance of these sections are described more fully in the Secondary and Feeder Road Development Programme final report (SFRDP 1995).

An increasingly used and alternative method to the construction of individual trials is the collection of data from existing roads. This approach was adopted on the recent DFID-SIDA funded TRL-SADC Regional Research Programme on natural gravel road bases. Although the variables cannot be as strictly controlled as with a full-scale trial, this approach has the advantage that data can be assimilated quickly, providing roads are selected which cover a range of age, deterioration, structure, material and subgrade type and environment. This recently completed study in southern Africa comprised a number of stages:

- network surveys in three countries in the region to determine the range of traffic, materials and climate.
- collection of construction records for preliminary investigation of the pavement designs and materials used.
- field reconnaissance surveys, complemented by materials testing for final selection of short sections of the road
- site marking, equipment installation and initial monitoring, comprising measurements of:
    - *in situ* strength using Dynamic Cone Penetrometer (DCP)
    - roughness using Merlin
    - *in situ* moisture content and density of pavement layers using nuclear methods
    - Rutting
    - Deflection using a falling weight deflectometer
    - Visual condition
    - Geometry, drainage and levels
    - Regular monitoring carried out twice a year at end of the wet and dry seasons.

A total of 57 sections on the road networks in Malawi, Botswana and Zimbabwe were established of which 33 were on the Zimbabwe network, as shown in Table 1. A wide range of pavement designs and material types were incorporated in the study with particular emphasis being made on the selection of sections with sub-standard or "marginal" base materials. The base materials included lateritic gravels, calcretes, weathered rocks (basic and acidic), quartz gravels, alluvial gravels and aeolian sands, in addition to crushed stone and stabilised base control sections.

The data collected during the programme has been used to develop a series of structural design charts to promote better use of natural gravel bases for low to medium volume rural roads throughout the southern African region and were further adapted to Zimbabwe conditions for the recently published DoR-SFRDP "Guidelines to road design of low volume roads" (DoR 1997).

3. STRUCTURAL DESIGN CHARTS

Two thickness design charts are available, their use depending on the climatic area and whether a sealed shoulder design is selected. The criteria for selecting the design chart to use are given in Figure 1. The pavement thickness designs given in Tables 2 and 3 are appropriate in the range ≤0.01 to 1 million cumulative esa's. The 3 million esa design class follows the recommendations given in Road Note 31 (Transport Research Laboratory 1993) and is similar to that offered in the DoR pavement design manual (DoR 1983). Table 4 outlines the materials requirements for the base materials with the grading envelopes given in Table 5.

4. THE DEVELOPMENT OF STRUCTURAL DESIGN CHARTS

It is an important principle of developing a design chart that the performance of each structure is associated with the actual field conditions that have been experienced by that structure. The behaviour of road pavements is controlled very largely by the most adverse conditions that prevail, even if such conditions occur for a relatively short time. Thus it is important to associate the performance of individual roads with the most adverse conditions experienced by that road. In practice, this means the weakest conditions experienced by the subgrade and, by implication, all the other pavement layers. The spread of sites in the region which were used to develop the charts covered a reasonably wide range of climates, which during the period of the study, experienced both very dry and very wet seasons.

Design charts can be presented to the user as a single design chart 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. This approach has advantages but the complexity and demand of the procedures involved are usually beyond the scope of the facilities available to engineers. An alternative is to develop several design charts based on a subgrade classification test but varied to suit the different climate, drainage conditions and so on. The large number of sites incorporated within the study provided sufficient information for this approach to be feasible.

The laboratory test procedure used by most authorities in the region is the soaked CBR test which is carried out on subgrade samples prepared under a standard set of conditions. Adopting this test approach reduces the task to estimating a relationship between the soaked values and the *in-situ* CBR of the subgrades. Examination of the data collected in southern Africa showed that in wet climates with poor drainage, the most adverse *in-situ* conditions gave *in-situ* CBR values no worse than the laboratory soaked values. Furthermore, sufficient examples were found in the region to tie down the performance of low volume roads at various points in the inference space. In arid areas the *in-situ* CBR was found to be about twice the value in wet areas. Structures that are known to work well under wet and poorly drained conditions (i.e. when the *in-situ* subgrade strength at the seasonally worst condition is similar to that obtained in the standard laboratory soaked CBR test) will behave in a similar way on a subgrade of half this strength in arid conditions. Therefore, as a first approximation, the design chart for arid climates can be identical to that for 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 covers a CBR range of a factor of two (ie. 2-3, 4-7, 8-15, etc).

After climate, the next most important factor to influence road performance was found to be the drainage conditions as measured by the height of the crown of the road above the invert of the drainage ditch, and the distance of the outer wheel track from the edge of the sealed area. Until fairly recently, the provision of sealed shoulders on low-volume roads would have been considered to be both expensive and unnecessary. However, there is also a structural benefit from maintaining a drier environment under the running surface. The resulting high strengths derived from the relatively dry condition results in a stronger pavement. It also allows weaker materials to be used in the upper pavement layers in situations where materials which satisfy conventional specifications are unavailable. There is a whole-life benefit from the reduced maintenance alone, as well as a safety benefit from the sealing of shoulders.

It was apparent from the data collected in the region that the subgrade strengths in the wheel tracks are affected only marginally by the addition of sealed shoulders of 0.5 metres width whereas with sealed shoulders of 1 metre or more, the subgrade strength is increased to about 2.5 times the worst case (wet and poorly drained conditions) in arid and moderately wet conditions.

If the shoulders of the road are sealed to a sufficient width such that the outer wheel track is more than 1.5 metres from the edge of the sealed area, and the drainage is ensured by maintaining the crown height greater than 0.75 metres above the ditch, a further improvement on the performance is possible. For arid areas this is equivalent to a reduction in the subgrade strength requirement by a factor of 3, in moderate climates the factor is 2.5 and for wet climates it is around 1.5 to 2. Where the factor is a whole number, a simple shift in subgrade strength by one category is reasonable if sealed shoulders are provided. If the shift is not a whole number, thickness interpolations become necessary.

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

a) the thickness design is sufficient to protect the subgrade from traffic 'fatigue' type failure such that greater traffic means thicker structures.

b) the strength of the base is sufficient to prevent failures of any sort, i.e. the base is a zero risk design.

The evidence from the studies in Zimbabwe and the rest of the region indicates that marginal quality base coarse materials have performed satisfactorily for low volume rural roads carrying typical rural road traffic. As the traffic level increases, the specification for road bases should approach those of the traditional design charts. Experience in the region indicates that this change of function occurs when the traffic levels reach 0.5 million cumulative esa's and therefore the local design specifications or Road Note 31 should be used at these higher traffic levels. The traffic category 0.5 million cumulative esa's is a suitable intermediate level at which intermediate material specifications are used. If for any reason, the functional use of roads at lower traffic levels differs from the basic assumption, eg. roads serving a specific "heavy" but small industry such as mining or timber then either the road base specifications can be tightened or, more simply, the next higher traffic category can be used for design to reduce risks. At lower traffic levels, traffic induced failure is most unlikely and all of the deterioration observed on the low volume roads in Zimbabwe was controlled mainly by the environment. Thus the thickness designs and material specifications have been devised to mitigate this deterioration mechanism and the increases in thickness as traffic increases have been kept to a minimum commensurate with gradual transitions to the thickness required at the higher traffic levels where road function essentially changes.

5. GUIDELINES FOR BASE MATERIAL SELECTION

The materials design characteristics recommended for use with the design chart have been developed using the laboratory and field data collected from the road sections in Zimbabwe, Malawi and Botswana in addition to other information available from other pavement studies, including the SFRDP, and published sources such as the CIRIA report on laterites (CIRIA 1988). The materials design follows the format of the design chart and upper limits on material properties assigned to reflect traffic level, poorer subgrades and the influence of climate.

As mentioned, very little evidence of traffic related distress has been found on the secondary roads in Zimbabwe and in the road base layers studied. This enabled revisions to the current road base specifications to be made.

The principles of the materials design are:-

i) The strength, plasticity and grading requirement varies depending on the traffic level and climate.
ii) The soaked CBR test has been used to specify the minimum base material strength. The compaction requirement for the test is 98% Mod.AASHTO and the soaking time is a minimum of 4 days or until zero swell is recorded.
iii) Four grading envelopes (A,B,C and D) are used which depend on the traffic and subgrade design class.
iv) The maximum plasticity index of the base also depends on the traffic and subgrade design class. A maximum value of 6 for the plasticity has been retained for higher traffic levels and weak subgrades.

The wider grading envelopes allow the use of a much wider range of natural gravels including the more commonly gap-graded materials such as laterites, ferricretes etc. However, to prevent excessive loss in stability a requirement of 5 to 10% retained on successive sieves has been specified. Envelope C applies only to dry climates and extends the upper limit of B to allow the use of calcareous materials and Kalahari sands, common in the western and southern provinces. Envelope D for very low traffic volumes is essentially a gravel wearing course specification which is given in terms of a grading modulus range. A number of roads in Zimbabwe and the rest of the region, which were constructed to gravel wearing course standards were sealed after construction and have performed well.

6. ADAPTION TO ZIMBABWE CONDITIONS

The general principles of the structural design and pavement materials guidelines outlined above have been further adapted for Zimbabwe by DoR-SFRDP in the "Guidelines to road design for low volume roads". These guidelines generally follow the DoR notation (DoR 1983) for subgrade design, subgrade treatment and traffic class but do include a number of modifications. The pavement design guidelines (DoR 1997) provide guidance on the design approach for low volume roads and should not be construed as being a prescriptive manual or specification. The message throughout is for the engineer to be more flexible in his approach to the design standards used for low volume roads and to move away from the rigidity of design manuals. Considerations for relaxing standards need not apply to the whole road length but there may be sections where such changes in approach are justified.

6.1 Two new class traffic classes are introduced at <0.01M and 0.5M

There will sometimes be special cases where, for example, heavy traffic is serving a local industry, and it is advisable to use the next highest design traffic class to reduce risk. If this occurs at the 0.3 design class the current DoR designs (DoR 1983) would force a jump to the 1M design and provision of an extra layer with resultant extra costs.

6.2 Two new subgrade classes at SG15 and SG30

The DoR specification (DoR 1983) uses four subgrade design classes (SGE,SG3,SG5 and SG9). About 75% of Zimbabwe is covered by low to medium plasticity residual soils from acidic parent rocks and Kalahari sands. These quartzitic rich soils are often much stronger than the DoR upper category SG9 and soaked CBR values well in excess of 30 are common. Substantial benefits are available by recognising the inherent strength of these materials and this is recognised in the new pavement design with introduction of SG15 and SG30+ designs.

6.3 A new SG15+ subgrade treatment class

The new subgrade treatment class requires that the top layer is compacted to a minimum density of 95 per cent mod. AASHTO. At this level of compaction the top layer of the subgrade is effectively performing the function of the sub-base, and thus at SG30+ there is no requirement for a sub-base in the structural designs and savings are made on provision of this layer.

6.4 Optional choice of sealed width of carriageway

The width of sealed surface affects the distance between the outer wheel path and the edge of the seal influenced by seasonal wetting. On total sealed widths of seven metres or less, the outer wheel path 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 wheel to be more than 1.5 metres from the pavement edge, and good drainage is ensured by maintaining the crown height at least 750mm above the ditch, a further improvement in performance results which is recognised in the charts. The different sealed surface widths are, therefore, treated separately in the design charts and ultimately economics and cost comparison will dictate the most feasible selection.

6.5 Climate

Account has been taken of local conditions of climate and how these effect the road deterioration as observed in Zimbabwe. Zimbabwe has been mapped using Weinert's climatic "N" value and although traditionally four separate climatic regions have been identified (<2, 2-3.9, 4-5 and >5) the design method recognises only two N<4 and N>4. From the pavement design perspective N-values of less than four imply a climate that is seasonally tropical and wet; whereas N-values of greater than four imply a climate that is arid, semi-arid, or dry.

The use of a wider sealed cross-section in geo-climatic zones where N<4 (likely to be relatively wet environments) allows a shift from chart 1 to 2. This results in the use of thinner pavement layers and a relaxation of the quality requirements for road base. In geo-climatic zones where N>4 (likely to be drier climates), it can be assumed that the subgrade strength requirement will approximately be halved, as described earlier. In borderline cases where the project is located close to the border between the two climatic zones (that is, between N = 4.0-5.0 and N= <2.0-3.9), the lower N-value is used to reduce risks.

Recognition of the effect of climate and the width of the seal can therefore provide a more cost-effective method for designing low volume roads.

6.6 Embankments

When a road is on an embankment of more than 1.2 metres 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 again be relaxed, and a pavement with a seven metre total sealed width (0.5m sealed shoulder) can be designed to the same criteria as an eight metre seal (1m sealed shoulder).

6.7 Materials

The normal practice in Zimbabwe is to add between 1 and 3 percent cement to natural gravel roadbase materials. The evidence gathered during the recent research programmes shows that the unmodified natural gravels have all performed satisfactorily and that the addition of cement is generally not required. The unnecessary addition of cement is expensive and for the most part is unjustified on low volume secondary and feeder roads. The design guidelines (DoR 1997) for low volume roads utilises that natural gravels are used for both road base and sub-base layers.

Experience has shown that certain pedogenic materials, such as laterite, silcrete and calcrete perform extremely well as roadbase and sub-base materials, even though the plasticity is out of the recommended ranges. There is therefore provision in the design to modify the acceptable plasticity ranges of these materials.

6.8 Sealing gravel roads

Investing in a sealed road will normally result in both road maintenance costs and vehicle operating costs being reduced. It becomes worth investing in sealing, therefore, when the discounted life cycle benefits of the resealing are greater than the discounted costs. This decision will depend on the condition of the existing gravel road, the traffic type and level, the environment and the type of pavement provided as a result of the sealing. Generally, as traffic levels increase, the case for sealing is strengthened as there are more vehicles to benefit from the lower vehicle operating costs. An analysis carried out during the SFRDP suggests that in some cases it may be economic to seal a road at between 30 to 40 vehicles per day.

A significant reason for the low traffic threshold relates to the comparatively small cost difference between the sealed pavement and the gravel surface. The cost of providing a thin base is very similar to that of re-gravelling and the additional cost is mainly related to the provision of the bituminous seal, if the sealed road is to be follow the same alignment and cross-section and utilises the structures present on the gravel road e.g. culverts etc.

There is provision for this approach in the pavement design at lowest traffic class, where the materials specification essentially follows that of the gravel wearing course. Where existing gravel is to be utilised as road base it can be removed (stockpiled), whilst the underlying layers are then treated as appropriate to the subgrade design class. The stockpiled gravel wearing course can be re-used as road base or mixed with imported material if required to form the road base.

6.9 Other factors

Careful consideration needs to be given to determining the traffic growth rate. Projecting traffic growth and assigning accurate equivalence factors to the traffic is crucial if economic designs are to be achieved. Using unrealistically high growth rates or equivalence factors opens the door to the traditional pavement design approaches and construction methods required for more heavily trafficked roads. This reduces the level of risk for the engineer but results in conservative pavement designs which can ultimately negate the project feasibility. From a road design point of view it is better to obtain reliable estimates of esa's rather than using estimates of ADT's. However, it is quite often the case that axle load surveys carried out for these roads are of little benefit because of the difficulty in generating statistically reliable data.

Performance data collected during the TRL-SADC and SFRDP studies has shown that the deterioration due to traffic, e.g. the development of permanent deformations, is negligible until the traffic level gets to about 0.3-0.5 million esa's. Below this level of traffic the road deterioration was found to be highly dependent on climate and environment, with cracking and embrittlement of the surfacing of most concern.

If resources are not made available to carry out an axle load survey, the design guidelines (DoR 1997) offer a default values of 0.46 esa's per heavy vehicle for secondary and feeder roads in Zimbabwe. The design traffic used is for heavy vehicles only. Provision is made to revise this estimate in light of local conditions of vehicle type and axle configuration. Where projections on growth are uncertain an alternative approach is to select a shorter design life e.g. 10 rather than 20 years. In this way the pavement and geometric designs are improved in stages in response to the traffic growth (rapid or uncertain). It is often the case that the lighter designs provided for 10 years, if well maintained, are sufficient for 15 or even 20 years anyway.

7. SUMMARY

One of the arguments often voiced against using unconventional designs, materials and techniques for road construction is that the level of risk is unacceptable. However, evidence from the studies in Zimbabwe and elsewhere do not support this argument. For example, some relatively highly trafficked roads constructed using sub-standard gravels have out-performed adjoining sections of road constructed using conventional materials. Also, the correct combination of many of the innovative developments which have emerged during the research actually yield additional benefits which outweigh the apparent, perceived risks in the adoption of any one of the measures.

The recent research programmes carried out in Zimbabwe have highlighted some aspects of economic, geometric, drainage and pavement design where a more flexible approach to low volume road provision could be introduced. There are very large potential savings indeed to be made from application of research in low volume road provision. Flexibility in structural and geometric design, low-cost improvements to drainage, sealed shoulders, judicious use of materials in the pavement structure, alternative surfacing techniques and drainage structures have all been identified as being potentially cost effective measures which could be used in the construction of low volume secondary and feeder roads in Zimbabwe.

Ultimately, guidelines or recommendations that are produced need to be accepted, approved and implemented through incorporation into road design manuals. This task is the responsibility of the DoR who have set an example to the whole region in their capacity to invest in research and benefit from its implementation. Engineers in donor agencies, roads departments and consultants outside Zimbabwe need to be far more flexible in the design, construction and maintenance of low-volume roads if the findings from research studies, such as those carried out in Zimbabwe are to benefit them as well. The penalty of not adopting new ideas and technologies is that progress through development is impeded.

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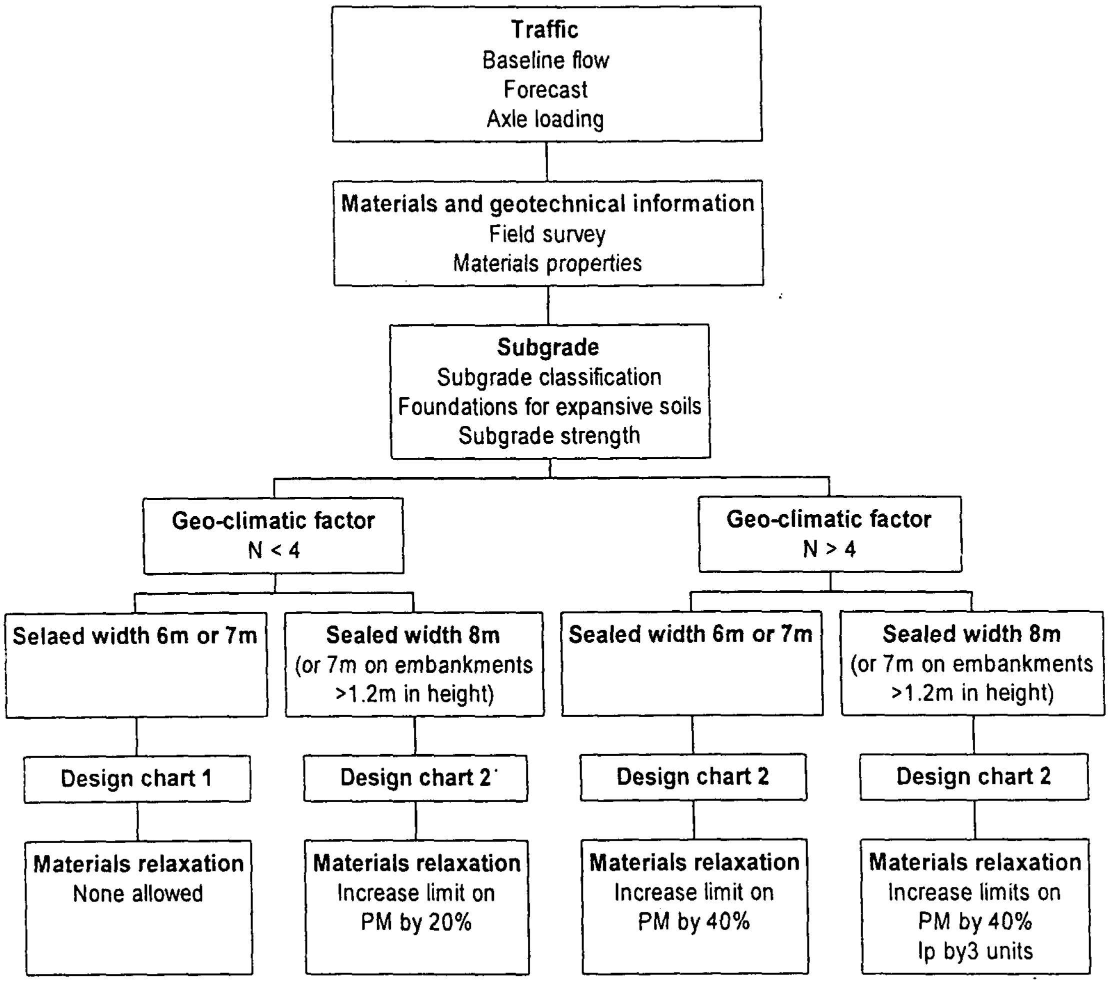

Figure 1 : Flow Chart for Sealed Road Pavement Design process

Table 1 **Distribution of SFRDP and TRL-SADC paved road research sections in Zimbabwe**

Road	Route Number	Design Traffic	Number of sections	Research programme
Bulawayo-Kezi	643		1	TRL-SADC
Glendale-Centenary	138	0.3-0.1	3	TRL-SADC
Headlands-Mayo	239	0.1M	1 2	SFRDP TRL-SADC
Karoi-Binga	954	1M-0.3M	4	SFRDP
Kamativi-Binga	839	0.05M	2 5	SFRDP TRL-SADC
Lupane-Tsholotsho	755	0.05M	1	TRL-SADC
Marondera-Musami	267	0.05M	5	TRL-SADC
Mlibizi Access	852	0.05M	3	TRL-SADC
Murewa-Madicheche	169	0.1M	1	TRL-SADC
Nyanga-Ruangwe	264	0.1M	9	TRL-SADC
Nyika-Zaka	438	0.3M	7	SFRDP
Rusape-Nyanga	214	0.3M	1	TRL-SADC
St Joseph's-Maphisa	663	0.05M	1 1	SFRDP TRL-SADC
Wedza-Mutiweshiri	349	0.3M	1	TRL-SADC

Table 2 Pavement design chart 1 (N<4)

		Upper limit of design traffic class													
		0.01M		0.05M		0.1M		0.3M		0.5M		1M		3M	
CBR	Layer	Thickness	CBR	Thickness	CBR	Thickness	CBR	Thickness	CBR	Thickness	CBR	Thickness	CBR	Thickness	CBR
SG3	Road base	150	45	120	65	150	65	150	80	175	80	200	80	200	80
	Sub-base	-	-	120	30	120	30	120	30	150	30	175	30	225	30
	Select fill	150	15	120	15	120	15	150	15	150	15	200	15	200	15
SG5	Road base	120	45	150	55	150	65	175	65	200	65	200	80	200	80
	Sub-base	-	-	120	30	150	30	175	30	200	30	225	30	275	30
	Select fill	150	15	-	-	-	-	-	-	-	-	-	-	-	-
SG9	Road base	150	(1)	120	45	150	55	175	65	200	65	200	80	200	80
	Sub-base	-	-	120	30	120	30	120	30	120	30	150	30	200	30
	Select fill	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SG15	Road base	150	(1)	200	45	120	45	120	55	150	55	200	65	200	80
	Sub-base	-	-	-	-	120	30	120	30	120	30	120	30	120	30
	Select fill	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SG30	Road base	150	(1)	150	45	150	45	175	55	175	55	175	65	200	80
	Sub-base	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Select fill	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

1. Gravel wearing course quality

- All base and sub-base materials are natural gravels
- Base CBRs are soaked and at 98% mod AASHTO (or equivalent) at optimum moisture content
- Sub-base and selected fill CBRs are at 95% mod AASHTO (or equivalent) at optimum moisture content
- Subgrades are non-expansive
- Thicknesses in mm

Table 3 Pavement design chart 2 (N>4)

		Upper limit of design traffic class													
		0.01M		0.05M		0.1M		0.3M		0.5M		1M		3M	
CBR	Layer	Thickness	CBR	Thickness	CBR	Thickness	CBR	Thickness	CBR	Thickness	CBR	Thickness	CBR	Thickness	CBR
SG3	Road base	150	45	120	65	150	65	150	80	175	80	200	80	200	80
	Sub-base	-	-	120	30	120	30	120	30	150	30	175	30	225	30
	Select fill	150	15	120	15	120	15	150	15	150	15	200	15	200	15
SG5	Road base	150	(1)	120	45	150	55	175	65	200	65	200	80	200	80
	Sub-base	-	-	120	30	120	30	120	30	120	30	150	30	275	30
	Select fill	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SG9	Road base	150	(1)	200	45	120	45	120	65	120	65	150	65	200	80
	Sub-base	-	-	-	-	120	15	120	15	120	30	150	30	200	30
	Select fill	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SG1 5	Road base	150	(1)	150	45	150	45	150	55	175	55	150	65	200	80
	Sub-base	-	-	-	-	-	-	-	-	-	-	120	30	120	30
	Select fill	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SG3 0	Road base	150	(1)	120	45	120	45	120	55	150	55	175	65	200	80
	Sub-base	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Select fill	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Notes:

2. Gravel wearing course quality

- All base and sub-base materials are natural gravels
- Base CBRs are soaked and at 98% mod AASHTO (or equivalent) at optimum moisture content
- Sub-base and selected fill CBRs are at 95% mod AASHTO (or equivalent) at optimum moisture content
- Subgrades are non-expansive
- Thicknesses in mm

Table 4 Selection of natural gravel road base materials

Subgrade class	Property	Upper limit of design traffic class						
		0.01M	0.05M	0.1M	0.3M	0.5M	1M	3M
SG3	I_P	≤ 12	≤ 12	≤ 9	≤ 6	≤ 6	≤ 6	≤ 6
	PM	400	250	150	120	90	90	90
	Grading	B	B	B	A	A	A	A
SG5	I_P	≤ 15	≤ 12	≤ 12	≤ 9	≤ 6	≤ 6	≤ 6
	PM	550	320	250	180	90	90	90
	Grading	C(1)	B	B	B	A	A	A
SG9	I_P	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
SG15	I_P	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
SG30	I_P	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

Road base CBR	Max swell (%)
45	0.5
55	0.3
65-80	0.2

Notes:

3. Grading 'C' is not permitted in wet climates; grading 'B' is the minimum requirement
4. Maximum $I_P = 8 \times GM$
5. Grading 'D' is based on the grading modulus $1.65 < GM < 2.65$

- All base materials are natural gravels
- Subgrades are non-expansive
- Separate notes are provided covering the use of laterites and calcretes
- I_P Plasticity index
- PM Plasticity modulus
- n/s Not specified

Table 5 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 Nominal maximum particle size			*Envelope B*	*Envelope C*	*Envelope E*
	37.5mm	20mm	10mm			
50mm	100	-	-	100	-	100
37.5mm	80-100	100	-	80-100	-	80-100
20mm	55-95	80-100	100	55-100	-	60-100
10mm	40-80	55-85	60-100	40-100	-	-
5mm	30-65	40-70	45-80	30-80	-	30-100
2.36mm	20-50	30-55	35-75	20-70	20-100	-
1.18mm	-	-	-	-	-	17-75
425µm	8-30	12-30	12-45	8-45	8-80	-
300µm	-	-	-	-	-	9-50
75µm	5-20	5-20	5-20	5-20	5-30	5-25
Envelope D 1.65 < GM < 2.65						