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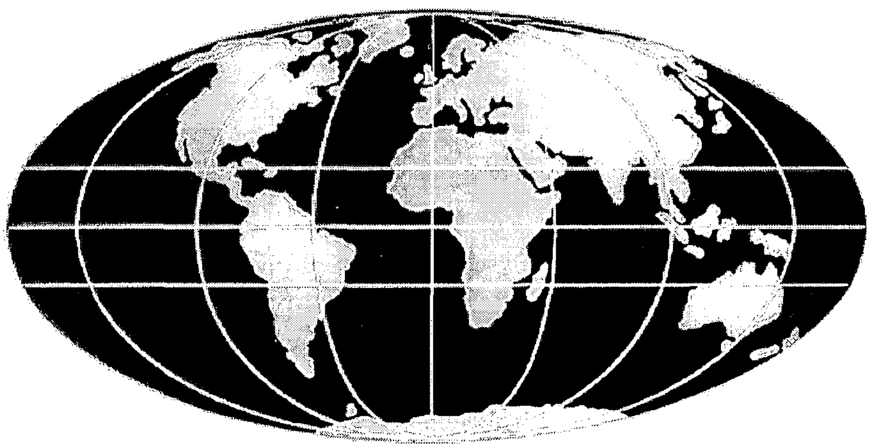

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LIGHTLY TRAFFICKED SEALED ROADS IN SOUTHERN AFRICA: Flexibility in design and construction

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ABSTRACT

It is estimated that approximately 70% - 80% of the total length of the road network in sub-Saharan Africa are of gravel or earth standard.. Much of the current investment in new road projects involves upgrading these secondary and feeder roads to a bituminous standard. Traffic volumes on these roads are low and it follows that the benefits accruing from savings in vehicle operating costs will also be low. One method of improving the return on investment is to reduce construction costs. This can be achieved by applying a more innovative, flexible and, in some cases, relaxed approach to the traditional engineering methods normally used.

High cost designs are often applied because of lack of knowledge of the available alternative or innovative design technologies which could benefit the project. A new, more flexible approach to low volume road provision is crucial if the needs and economic well being of rural communities in southern Africa are to be improved. Aspects of economic, geometric, drainage and pavement design need to be considered in terms of the purpose and function of low volume roads. The perception that because these roads are low-volume they should also be low technology is misguided. The road engineer needs to draw on all of his engineering skills, judgement and local experience if more economic designs are to be used without incurring unacceptable risk.

Good engineering practice, flexibility in approach and importantly a reactive maintenance strategy are fundamental to the development of appropriate and economic designs for low volume sealed roads. Research provides the means by which the risks can be identified and often provides the technology required to reduce or control them within an economic framework. However, engineers are often conservative and excessively cautious when designing roads and more often than not choose to ignore this innovative technology. The research carried out by the Transport Research Laboratory (TRL) in southern Africa is briefly described and is used to highlight the potential for achieving substantial savings if research findings are implemented. The results from this recently completed study have been used to develop a series of provisional road design tables and guidelines for the selection of natural gravel bases. The charts and recommendations given are specific to lightly trafficked roads in the southern Africa region and should not, at this stage, be used elsewhere.

1. INTRODUCTION

Transport and its associated infrastructure is a key component in the development process. Most of the developing world now has a fairly well established trunk road network and the early research work by TRL and others in developing countries assisted in achieving this at a reasonable economic cost. Today in the developing countries of southern Africa the emphasis has shifted toward the maintenance and rehabilitation of this primary network and, importantly, to the provision of a secondary and feeder network to develop the rural areas. The provision of roads, especially surfaced roads, are always high on the list of the priorities requested by rural communities in developing countries. One of the benefits of road provision for rural communities in Africa is that operators more readily provide public and commercial transport services. This provides greater mobility, better access to education and medical services, improved employment opportunities with better access for tourist traffic. Therefore improved transport promotes greater economic activity and local communities experience a better quality of life. This improvement in access is extremely important as a high proportion of the agricultural activity is often carried out in these areas by small scale farmers. Transport provision is also needed to enable movement and exploitation of natural resources such as mining, timber, etc. Of the 70 to 80 per cent of roads in Africa which are unpaved, most serve communities outside the major towns, cities and connecting corridors. There is considerable scope for improving the well-being of these communities if ways can be found of providing surfaced roads at an economic cost.

Low-volume sealed roads fall into a number of categories such as strip roads, narrow mats (3.5m wide) and wide mats (6m+ wide). The successful performance of strip roads and narrow mats is a function of the traffic volume and nature of the shoulder materials. Full-width sealing, even for very low volume roads, may be justified if for example, shoulder maintenance costs become excessive. These roads often arise in stages starting as basic tracks and access roads and, as the level of demand and traffic rises, so the economic justification for upgrading to a bituminous standard increases and the function of the road changes (i.e. from feeder to secondary to primary trunk).

Conferences such as this, which deal specifically with the issues of providing low volume roads, demonstrates the need to treat these roads differently from other roads on the network. Certain issues need to be addressed when considering the sealing of low volume roads, such as the:

- traffic levels at which sealing should be considered i.e. what do we mean by "low-volume"
- applicability of the economic appraisal techniques used
- appropriateness of conventional pavement design methods
- suitability of standard materials and construction specifications
- feasibility of relaxing geometric design standards
- quality and construction standards
- identification of acceptable levels of engineering risk
- establishment minimum maintenance requirements

Some of these issues will be raised in this paper but it expected that many others will be raised during the course of the conference. In most cases these questions can be addressed through research but this, in itself, is of little value unless the results are applied by the engineering fraternity. Some of TRL's research on the development of pavement design and materials specifications will be described with suggestions on other engineering provisions that may also be of interest to the engineer.

2. ECONOMIC APPRAISALS FOR LOW VOLUME ROADS

Roads are often subjected to the same economic justification criteria as other developmental projects, particularly when external donor or loan funding is sought. The approaches used for the feasibility study, economic appraisal, and the designs and standards selected, often use the same techniques that would be applied to "highly trafficked" or primary roads, e.g. using transport investment models. These models, such as the TRL's Road Transport Investment Model, RTIM3 (Transport Research Laboratory (1994)) and the Highway Design and Maintenance Model, HDM3, (WORLD BANK (1987)) have been produced from extensive studies in Kenya, India, the Caribbean and Brazil. Most of the models used to determine return on the investment are driven by savings in vehicle operation costs (VOC's). If traffic volume is expected to be low over the duration of the (low volume road) project, then savings made on VOC's will also be low.

For low volume roads it is important to recognise and use other benefits that the road investment produces. These include the benefits to the rural populations created by opening new markets, increasing local development, creating greater community productivity and new job opportunities, providing easier access to places of education, markets, clinics and the like. There are also other non-motorised transport benefits which the new World Bank model (HDM4) addresses.

3. DESIGN CONSIDERATIONS FOR LOW VOLUME ROADS

Low volume can be understood as low average daily traffic (ADT) or low cumulative number of equivalent standard axles (esa's) over the design life. Indeed some would equate low volume with low cost and even low standard. Most low volume road documentation will cite around 200 vehicles per day (vpd) as the upper limit for low volume roads. However, even this upper limit can range from a lightly to heavily trafficked road depending on the type of vehicles using the road.

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 TRL's studies in southern Africa 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.

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.

The investment through donor funding in road construction projects during the last two decades has, in most countries of southern Africa, not been matched by a similar investment in road maintenance. Donors generally took the view that maintenance of the road network was the responsibility of the recipient governments. The impact of inadequate funding for road maintenance on road deterioration is not immediate and, consequently, maintenance funds have often been an easy target for politicians seeking funds for other projects. Because of this, roads in some countries in the region did not receive a reseal in over 20 years, so it was not surprising that parts of the regional road network fell into disrepair. This lack of provision of resources for maintenance both by donors and recipient countries affected the performance of many roads and in this climate there was a view that it was more prudent to over design to allow for poor maintenance.

Recently, donors have given more support for road maintenance and there is now a move, especially in the southern African region, to develop schemes designed to yield dedicated funding for road maintenance (e.g. direct funding through fuel levies). There are also moves to involve greater participation of the private sector under the direction of Road Authorities. These moves are strongly supported by the World Bank sponsored Road Maintenance Initiative (RMI) which is also supported by many other donor agencies. It is now strongly believed that these measures should prevent the mistakes of the past being repeated through a greater awareness of the consequences of inadequate funding for road maintenance and by reducing the opportunities for interference in the funding mechanism. In this climate of increased awareness, there are greater opportunities to exploit the results of research.

Very large savings indeed can be made at the construction phase of rural road projects. 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 in the country. There is now increasing evidence that these designs are not only inappropriate but are actually preventing investment because of the unnecessarily high costs involved. This situation has prompted development agencies such as the U.K's Department for International Development (DFID) and the Swedish International Development Agency (SIDA) to fund research to provide more appropriate design standards for rural roads in southern Africa. There is now overwhelming evidence to indicate that a general relaxation in the specifications for rural roads is required. Recent research carried out by TRL in southern Africa was aimed at achieving this.

4. NATURAL GRAVEL BASES FOR LOW VOLUME ROADS

A common feature of the specifications for natural gravel base materials are the requirements to meet strict compliance criteria on particle size distribution, plasticity ($Ip \leq 6$) and strength (soaked $CBR \geq 80$ at 98% Mod.AASHTO compaction). In many parts of the tropics and sub-tropics one of the biggest problems for the engineer is the location of materials which meet these specifications. Many natural gravels are often excluded from use because they fail to meet at least one of these criteria. Where materials meeting the specification are not available locally the alternatives are to:

- import suitable materials over long distances
- improve the materials by addition of stabilising agents such as lime or cement
- utilise sources of crushed stone if these are available

Chemical stabilisation has been used successfully in the tropics for many years. However, this and the other options mentioned are expensive and for low volume sealed roads their use could jeopardise the economic feasibility of the project. The greatest potential for savings can be achieved by making use of the untreated or natural gravels even though they may be of inferior quality when judged against the test criteria and limits set out in the specifications. The suitability of the material is often only a conceptual problem because the material is being compared to a specification which in itself may be unsuitable when due consideration is given to the type of material, the method of laboratory assessment, the level of traffic and the influence of local climate, drainage and environment. These specifications have generally been derived from the industrialised countries where the traffic and climatic conditions can be very different to those in the tropics. Often, as experience shows, these imported specifications are unable to discriminate between materials which perform and those which do not.

TRL has carried out many studies in the tropics over the years on these so called "sub-standard" or "marginal" materials to determine the feasibility of using them as alternatives to the more conventional base materials. TRL's strategy for determining suitability of materials is generally based on experience of use. This is usually achieved through careful construction of full-scale road trial sections where the number of variables is strictly controlled. A representative range of the materials based on their engineering properties determined in the laboratory are incorporated into the trial. Measurements of the performance of the sections are made by assessing the deterioration that occurs in the road over time as a result of traffic or environment. To cover a range of environments it may be necessary to conduct a series of trials at different locations.

The aim of these studies is to derive solutions to particular materials design problems so that costs can be reduced by developing appropriate design and materials standards and construction practices. Ultimately, guidelines or recommendations on the use of the materials are produced that can be incorporated into road design manuals, thus promoting wider application of the materials on future projects. These studies have generally been specific to particular materials and regions and much of this research work carried out by TRL has recently been synthesised in a state-of-the-art book by Millard (1993).

Studies such as these, for marginal base materials, have been carried out on cinder gravels in Ethiopia (Newill et al 1987), marls and soft limestones in Belize, Sabka soils in the middle east (Ellis 1973) and for calcretes in Botswana (Greening and Rolt 1997). In all of these studies revisions have been made to the local guidelines for selection of materials and substantial savings have been made on road construction projects where the technology has been adopted. Common to all of the studies is that good performance most often results if the road is kept well drained, good compaction has been achieved during construction and that the bituminous seal is well maintained, remains intact and waterproof.

5. RECENT TRL RESEARCH IN SOUTHERN AFRICA

An increasingly used and alternative method to the construction of individual trials is the collection of data from existing roads. This approach has been adopted on a recent DFID-SIDA funded TRL investigation of marginal natural gravel road bases in southern Africa. 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. The monitoring programme was carried out by five teams operating independently. 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 provisional structural design charts to promote better use of natural gravel bases for low to medium volume rural roads throughout the southern African region. Two thickness design charts are available which depend on the climatic area and whether a sealed shoulder design is selected. The criteria for selecting the design chart to use are given in Table 1. The pavement thickness designs given in Table 2 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). Table 3 outlines the materials requirements for the base materials with the grading envelopes given in Table 4.

The charts are specific to southern Africa and should be used only as a guide. If other local evidence and experience is available to the engineer they should be modified accordingly.

Table 1. Selection of appropriate design chart

SHOULDER DESIGN	CLIMATE (N AREA)	
	<2	>2
UNSEALED*	CHART 1	CHART 2
SEALED	CHART 2	CHART 2

*If drainage conditions are judged to be poor or if the maximum crown height is <0.75m, Chart 1 will be used irrespective of climatic area.

CLIMATIC AREA: Approximate Mean Annual Rainfall for N areas

N >5+	<250mm	(ARID)
N=4-5	250-500mm	(SEMI-ARID)
N=2-3.9	500-1000mm	(SEMI-ARID TO SUB-TROPICAL)
N<2	1000-1500mm	(HUMID TROPICAL)

5.1 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. During the period of the study, the southern African region experienced both very dry and very wet seasons. Southern Africa has been climatically mapped using a numeric or "N" system developed by Weinert. The spread of sites in the region covered a reasonably wide range of climates, classified broadly as dry or arid (N > 5), moderate (N 2-5) and seasonally wet (N < 2). This climatic classification was adopted in the development of the design charts.

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 in developing countries. 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 southern Africa 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).

Table 2. CHART 1: Provisional structural design of low volume roads

	DESIGN TRAFFIC (millions esa's)						
CBR	<0.01	0.05	0.1	0.3	0.5	1	3
3[1]-4[1]	B 150 (45) SF 150 (15)	B 120 (65) SB 120 (30) SF 120 (15)	B 150 (65) SB 120 (30) SF 120 (15)	B 150 (80) SB 120 (30) SF 150 (15)	B 175 (80) SB 150 (30) SF 150 (15)	B 200 (80) SB 175 (30) SF 200 (15)	B 200 (80) SB 225 (30) SF 200 (15)
5-7	B 120 (45) SF 150 (15)	B 150 (55) SB 120 (30)	B 150 (65) SB 150 (30)	B 175 (65) SB 175 (30)	B 200 (65) SB 200 (30)	B 200 (80) SB 225 (30)	B 200 (80) SB 275 (30)
8-14	B 150[2]	B 120 (45) SB 120 (30)	B 150 (55) SB 120 (30)	B 175 (65) SB 120 (30)	B 200 (65) SB 120 (30)	B 200 (80) SB 150 (30)	B 200 (80) SB 200 (30)
15-29	B 150[2]	B 200 (45)	B 120 (45) SB 120 (30)	B 120 (55) SB 120 (30)	B 150 (55) SB 120 (30)	B 200 (65) SB 120 (30)	B 200 (80) SB 120 (30)
30+	B 150[2]	B 150 (45)	B 150 (45)	B 150 (55)	B 175 (55)	B 200 (65)	B 200 (80)

CHART 2: Provisional structural design of low volume roads

	DESIGN TRAFFIC (millions esa's)						
CBR	<0.01	0.05	0.1	0.3	0.5	1	3
3[1]-4[1]	B 150 (45) SF 150 (15)	B 120 (65) SB 120 (30) SF 120 (15)	B 150 (65) SB 120 (30) SF 120 (15)	B 150 (80) SB 120 (30) SF 150 (15)	B 175 (80) SB 150 (30) SF 150 (15)	B 200 (80) SB 175 (30) SF 200 (15)	B 200 (80) SB 225 (30) SF 200 (15)
5-7	B 150[2]	B 120 (45) SB 120 (30)	B 150 (55) SB 120 (30)	B 175 (65) SB 120 (30)	B 200 (65) SB 120 (30)	B 200 (65) SB 150 (30)	B 200 (80) SB 275 (30)
8-14	B 150[2]	B 200 (45)	B 150 (45) SF 120 (15)	B 150 (55) SF 120 (15)	B 200 (65) SB 120 (30)	B 150 (65) SB 150 (30)	B 200 (80) SB 200 (30)
15-29	B 150[2]	B 150 (45)	B 150 (45)	B 150 (55)	B 175 (55)	B 150 (65) SB 120 (30)	B 200 (80) SB 120 (30)
30+	B 150[2]	B 120 (45)	B 120 (45)	B 120 (55)	150 (55)	B 175 (65)	B 200 (80)

NOTES:
1. Non-expansive subgrade.
2. Gravel wearing course quality.

All base (B), sub-base (SB) and selected fill (SF) thickness in mm.

All materials are natural gravels.

CBR's in brackets are soaked and at 98% and 95% Mod.AASHTO compaction respectively for base and sub-base.

Table 3. Provisional guideline for selection for natural gravel base materials for low volume roads

		DESIGN TRAFFIC (millions esa's)						
Subgrade CBR		≯0.01	0.05	0.1	0.3	0.5	1.0	3
3[1], 4[1]	Ip PM GE	≯12 ≯400 B	≯12 ≯250 B	≯9 ≯150 B	≯6 ≯120 A	≯6 ≯90 A	≯6 ≯90 A	≯6 ≯90 A
5-7	Ip PM GE	≯15 ≯550 C	≯12 ≯320 B	≯12 ≯250 B	≯9 ≯180 B	≤6 ≯120 A	≤6 ≯90 A	≤6 ≯90 A
8-14	Ip PM GE	≯20[2] ≯800 GM 1.6-2.6	≯15 ≯450 B	≯12 ≯320 B	≯12 ≯300 B	≤9 ≯200 B	≤9 ≯90 A	≤6 ≯90 A
15-29	Ip PM GE	≯20[2] NS GM 1.6-2.6	≯15 ≯550 C	≯15 ≯400 B	≯12 ≯350 B	≯12 ≯250 B	≯9 ≯150 A	≯6 ≯90 A
30+	Ip PM GE	≯20[2] NS GM 1.6-2.6	≯18 ≯650 C	≯15 ≯550 C	≯15 ≯450 B	≯12 ≯300 B	≯9 ≯180 B	≯6 ≯90 A

NOTES: 1. Non-expansive subgrade; 2. Ip maximum = 8 x GM; Ip = plasticity index; PM = plasticity modulus
GE = grading envelope; GM = Grading Modulus; NS = not specified

SHOULDER DESIGN	CLIMATE (N AREA)		
	<2-3.9	4-5	>5
UNSEALED (Gravel)	No modification	Increase limit on PM by 40%	Increase limit on PM by 40%
SEALED (1 metre+)	Increase limit on PM by 20%	Increase limit on PM by 40% and increase limit on Ip by 3 units	Increase limit on PM by 40% and increase limit on Ip by 3 units

NOTE: Envelope "C" is only permitted in dry climates, N>5, otherwise grading "B" is minimum requirement. Envelope "C" extends the upper limit of envelope "B" to allow the use of calcareous and Kalahari sands.

TABLE 4: Recommended particle size distributions for natural gravel road bases

Test sieve size (mm)	Percent by mass of total aggregate passing test sieve				
	Nominal maximum particle size				
	37.5mm	20mm	10mm	37.5mm	5mm
	GRADING ENVELOPE "A"			GRADING ENVELOPE "B"	GRADING ENVELOPE "C"
50	100	--	--	100	
37.5	80-100	100	--	80-100	
20	55-95	80-100	100	55-100	
10	40-80	55-85	60-100	40-100	
5	30-65	40-70	45-80	30-80	100
2.36	20-50	30-55	35-75	20-70	20-100
0.425	8-30	12-30	12-45	8-45	8-80
0.075	5-20	5-20	5-20	5-20	5-30

5.2 Sealed Shoulders

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 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, ie. the base is a zero risk design.

The evidence from the studies in southern Africa 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 Road Note 31 or similar specifications 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 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.

5.3 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 information available from current specifications (e.g. TRL's Road Note 31 (Transport Research Laboratory 1993) and other local specifications), other TRL pavement studies and published sources of information 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 have been assigned based mainly on traffic level and climate. As mentioned, very little evidence of traffic related distress has been found on the roads and in the road base layers studied. This enabled revisions to the current road base specifications in the region 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 central part of the region. 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 the region, which were constructed to gravel wearing course standards were sealed after construction and have performed well.

5.4 Cost savings

There are very large potential savings indeed to be made from the implementation of research findings from work done by TRL and others on design standards for low volume secondary and feeder roads. For example, in Malawi, the provision of a crushed stone base, which is often the preferred design option, is generally around 15% of the total project costs. The differential between the cost of 1Km of crushed stone base and 1Km of locally available lateritic gravel is at least 4:1. Substantial savings on the cost of construction of low volume roads can be achieved if these locally abundant gravels can be utilised for the base construction. Where sources of crushed stone are not readily available, which is the case in many areas in southern Africa the differential in costs between crushed stone and the natural gravel base is much higher than the 4:1 quoted.

6. OTHER DESIGN CONSIDERATIONS

It is often extremely difficult to ensure that the findings from research studies are put into practice. Engineers in donor agencies, roads departments and consultancies need to be far more flexible in their approach to the design, construction and maintenance of low-volume roads. Only in this way will the benefits of the investment made in the research be fully realised.

Measures such as "design-by eye" geometrics, low-cost improvements to drainage, provision of sealed shoulders, use of "sub-standard" materials in the pavement structure and alternative surfacing techniques, have all been identified as being extremely cost effective in the construction of secondary and feeder roads. There is also little evidence that these measures have increased the risk of failure when they have been used appropriately.

6.1 Geometric Design

Substantial savings in construction costs can be achieved if relaxed geometric designs are used. On major roads, with relatively high volumes of traffic travelling at high speeds, it is important to set high standards for horizontal and vertical alignment for reasons of safety and economics. On rural roads, where traffic volumes and design speeds are generally less, it is possible to adopt a more relaxed approach without compromising road safety. During the construction of feeder roads in Zimbabwe recently, a more flexible approach was adopted, outlined in TRL's Overseas Road Note 6 (Transport and Road Research Laboratory 1988) which allowed some relaxation of the geometric design standards. This flexibility allowed variation of the design speeds and steeper gradients. Using a "design by eye" approach, where no formal alignment calculations are made, engineering judgement and simple surveys are used to set the alignment and identify where spot-improvements are necessary. In this way, maximum use can be made of the existing formation thus reducing the requirement for additional expensive earthworks. The geometric design standards should be reviewed in light of the particular traffic and safety demands of the road.

Where relaxations are possible the engineer will still need to consider problems arising from erosion, drainage, excessive run-off etc.

6.2 Improved drainage

One of the major concerns when using lower standard materials in the pavement layers is that they will be more susceptible to weakening by moisture ingress if for example the drainage provided is inadequate or becomes ineffective with time. This problem can be partly solved by the provision of sealed shoulders. However, there is still a possibility of moisture rising from below the load-bearing layers. A low-cost precaution against this eventuality would be to win the fill materials from within the road reserve thus raising the embankment and improving drainage at little extra cost. This technique has been used successfully on projects in Malawi. The resulting wider drains and road reserve also provides additional road safety benefits for both motorists and other non-motorised road users.

It is often uneconomic to provide high standard bridges on streams and minor river crossings on low volume roads. One method which has been adopted on feeder roads in Zimbabwe is to provide a combination design of a culvert and "Irish Bridge" or "drift" which is expected to be overtopped for only very short periods in the wet season.

6.3 Dry compaction

A major problem often encountered in dry areas is the provision of water for compaction. In some areas water provision can be 20 per cent of the construction costs. Studies carried out by TRL in Kenya and Sudan have shown that, in favourable circumstances, compaction of embankment and pavement materials can be achieved at moisture contents below optimum without any deleterious effect on the future pavement performance. (O'Connell et al, 1987)

6.4 Low-cost surfacings

Surface dressings are the normal seal provided for low and medium trafficked roads in southern Africa. Studies in the region have shown that graded (or Otta) and sand seals can provide economic and practical alternatives to these conventional seals. These surfacing techniques are particularly suited to road construction in rural areas where conventional sources of surfacing aggregate might be unavailable. Otta seals have the added advantage that they use an increased output from the crushing plant or natural gravel source, are cheap and easy to construct, durable and easy to maintain. Rubberised or polymer modified bitumens could also be beneficial where moisture sensitive soils are used in the pavement structure.

In a similar way as has been the case for the base materials, aggregate specifications for chippings can be inappropriately high for low volume roads and where reductions in the specifications can be made substantial savings can be achieved (Woodbridge et al 1991).

6.5 Materials location and data archiving

It is important that full use is made of all of the available published and unpublished information during desk and feasibility studies to maximise site knowledge and make savings on site surveys. Remote sensing techniques such as use of air photography and satellite imagery when coupled with ground surveys can provide relatively cheap alignment soils and resource information, for example identifying the occurrence of expansive, collapsible and dispersive problem soils. Furthermore, these terrain techniques can be used to assist with the geometric alignment for example by locating routes close to the crests of ridges where the soils are generally stronger and are well drained and the need for drainage structures can be minimised.

Correlations between geology, topography, climate, hydrology and vegetation should be used to target possible materials locations. A useful way of controlling this stage is to follow the principles of terrain evaluation where the landscape is sub-divided into similar morphological units. These principles are fully described in TRL's state-of-the-art Terrain Evaluation Manual (Lawrance et al 1993). A good example of the use of these techniques was the TRL study in Botswana where it was possible to locate calcrete deposits under the Kalahari sand. Calcrete landforms were located along a road corridor in southern Botswana (17000 sq km) using standard black and white aerial photography and computer enhanced Landsat images. The success of these techniques enabled survey teams to be directed to the target resources for further exploratory testing (Lawrance and Toole 1984). These same techniques have been used to locate other natural gravel deposits such as laterites (CIRIA 1988), quartz gravels, cinder gravels and weathered rocks (Lawrance et al 1993).

The terrain evaluation approach can often be extended to encompass tools such as a materials inventory. These computer based data archiving systems provide a method of storing information on previous materials deposits. Information on location of existing borrow pits, alignment soil types etc can be displayed spatially on maps and when used in combination with digitised topographic, geological, climatic and soils maps to enable predictions to be made on where new resources can be expected to be located. This has particular applications for low volume roads where resources for site surveys may be at a premium.

7. SUMMARY

There are very large potential savings indeed to be made from application of research in low volume road provision. Flexibility in geometric design, low-cost improvements to drainage, sealed shoulders, dry compaction, use of "sub-standard" 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.

The message is for the engineer to be more flexible in his approach to low volume roads and to move away from the rigidity of design manuals. Clearly there will also be circumstances when the benefits of one approach out weighs the other. There will be circumstances when an approach such as using marginal materials may not be appropriate, for example where the materials are too poor and stabilisation or modification is required. Where poor subgrades are prevalent, judicious and selective stabilisation with lime may be warranted by the savings that can be made in pavement material thickness and quality. Safety or other engineering circumstances may dictate the needs of the geometric alignment and determine what is feasible. Considerations for relaxing standards need not apply to the whole road length but there may be sections where such changes in approach are justified.

The road designs and the materials specifications adopted in the developing countries of southern Africa have evolved under conditions of severe over-loading of vehicles, poor or no road maintenance and poor construction quality control. Networks have suffered and this has led to some donors and investors to move into other investment sectors. Nowadays, road authorities are establishing road management systems and road maintenance initiatives which should ensure that timely maintenance is carried out in the future. These policies together with the increased involvement of the private sector plus community based participation in the road maintenance programmes should help to promote a better climate for innovation and investment in the low volume roads sector.

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 many of TRL's studies 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 described in this paper actually yield additional benefits which outweigh the apparent perceived risks in the adoption of any one of the measures. However, it is recognised that further demonstration projects are required before some elements of the naturally conservative engineering fraternity are convinced of the benefits of these techniques.

Engineers in donor agencies, roads departments and consultants need to be far more flexible in the design, construction and maintenance of low-volume roads if the findings from research studies are put into practice. Only in this way will the benefits of the investment in the research be fully realised. The penalty of not adopting new ideas and technologies is that progress through development is impeded.

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