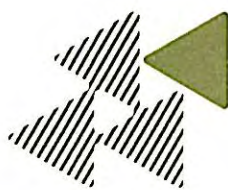
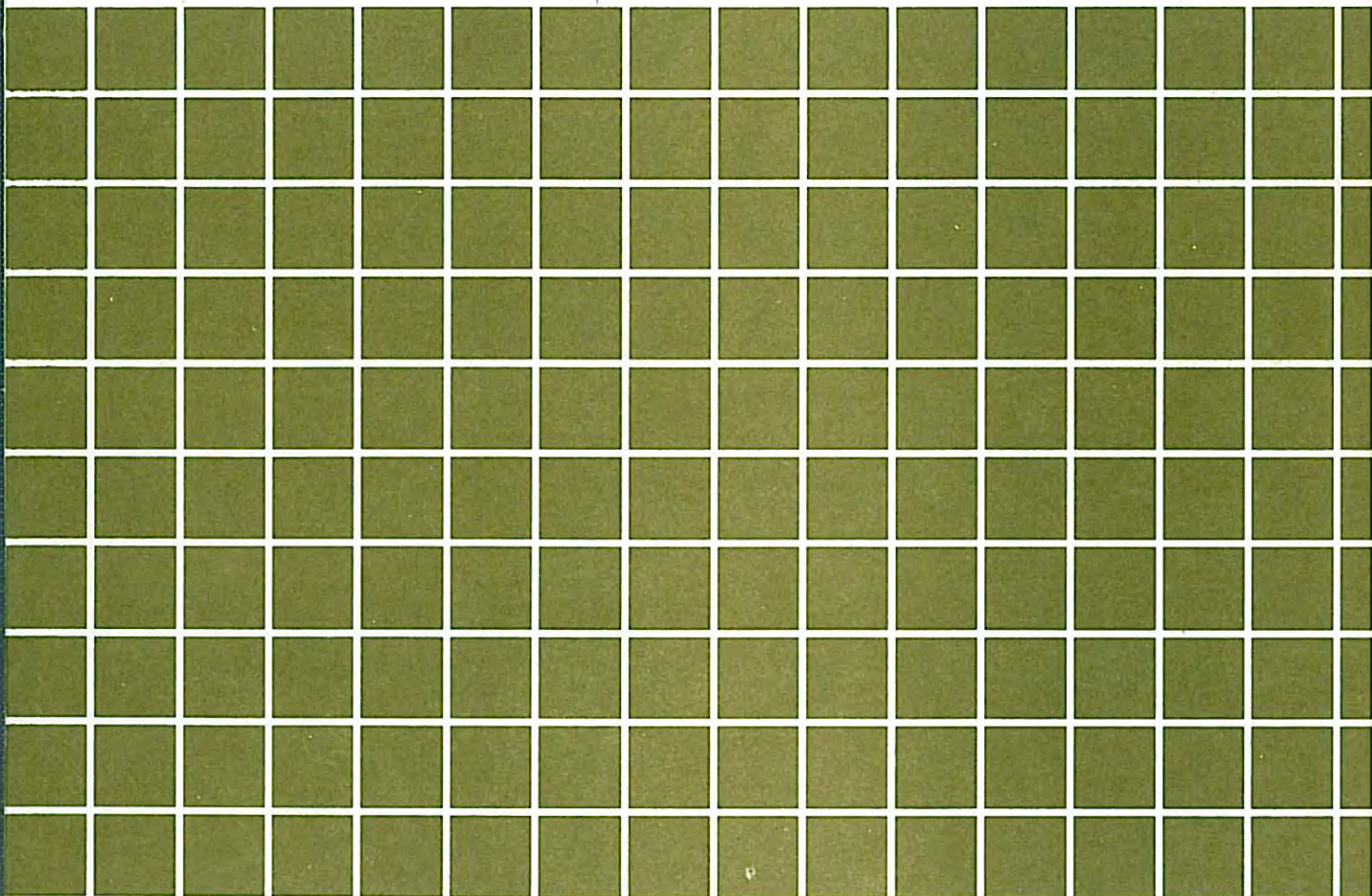


Wearing courses for unpaved roads in southern Africa: a review

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WEARING COURSES FOR UNPAVED ROADS IN SOUTHERN AFRICA: A REVIEW

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SUMMARY

The requirements of and some specifications for wearing courses for unpaved roads are reviewed. It is concluded that further development of specifications is required, and that there is probably great scope for improvement of our unpaved roads through better materials selection and proper compaction. Whereas it may often be relatively easy to select a satisfactory coarse grained material visually, it appears that there is only a 50:50 chance of satisfactory material being placed on the road when it is fine-grained. In such cases testing must be carried out. More use of the CBR test for materials selection seems to be indicated, as well as simple field and laboratory control tests. For improved materials selection to be successful more attention will probably also have to be paid to improved materials location.

OPSOMMING

'n Oorsig word aangebied van die vereistes en sommige spesifikasies vir slytlae van ongeplaveide paaie. Die slotsom is bereik dat verdere ontwikkeling van spesifikasies verlang word, en dat daar heelwaarskynlik groot moontlikheid lê in die verbetering van ongeplaveide paaie deur beter materiaal seleksie en behoorlike kompaksie. In baie gevalle mag dit relatief maklik wees om geskikte grofkorrelrige materiaal visueel te selekteer. Daarenteen wil dit egter voorkom of daar net 'n 50:50 kans bestaan om geskikte visuele geselekteerde materiaal op die pad te plaas as dit fynkorrelig is. In hierdie gevalle moet toetsing van materiaal uitgevoer word. Daar is aanduidings vir meer gebruikmaking van die KDV-toets sowel as eenvoudige veld- en laboratoriumkontrole tydens materiaal-seleksie. Vir verbeterde suksesvolle materiaal-seleksie sal daar waarskynlik meer aandag geskenk moet word aan verbeterde materiaal opsporingstegnieke.

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INTRODUCTION

Unpaved soil or gravel roads constitute a large part of the road network of most countries, even relatively developed ones such as the United States. In South Africa they still make up three-quarters of our rural road network and in neighbouring countries this figure is considerably higher. The condition of some of these roads often leaves much to be desired and better selection of materials would probably result in improvements in almost all respects. While all Roads Departments have specifications for wearing courses, they seldom appear to be effectively applied. In addition, their reliability is difficult to assess as the bases for their derivation are often obscure.

It is the purpose of this paper to present a state-of-the-art review of the requirements of a wearing course in relation to the authors' own experience and some local and overseas specifications, and to suggest methods for their improvement. Maintenance aspects are not considered. However, the level of maintenance is probably at least as important as the initial construction standard¹ and the materials used. Thickness design is also not considered and it is assumed that we are concerned only with the quality of the top 100 to 150 mm of material. This may represent in-situ material, the only layer of imported material, or merely the top layer of a substantial thickness of imported material in the case of high-class, engineered, unpaved roads. Other factors influencing the performance of wearing courses such as the volume, weight and speed of traffic, longitudinal gradient, crossfall, drainage, and climate (in terms of for example, rainfall intensity and annual and seasonal rainfall and evaporation) have also not been quantified to any great extent.

REQUIREMENTS OF WEARING COURSES FOR UNPAVED ROADS

The requirements of an ideal wearing course for unpaved roads can be listed as follows^{1,2,3,4,5}:

- Ability to provide an acceptably smooth and safe ride without excessive maintenance (ie freedom from corrugations, potholes, ruts and oversize material).
- Stability, in terms of resistance to deformation under both wet and dry conditions (ie essentially resistance to rutting and shearing).
- Ability to shed water without excessive scouring.
- Resistance to the abrasive action of traffic and erosion by water and wind.
- Freedom from excessive dust in dry weather.
- Freedom from excessive slipperiness in wet weather without excessive tyre wear.
- Low cost and ease of maintenance.

A good, soaked California Bearing Ratio (CBR) value is generally indicative of materials with high stability, especially when wet, and the use of both soaked and oven dried values has been suggested⁶. A minimum soaked value of 60 is desirable for heavy truck traffic⁷, while Australian specifications often call for a maximum dry compressive strength⁸ of at least 2,8 MPa in the case of materials with low plasticity⁴, ie usually a plasticity index (PI) of three or less⁹. Particle size distribution and Atterberg limits are often employed in addition to or as a substitute for strength tests. The Natal Roads Department's table¹⁰ (Table 1) and Olmstead's chart¹¹ (Figure 1) represent particularly useful examples of this approach.

In order to understand the thinking behind the use of empirical short-cut methods such as these, it is necessary to consider the effect of particle size distribution on stability. All graded road materials can be divided into three basic classes⁷ after compaction.

- Aggregate with a deficiency of fines.
- Aggregate with just sufficient fines to fill the voids.
- Aggregate with excess fines.

In a material with a deficiency of fines the coarser material forms a

TABLE 1 - Natal Roads Department wearing course guide¹⁰

Behaviour	LL	PI	Per cent coarse and medium sand	Per cent clay
Corrugates	< 20	-	> 55	-
Potholes	> 35	-	< 30	-
Dusty in dry weather	< 20	-	< 30	-
Ravels in dry weather	< 20	< 6	-	< 6
Slippery in wet weather	-	> 14	-	-
Cuts up in wet weather	-	-	< 25	> 10

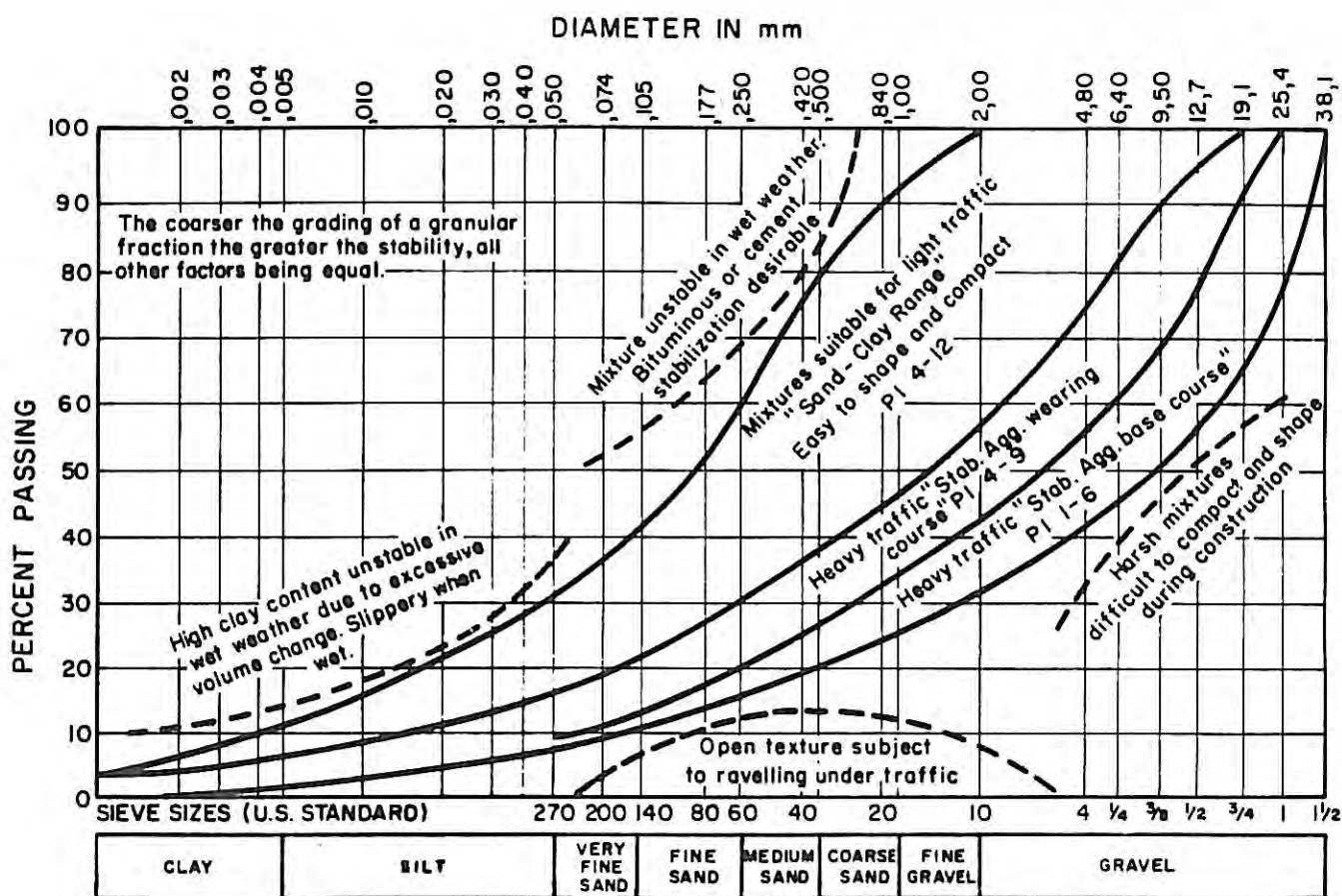


FIGURE 1
OLMSTEAD'S CHART FOR MECHANICALLY STABLE MIXTURES¹¹

relatively rigid structural framework and the material derives its stability from grain-to-grain contact. The stability therefore depends primarily upon compacted density, interlock, and aggregate strength, shape and roughness. Under these conditions the nature of the fines is of secondary importance and their most important property is that they should not be able to expand sufficiently to unseat the coarser fraction¹¹. If this occurs, the stability, at least under wet conditions, is reduced and the material becomes one of the third type in which the aggregate floats in an excess of fines. Under such circumstances the properties of the fines control the properties of the soil mass and the nature of the aggregate becomes of secondary importance. The boundary between these two groups of materials is 30 to 45 per cent passing the 0,42 mm sieve for sand-clays and 30 to 45 per cent passing the 2 mm sieve for coarser materials; minus 0,075 mm fines apparently not forming a structural framework¹¹. Materials deficient in fines are stony, porous, permeable, difficult to shape and to compact, and have low surface shear strength. They may also be very difficult to maintain by routine grader blading. Those with an excess of fines are also of relatively low density, but are practically impermeable and, whilst they may be easy to shape and to compact, their stability is greatly affected by water.

A material of the second type in which all the voids between the larger particles are neatly filled by smaller particles is a special case which rarely occurs in nature. It forms a narrow dividing line between the other two classes and can be most accurately defined by a formula such as Fuller's of the type¹²:

$$p = 100 (d/D)^n \quad (1)$$

Where p is the per cent by volume passing sieve size d for maximum particle size D and n is an exponent which, for maximum density, generally equals 0,5^{7,12}. Most authorities adopt specifications with limiting values of n of 0,5 (or 0,45) and 0,33 (or 0,30) together with strict plasticity requirements. When n is greater than 0,5 the material

tends to be deficient in fines; when n is less than 0,33 an excess of fines is present⁴. What is frequently overlooked is that such a formula actually represents the packing of spheres by volume⁸ and that the results it yields are affected by particle shape and particle density. A particle size distribution curve by mass is the same as one by volume only when the particle bulk density does not vary with particle size. In either event the fines content for optimum stability as measured by a CBR appears to be a little less than the fines content for maximum density, while a slight excess of fines over the optimum for maximum density is desirable for wearing courses in order to provide cohesion when dry⁷.

Both of these optimum fines contents as well as plasticity criteria are also affected by the presence of gap (skip) grading in which case Fuller's formula also does not apply⁷. Most natural gravels and soils, both in Australia^{4,9} and in southern Africa, are probably gap-graded with a deficiency of coarse and an excess of fine sand. Many specifications attempt to exclude excessively gap-graded materials by specifying a certain percentage retained between successive pairs of sieves¹³ or a ratio of the percent passing two sieves such as the numbers 200 and 40, known as the dust ratio. A common requirement for wearing courses such as that of AASHTO M-147¹⁴ is that the dust ratio shall not exceed 0,67. However, the presence of gap grading can actually be beneficial⁷ and the limitations of the theoretical maximum density and minimum plasticity type of specification must be clearly appreciated.

It has frequently been observed that mixtures which do not comply with such requirements, due to apparently poor grading or high Atterberg limits, have nevertheless been successful^{3,7,8,11,13,15,16,17,18,19} and all that is (or should be) claimed for such specifications is that materials which comply with them are more likely to be successful than those which do not¹³.

Many such specifications owe much to the old Public Roads Administration subgrade soil classification system which was tentatively offered as an easy and inexpensive indication of the important subgrade characteristics

which one really would have liked to measure directly, ie stability, compressibility, elasticity, volumetric stability and slope stability². Reasons for the successful performance of certain materials which did not comply with such specifications include particle shape, variation of particle bulk density with particle size^{17,18}, gap grading⁷, low percentage of fines^{4,9}, climate^{4,11,17,20} (for example AASHTO M-147 requirements for plasticity index of four to nine for wearing courses may be relaxed to fifteen in arid climates where the rainfall is less than 380 mm per annum⁴), unreliability of laboratory determinations of particle size distribution on ferricretes and calcretes due to the variable particle hardness²⁰, problems with mechanical analysis, aggregate strength, liquid limit and plastic limit tests on calcretes¹⁷, low traffic¹⁷, particle porosity (absorption)^{14,17,18}, presence of clay minerals different from those in the materials for which the specifications were established^{11,17,18}, and possible self-stabilization of laterites, coral, ferricretes and calcretes^{4,9,17,18,19,21}. It is abundantly clear that far too much reliance is placed on grading and Atterberg limit requirements uncorrelated with local experience and that more use should be made of both strength tests and of empirical specifications based on local experience.

Densely graded materials are practically impermeable and shed water naturally⁷. Alternatively, the first rain that falls should cause the fines to expand and close the pores, preventing water from entering and softening the material, although a thin layer of non-slippery mud may be present³. Excessive expansion is deleterious and a maximum CBR expansion on soaking of one per cent is often specified³. Measurement of the expansion on soaking from a lower moisture content than optimum or measurement of the shrinkage on drying after soaking may be even more revealing.

For good wear resistance and easy maintenance the percentage coarse aggregate retained on a 2 mm sieve should not be less than 20 per cent and preferably not less than 40 per cent⁴.

For riding comfort and reduction of wear on tyres, the oversize material retained on a 19 mm sieve should not exceed about 5⁴ to a maximum of 15 per cent⁸. Oversize material also makes construction and grading difficult and labour-intensive.

Materials containing excessive clay, as measured either by particle size distribution (Figure 1) or by plasticity index (Table 1), are liable to be slippery when wet, while an inadequate liquid limit and coarse and medium sand content can lead to dustiness in dry weather (Table 1). Sufficient clay should be present to bind the material when dry and to keep it damp by virtue of its capillary^{2,3} and suction properties, although under arid conditions the addition of salts such as CaCl₂ or NaCl may be necessary⁷.

It is a common observation with all materials that potholes are normally associated with cohesive materials (ie usually a high PI) and corrugations with non-cohesive materials (ie a low PI), although other factors also affect these modes of distress. Some low plasticity weathered granites, for example, are particularly prone to form potholes.

In order to minimise costs, extensive use is made of what the road builder believes is the best local material, haul distances are kept to a minimum, and laboratory testing is often neglected. However, approximately 133 000 km (72 per cent) of the rural road network in the Republic consists of unpaved roads²². In the case of South West Africa some 37 000 km (89 per cent) remain unpaved²³. While the total distance of unpaved roads is decreasing in the Republic, although not in South West Africa, such roads require regular maintenance and regravelling and it is suggested that significant improvements can be made by the better selection of locally available materials.

SOME EXISTING SPECIFICATIONS

An extensive survey of specifications for wearing courses was carried out by Fossberg^{6,24,25} and the following conclusions, which are still valid

today, may be drawn from his work:

- There is no universally applicable method for the design of wearing courses for unpaved roads.
- Unlike a bituminous or concrete-surfaced road, an unpaved road is profoundly affected by the weather.
- Specifications vary widely - many are wanting - and the allowance made for climate, if any, also varies widely.
- Performance data and suitable test methods for wearing courses, which differ from basecourses for surfaced roads in their requirements, are lacking.
- Most authorities rely heavily on 'indicators', ie grading and Atterberg limits.
- The importance of proper compaction is stressed.
- Plasticity should always be considered in relation to the grading.

A literature survey carried out in 1978 with specific reference to calcrete wearing courses did not reveal any modern specifications specifically intended for calcrete except the one of Netterberg^{17,18}. The most useful survey of early United States experience is that by Runner²⁶ who included the following specification used by the New Mexico Highway Department for 'Crushed Selected Material Surface Course' composed of crushed rock, caliche (calcrete) or gravel:

Per cent passing one inch (25,4 mm) circular mesh screen:	100
Per cent passing quarter inch (6,4 mm) screen:	35 - 50
Per cent wear in abrasion test using round pebbles:	≤ 25
Per cent wear in abrasion test using broken fragments:	≤ 15
Cementing value of binder:	≥ 100

A feature of all these early papers is their constant reference to the self-cementing properties of calcretes when compacted wet and a great enthusiasm for the material. Compaction was carried out wet or dry and general freedom from corrugations^{27,28}, but a tendency to pothole²⁷ was noticed. Dry compaction was most easily obtained when finely graded

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material (ie usually crushed minus one to one-and-quarter inch (25-32 mm) aggregate was used²⁷. When compacted, calcrete wearing courses will carry a substantial volume of traffic and plasticity indices of over eighteen have been used successfully in Australia, although values of zero to eight are desirable if the drainage is questionable²⁸. More clay was tolerated in Zimbabwean calcrete wearing courses than in other materials and a maximum plasticity index of twenty was allowed²⁴. The high optimum moisture content of many calcretes can be a disadvantage when compaction water is in short supply.

A comparison of extracts from some wearing course specifications is shown in Table 2. In comparing specifications it should be borne in mind that test methods may differ from authority to authority and that the specifications may not be complete or even strictly comparable. For example, Commonwealth countries usually employ a BS 1377 liquid limit device which yields both liquid limits (and therefore PIs) an average of four units higher than the ASTM D4318 device specified in South Africa and South West Africa⁴³. Other differences in test procedures such as the drying temperature of soil fines can also make large differences to the Atterberg limits of some materials. Even some calcretes are surprisingly greatly affected⁴⁴.

Strahan⁴⁵ noted the importance of the characteristics of the clay minerals in the behaviour of wearing course materials. All the specifications summarised in Table 2 contain at least the plasticity index, although the limits range from slightly plastic up to 30 percent. In a number of cases allowance is made for climate by adjusting the plasticity index within the ranges shown. Although no correlation could be found between the requirements of the different states of the USA and their climate²⁴, Fossberg²⁵ recommended the use of both finer gradings (upper envelope) as well as higher plasticity indices of up to 20 under dry conditions. A number of authorities now adjust their plasticity index requirements according to the grading, while several also permit higher plasticity indices (of sixteen to twenty in the case of the Orange Free State⁴⁶) in the case of calcretes due to their self-hardening properties.

TABLE 2 - Some wearing course specifications for unpaved roads^a

Property	Department of Transport ²⁹		Fossilberg ²⁵		Orange Free State ³⁰	Transvaal ³¹	AASHTO M 14.7 - 65 ¹⁴			Annual rainfall (mm) < 400 > 400	
	Gravel	Semi-sand-clay	Lower	Upper			C	D	E		F
% Passing (mm)											
37,5	100				100						
26,5	75-100				90-100						
19,0	70-90	100			75-100						
13,2	60-80				60-95						
9,5			50-80	80-100			50-85	60-100			
4,75	40-60		35-65	65-85			35-65	50-85			
2,00	25-50	50-80	25-50	50-70			25-50	40-70	55-100	70-100	
0,425	10-35	20-55	13-30	30-50			15-30	25-45	40-100	55-100	
0,075	4-15	8-25	5-15	15-30			8-15	8-20	20-50	30-70	
0,053									8-20	8-25	
GM ^b					≥ 1,5		≥ 1,5				
Dust ratio ^c											
LL (%)	≤ 35	≤ 35					≤ 2/3	≤ 2/3	≤ 2/3	≤ 2/3	≤ 35
PI (%)	6-15	6-12	6-8	8-20	10-18		≤ 35	≤ 35	≤ 35	≤ 35	≤ 35
LS (%)	≤ 7	≤ 4,5					4-9	4-9	4-9	4-9	4-9
Fineness index ^d											
Aggregate strength	≤ 25%										
loss					10% FACT		LAA ≤ 50%	LAA ≤ 50%	LAA ≤ 50%	LAA ≤ 50%	LAA ≤ 50%
after					≥ 90-135 kN						
5 cycles											
CBR (%) at											
Compaction (%) ^e					≥ 25		≥ 45				≥ 60 ^g
MAASHO swell (%)					95		93				
					≤ 1						

^a Some rounding off and metrication has been carried out and specifications are not necessarily complete.

^b Grading modulus (cumulative percentage retained on 2, 0,425 and 0,075 sieves divided by 100).

^c Ratio of percentage passing 0,075 mm to percentage passing 0,425 mm.

^d Product of percentage passing 0,075 mm sieve and plasticity index.

^e MAASHO density. The field and lab. compaction are the same in all cases except TPA³¹ and DOT³⁸ who require 93 % field and 95 % lab. compaction.

^f Suggested values for gravels and soft rock. Suggested that sand-clays are limited to low traffic conditions and rainfall (< 400 mm) and a PI of 5-15.

^g At expected in-situ moisture and density. Also max. dry compressive strength of at least 2,8 MPa.

TABLE 2 (continued) - Some wearing course specifications for unpaved roads^a

Property	NITRR ³²		Natal ³³		Botswana ³⁴ (not calcretes)		Lesotho ³⁵		Swaziland ³⁶	
	Nominal Size (mm)		Nominal Size (mm)		Nominal Size (mm)		Nominal Size (mm)		Nominal Size (mm)	
% Passing (mm)	37,5	26,5	19,0	13,2	19,0	13,2	4,75			
37,5	100									
26,5	85-100	100								
19,0	70-100	80-100	100							
13,2	60-85	60-85	75-100	100	100	100				
9,5										
4,75	40-60	45-65	50-75	60-100	60-85	75-100	100			
2,00	25-45	30-50	35-55	45-70	45-70	50-75	80-100			
0,425	15-40	15-40	18-45	25-50	25-40	25-45	20-45			
0,075	7-30	7-30	7-30	7-30	10-25	10-25	10-25			
0,053										
GM ^b					1,6	1,55	1,3	1,5 - 2,8		
Dust ratio ^c										
LL (%)					20-35	≤ 55	≤ 55	≤ 30		
PI (%)	8-20 ^f	8-20 ^f	8-20 ^f	8-20 ^f	6-15	15-30	15-30	6-15		
LS (%)					8-15	8-15	8-15	8-20		
Fineness index ^d										
Aggregate strength					IAA	10% FACT				
					30-60 %	≥ 50 kN or Mod. AIV ^g				
CBR (%) at										
Compaction (%) ^e	≥ 93 %	≥ 93 %	≥ 93 %	≥ 93 %	≥ 93 %	≥ 95 %	≤ 60	95 - 98%	≥ 93 %	
MAASHO swell (%)										

a Some rounding off and metrication has been carried out and specifications are not necessarily complete.

b Grading modulus (cumulative percentage retained on 2, 0,425 and 0,075 sieves divided by 100).

c Ratio of percentage passing 0,075 mm to percentage passing 0,425 mm.

d Product of percentage passing 0,075 mm sieve and plasticity index.

e MAASHO density. The field and lab. compaction are the same in all cases except TPA³¹ and DOT³⁸ who require 93 % field and 95 % lab. compaction.

f Depending on climate (<14 if N<5; 14-20 if 5<N<10; 14 -20+ if N>10).

g See TRRL Report LR 293

TABLE 2 (continued) - Some wearing course specifications for unpaved roads^a

Property	CPA ³⁷		South West Africa ³⁹		TRRL ⁴⁰		Malawi ⁴¹		Rhodesia ⁴²	
	Nominal Size (mm)		Weinert's N-value		Nominal Size (mm)					
% Passing (mm)	37,5	26,5	19,0	13,2	< 10	> 10	19,0	13,2	4,75	
37,5					100	100				
26,5					100	100				
19,0							100			
13,2										
9,5										
4,75							80-100	100		
2,00	26-45	30-50	35-55	45-70			60-85	80-100	100	80-100
0,425							45-70	50-80	80-100	60-85
0,075	7-30	7-30	7-30	7-30	20-40	15-40	25-45	25-45	30-60	45-70
0,053							10-25	10-25	10-25	20-40
GM ^b										10-25
Dust ratio ^c					≥ 1,5	1,3-1,9	1,1-1,9	1,1-1,9		1,5-2,5
LL (%)										< 70
PI (%)	8-20+ (dry)	8-20 (wet)	6-15	4-20	4-18	4-18	35-55 ^g	35-55 ^g	35-55 ^g	≥ 40
LS (%)							4-30 ^g	4-30 ^g	4-30 ^g	≥ 8
Fineness index										
Aggregate strength			15-400	50-400	50-400	50-400	2-15 ^g	2-15 ^g	2-15 ^g	
CBR (%) at			≥ 45	≥ 25	≥ 25	≥ 25				
Compaction (%) ^e	≥ 95	≥ 95	≥ 95	≥ 95	≥ 95	≥ 95				
MAASHTO swell (%)										10(GM-0,25)- 15(GM-0,25)

^a Some rounding off and metrication has been carried out and specifications are not necessarily complete.

^b Grading modulus (cumulative percentage retained on 2, 0,425 and 0,075 sieves divided by 100).

^c Ratio of percentage passing 0,075 mm to percentage passing 0,425 mm.

^d Product of percentage passing 0,075 mm sieve and plasticity index.

^e MAASHTO density. The field and lab. compaction are the same in all cases except TPA³¹ and DOI³⁸ who require 93 % field and 95 % lab. compaction.

^f Kalahari only.

^g Depending on climate - a number of definitions exist.

Table 2 strikingly brings out the large variation in requirements from authority to authority. The only more or less unanimous requirement is a maximum size of around 25 mm and an acknowledgement that the plasticity index may be larger than the usual base requirement of six. This is in agreement with the findings of Frost⁴⁷ and others who concluded that gradings and Atterberg limits 'did not always give an indication of the likely performance of the material as a road surfacing gravel'. An examination of Frost's data⁴⁷ suggests however that a minimum CBR of 40 is generally associated with good performance.

The current specifications for South Africa suggested in TRH14³² only list grading, compaction and PI requirements for materials in general and part of Netterberg's specification⁴⁸ for calcrete wearing courses. Unfortunately, the basis for this TRH14 general specification has not been published so that it is difficult to judge its reliability. It appears to be similar in part to the Natal specification¹⁰, which was derived by an investigation into wearing courses used over many thousands of km of road⁴⁹. The gradings given are intended to be applied after compaction. In practice this means after subjection to 95 per cent MAASHO density (approximately equivalent to NRB (intermediate) effort) and 4 days soaking⁴⁹. The grading curve should ideally be smoothly parallel to the sides of the envelope and not jump from side to side. The new South West African specification for roads carrying less than 75 vehicles per day³⁹ represents a preliminary analysis of 308 samples from roads of good and poor riding quality from all over South West Africa.

AGGREGATE STRENGTH

Although the aggregate strength of gravel road wearing courses is seldom tested in southern Africa, the importance of this factor was confirmed during field investigations in South West Africa, where it was found that the calcretes which made good wearing courses were usually those with relatively strong aggregate. Those with weak aggregate tended to break up even under light traffic and form powder-filled potholes, especially when compacted dry. The importance of aggregate strength was confirmed by

Paige-Green and Netterberg⁵ who found the roughness to decrease with increasing aggregate strength as measured by means of the aggregate fingers value (AFV)⁵⁰. However, a much more important predictor was the presence of large stones which did not break down during compaction or under traffic. These are of course not included in the AFV.

The aggregate strength required depends greatly on the initial grading. If the material possesses large stones or lacks fines it will be an advantage if some of the aggregate breaks down. On the other hand, if too much of it degrades to fines unsuitable for a binder it will tend to be dusty, ravel and rut. A minimum 10% FACT of about 110 kN⁴⁸, AFV of 100%⁴⁸ or Aggregate Pliers Value (APV) of 75%⁴⁸, or a maximum ACV⁵¹ or Los Angeles Abrasion value (LAA)^{10,51} of 30% (all approximately equivalent) appears to be required for aggregate not to break down significantly under compaction nor to degrade under traffic. The Natal Roads Department currently specify a Los Angeles Abrasion value of between 30 and 60 per cent³³. This eliminates both the very soft materials which will degrade excessively and the very hard materials which will result in excessive stoniness if they are too large. A maximum value for the Los Angeles Abrasion loss of 50 per cent has been recommended in the United States⁵². The AFV and APV are simple field and laboratory tests intended as simple field aids to calcrete wearing course selection^{17,50}. The AFV is simply the total percentage of 13-19 mm aggregate which cannot be broken by the fingers and the APV the percentage which cannot be broken with a standard pair of 180 mm engineer's pliers.

The coarser good calcrete wearing courses generally had an AFV of at least 60 per cent and an APV of at least 20 per cent⁴⁸, equivalent to a 10 per cent FACT value of only about 20 kN^{17,18}, but the aggregate strength was not important in the case of the finer 'sand-clay' materials.

A useful aid to both traffic compaction and to the protection of certain disintegration - prone calcrete wearing courses is a thin (25-30 mm)

blanket of Kalahari sand^{17,46,48}. This may however cause severe corrugations should the sand become too thick and a current recommendation for all materials in South West Africa is a maximum thickness of 20 mm³⁹.

GRADING

For the reasons already discussed, as well as the lack of research and the simple facts of what materials are actually available, one cannot be too dogmatic about the grading required. The curves given for example in TRH14 should be used as a guide, not as gospel. Figure 2 (mostly after Netterberg¹⁸) shows that, for calcretes at least, considerable departures from these recommendations are possible. The 'sand-hunch' common in calcretes is at least partly illusory because of variations of particle density with particle size, ie it disappears or is reduced if calculated on a volumetric basis, which is what is really wanted^{17,53}.

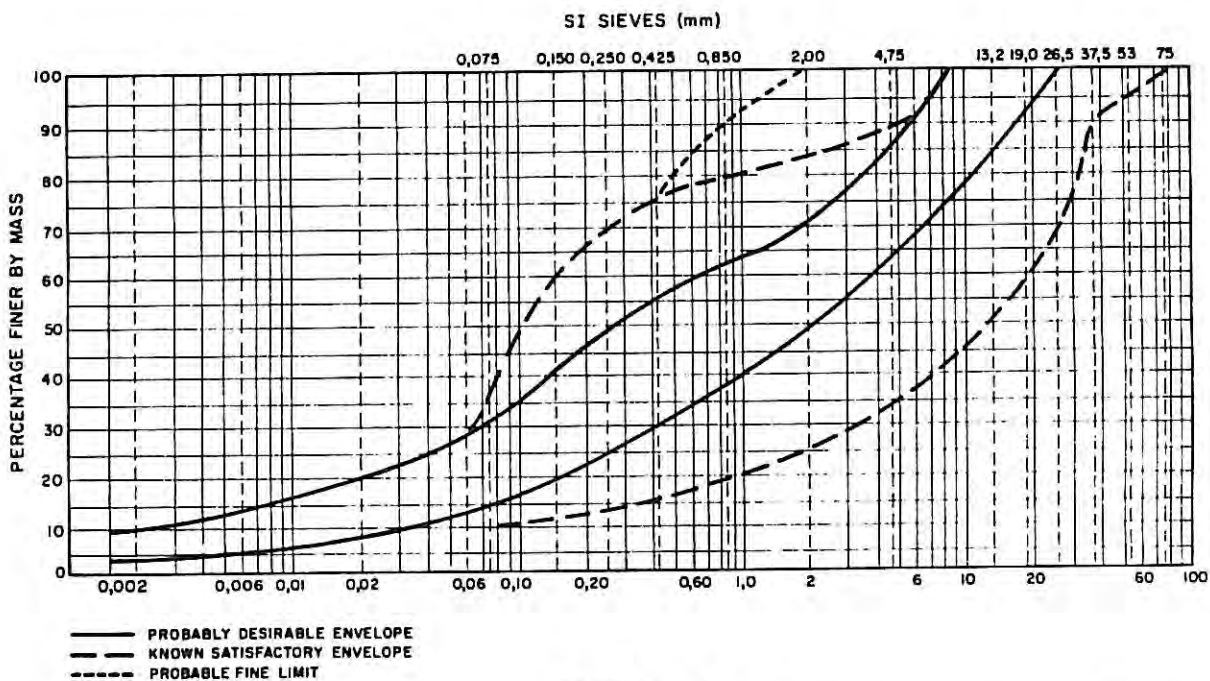


FIGURE 2

PROBABLY DESIRABLE GRADING ENVELOPE OF CALCRETE WEARING COURSES AND THE KNOWN SATISFACTORY ENVELOPE¹⁸

The maximum size should ideally be about 20 mm, less desirably 40 mm, but small (5 - 15 per cent?) amounts of material up to 50 or even 100 mm are tolerable. A maximum size of more than about 50⁵⁴ or 75 mm⁵⁵ makes blade maintenance difficult. Many of the existing specifications specify a maximum size, although in practice this is seldom adhered to, resulting in unnecessarily rough roads⁵. When used on roads carrying in excess of about 50 vehicles per day it is cost-effective to crush or screen oversize (>38 mm) material⁵⁶.

Analysis of the grading specifications in Table 2 indicates that for a nominal 19 mm material the n-coefficient (in terms of the Fuller curve) varies from 0,19 to 0,48. The lower values would be expected to result in material with a low density and poor stability when wet.

CLIMATE, GRADING AND PLASTICITY

It is difficult to quantify the effect of climate. It is generally agreed that one can allow (and needs) more clay in a wearing course in drier climates and less in wetter. For example, TRH14³² states that the PI can vary from about 8 to 20, but that, depending also on the grading, the lower half of this range is more suited to a wet climate and the upper half to a dry climate. Values of only 4 - 9 are suitable for moist temperate and wet tropical climates, whilst 15 - 30 might be tolerable in arid or semiarid areas^{57,58}. Widening of the plasticity index range from the AASHTO limits of 4 to 9 up to limits of 2 to 15 depending on climate has recently been recommended in the United States⁵². A value of 22 has been used here in dry areas and found especially useful in controlling corrugations⁴⁹. As the wet season in the drier areas is short, slipperiness is seldom a problem and the low traffic volumes do not lead to impassable conditions through excessive churning.

The Atterberg limits tolerable are very dependent on the grading, and the use of parameters such as the product of the percentage passing the 0,075 or 0,425 mm sieve and the PI or LS is helpful. Figure 3 (partly after Netterberg¹⁷) shows that this also correlates roughly with the CBR, for

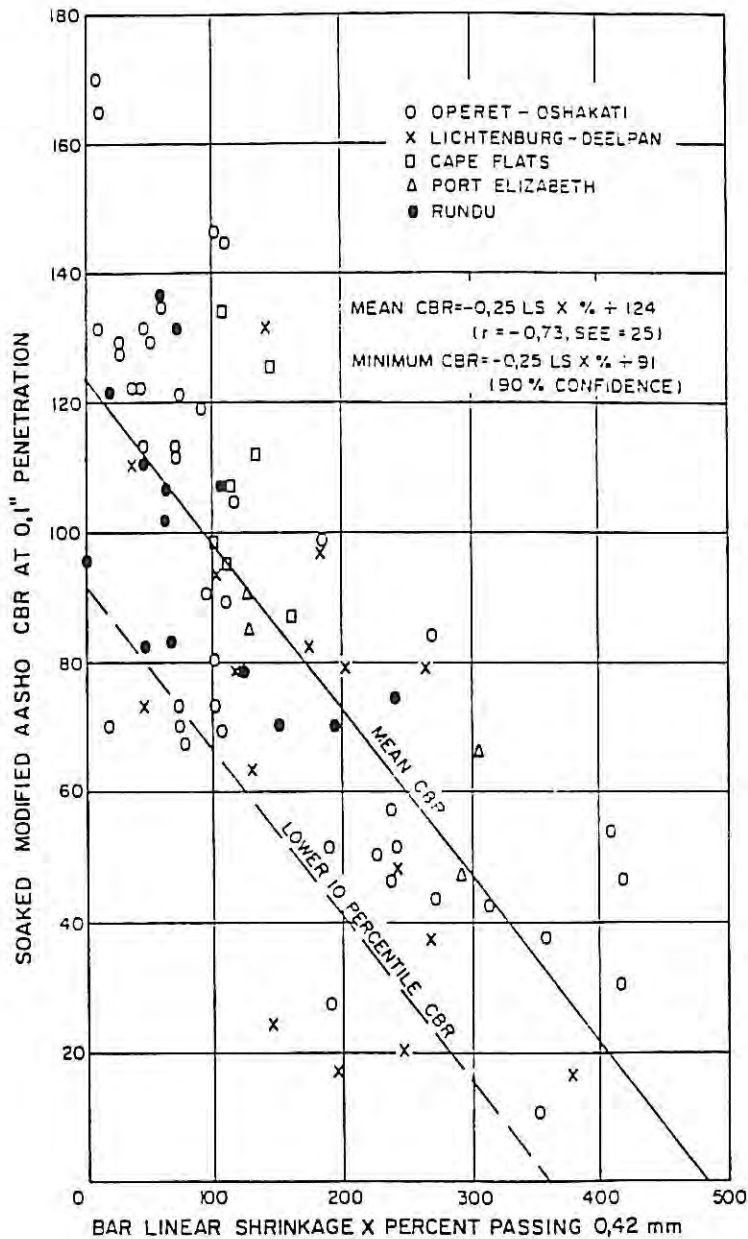


FIGURE 3
EFFECT OF THE QUALITY AND QUANTITY OF THE SOIL FINES
ON THE CBR OF CALCRETES¹⁷

calcretes at least^{17,59}. The bar linear shrinkage test is a simple test which can be carried out in the field by air or sun drying from the field moisture equivalent using larger (eg BS 1377) troughs on a coarser fraction (eg passing 2 mm) if necessary. Such non-standard procedures will of course yield results which differ from those yielded by the standard South African method of oven drying the fraction passing 0,425 mm from the liquid limit in a 10 mm square-section trough. Other simple tests such as the Gibbs and Holtz free swell⁶⁰ and the sand equivalent may also have application.

COMPACTION AND CBR

Proper compaction with water is always desirable if the best performance is to be obtained from the material available. This will also help to start any self-stabilization process going in calcretes and laterites. The common practice of leaving the compaction to the construction traffic and public does not achieve the best results. The levels of compaction recommended appear to vary between about 90 and 98% MAASHO. A minimum of about 93 should probably be aimed at. Recommended CBRs vary from a minimum of about 15 (at Proctor density) for wet weather passability⁵⁴ to a minimum of 60 for heavy truck traffic⁷. Unfortunately it is not always possible to reliably relate the published figures with what was actually obtained on the road. For good performance under average conditions a minimum 'field' soaked CBR of about 40 seems to be indicated, although South West Africa appear to be happy with a minimum of 25 under arid conditions (ie where Weinert's⁶¹ N-value is greater than 10)³⁹. NAASRA⁹ recommend a minimum of 60 at the expected in-situ density and moisture content.

The use of a test for compacted strength such as CBR greatly minimises the effects of material type and the problems of obtaining and interpreting reliable gradings and Atterberg limits, and is to be recommended. In all probability it will be found that one or two sieves for maximum size, CBR and perhaps CBR swell could provide all the necessary information, and that grading and Atterbergs could be discarded. A quick unsoaked CBR at optimum moisture content may prove adequate, at least in the drier areas.

Simple tests for compaction and CBR are one's judgement with a hammer or pick handle or, better, a Clegg hammer^{62,63} or dynamic cone penetrometer (DCP)⁶⁴.

GEOLOGICAL MATERIAL TYPES

The degree to which the geological⁶¹ or pedological material type affects

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the specifications required has not yet been fully quantified but is presently being investigated⁶⁵. It is true of materials in general that certain geotechnical characteristics affect the performance of the materials in specific ways, eg potholing is associated with cohesive materials (ie those with sufficient or an excess of clayey binder) and corrugations with non-cohesive materials (ie those deficient in clayey fines). However, large potholes are also commonly found as a 'terminal' form of corrugations where the troughs collect water and are deepened and rounded by the traffic. Potholes may also be caused by weak subgrades, stones being plucked during blading and by traffic compaction behind large stones.

Laterites

Laterite wearing courses have been intensively studied in Angola and Mocambique¹⁹. They accept the ASTM D1241-55T specification for wearing courses except that the ASTM limits for LL of 35 and PI of 4-9 should be replaced by 40 and 6-15, provided that the Castro swell does not exceed 10 per cent. Gradings 1,4 times finer than those indicated by the ASTM can also be accepted (also on condition that the swell does not exceed 10 per cent), but it is recommended in such cases to correct the percentages required in the larger sieve sizes so as to obtain curves with the same shape above the 0,075 mm sieve. They recommend only air drying of soil fines prior to Atterberg limit testing.

Pedogenic materials such as some calcretes and laterites appear to have self-cementing properties which make them perform better than expected. Whether the better performance of laterite (probably better called ferricrete locally) wearing courses⁶⁶ is due to this property or others such as better grading, etc., is not clear. This study⁶⁶ showed that the laterites required on average only 83 per cent of the annual number of bladings required by quartzites.

Transvaal ferricretes commonly contain an excess of oversize material, usually too hard to be broken to a suitable size under grid rolling. This

often results in a stony surface with concomitant roughness. The plasticity is generally low, leading to corrugations and the excessive production of loose material. A common problem with the use of ferricretes is that after construction or blading the riding quality is very good and cars tend to travel faster, resulting in more rapid deterioration. An interesting aspect of ferricrete roads noted during the unpaved roads project⁶⁵ was that of the four accidents recorded on or near the experimental sections, three were caused by thick, loose material on ferricrete-surfaced roads.

Basic crystalline rocks (mostly dolerite, gabbro, norite, basalt, andesite)

These materials are very similar mineralogically and can be expected to behave similarly as wearing course gravels. Dolerites were included in the studies carried out in the Orange Free State⁴⁶ and Natal⁴⁹, thus either of these two specifications or the similar TRH14³² one should be suitable for these materials.

These basic igneous rocks generally provide good wearing course materials but are prone to spheroidal weathering in the drier areas. This results in the presence of unacceptably large, very hard boulders which need to be removed in order to avoid excessive roughness and blading problems. The more humid climate in the eastern areas of southern Africa tends to form the well-known 'sugar dolerite'. This usually makes a very good surfacing material, although it may corrugate quite badly if the coarse sand content is high⁴⁹. Many of the weathered basic igneous rocks weather to a high plasticity material which can become extremely slippery when saturated. If the coarse sand content is low, dolerites tend to be both slippery and to pothole⁴⁹.

Acid crystalline rocks (mostly granites, gneisses)

These materials are widespread in southern Africa and generally weather to a low-plasticity, sandy material with a few large boulders of hard

material. If the large boulders are removed a well-graded, coarse sand can be obtained. This is likely to corrugate and ravel fairly badly if the plasticity index is much below about 6. In the Transvaal those sections with PI's greater than 8 perform well, but are susceptible to erosion if the grade or crossfall is greater than about 4 percent. Most granite and gneiss roads are prone to ravelling, though some have been observed to be ferruginous, resulting in an apparent self-cementation.

Arenaceous rocks (mostly sandstones)

Sandstones generally weather to a low plasticity, sandy material prone to ravel and corrugate. Many weathered sandstones contain boulders of unweathered or partly weathered sandstone which if they are hard must be removed. Some sandstones on the other hand contain softer boulders which are gradually worn down by traffic and can be cut by the grader. These materials tend to result in potholes and corrugations. Many sandstones are interlayered with mudrocks and it is often not possible to avoid mixing them together during winning. This usually results in a more cohesive wearing course with a better grading and plasticity.

Argillaceous rocks (mostly mudrocks and baked mudrocks)

Mudrocks (shales, mudstones) are often mixed with sandstones as discussed previously. However, vast thicknesses of pure mudrocks are common and these are often used for wearing course materials. The main problem encountered is the large quantity of oversize material, although in very fissile shales the resultant surface is often composed mainly of flat-lying shale boulders which make a good riding surface. The fragments are, however, often very angular and if hard can cause excessive tyre damage. On the other hand, a combination of a low PI with soft aggregate tends to lead to dust⁴⁹. On the whole mudrock wearing courses are extremely dusty and may become very slippery in wet weather.

High silica rocks (mostly quartz, chert, quartz porphyry, quartzites)

This material group consists of rocks with a large proportion of crystalline or non-crystalline silica. Quartzites are generally too hard and bouldery to consider for unpaved wearing courses although much quartzitic alluvial gravel is crushed for wearing course aggregate in the United States. Chert is a common wearing course material in South Africa but is usually naturally mixed with wad or some higher plasticity material. Large boulders of chert result in unnecessary roughness and should be crushed or removed.

Chert wearing courses are extremely dusty. An interesting aspect of chert roads is that they appear to be the only materials in which blading results in the complete restoration of potholes to a smooth surface. Quartz porphyry weathers to a fine gravel with a moderate to high PI and makes an excellent surfacing gravel.

Calcretes

On the basis of the areal extent of their use, calcretes rank as the most widely used wearing course materials in both the Republic^{61,67} and probably also in southern Africa as a whole. The statement in TRH14 that 'The selection of calcrete wearing courses should be based on local experience',³² is ambiguous. The calcrete specification^{48,67} (Table 3) was derived from a study of 54 Transvaal, South West African and Cape samples of known performance and appears at present to be the only local specification backed by published performance data.

An earlier version^{17,18} of this specification was used until the late 1970s³⁹ on most major South West African departmental unpaved calcrete road projects where wet compaction was employed, for which it was found to be an 'excellent guide',⁶⁸. The specification is also included in the current Botswana Road Design Manual³⁴. Netterberg⁴⁸ has provided two specifications, one for good performance and one for satisfactory to good performance (Table 3) as well as a guide to the likely performance of any

individual sample. Recent practice in South West Africa³⁹ has been to use a single specification similar to that in Table 2 for all materials regardless of material type, although calcretes are still preferred.

In applying either of these specifications all the requirements in Table 3 only should preferably be met. Detailed grading requirements are not warranted and the only additional (optional) requirement suggested is that the percentage passing 19 mm should preferably be about 80-100. Botswana³⁴ recommend that the materials with more than 55 per cent soil fines should be restricted to roads carrying a low proportion of heavy vehicles and that in all cases the minimum CBR should be 60 at field

TABLE 3 - As-built materials⁶⁷ standard for calcrete wearing courses for unpaved roads

Property ^a	Per cent passing 0,425 mm by mass			
	20-40	41-50	51-60	61-75
Max. size, mm	53	53	53	38
Liquid Limit, %	30-65	22-48	22-40	18-36
Plasticity Index, %	9-22	7-23	5-13	8-13
Bar Linear Shrinkage, %	2,0-9,5 ^b	2,7-9	2,0-5,5 ^b	2,0-5
Linear Shrinkage X % < 0,425 mm	70-340 ^c	130-395	100-320	130-330
Min. Aggregate Fingers Value, %	65	60	35	40
Min. Aggregate Pliers Value, %	20	20 ^d	15	-

a Test methods to be comparable with those of DOT, 1970.

b Linear shrinkages between 2,0 and 2,7 may cause slight looseness and dust.

c Values between 70 and 100 may cause slight looseness and dust.

d A minimum APV of 14 is permissible if the AFV > 75.

density, which should be a minimum of 98 per cent MAASHO. This is probably only necessary for heavy truck traffic⁷ and a minimum laboratory Proctor CBR of only about 15 is required for wet weather passability⁵⁴. The values of linear shrinkage times the percentage soil fines in Table 3 indicate that the minimum laboratory MAASHO CBR of satisfactory to good calcrete wearing courses is likely to range between about 0 and 70 and

the average between about 25 and 100 (Figure 3).

The range of LS x % passing 0,425 mm of 100-200 for the best samples suggest from Figure 3 that a minimum soaked laboratory MAASHO CBR of 40 to 70 is needed for good performance, giving some support to a minimum soaked field value of 40 derived earlier from the data of Frost⁴⁷.

The apparent self-stabilization often exhibited by calcrete wearing courses can be a disadvantage at times since they may pothole yet be too hard to blade⁴⁸.

The satisfactory to good calcrete specification presented here (Table 3) was set up to achieve 100 per cent success in rejecting poor materials. This it does at the cost of rejecting 11 per cent of the apparently satisfactory or good materials. It furthermore appears⁴⁸ that visual selection is only successful when the material is relatively coarse (less than 50 per cent soil fines), with a success rate of 92 per cent in comparison with 100 per cent for the specification. With finer materials it appears that there is only a 47 per cent chance of satisfactory material being placed on the road by visual selection, in comparison with 100 per cent by the specification. The specification achieves this at the cost of rejecting 13 per cent of the apparently satisfactory or good fine-grained materials.

GENERAL COMMENTS ON MATERIALS

Most unpaved roads investigated over the past few years would appear to be constructed from the nearest available material. Very little processing or testing would appear to have been carried out and the quantity of oversize material always exceeds the standard specifications. There is an obvious bias towards the use of lower plasticity material in order to reduce the possibility of the roads becoming slippery when wet. Compaction is minimal, usually consisting of a nominal two or three passes of a grid roller, the main purpose of which is to break down large boulders (usually unsuccessfully), or simply by traffic.

Many of these roads do however provide a satisfactory service⁵ despite the deviation from the specifications. There is therefore an obvious need for more realistic specifications for local materials (probably other than for calcretes) which have been empirically derived from local performance studies. Modified specifications, however, must be easy to use and should be based on simple field and laboratory tests in order to gain acceptance. This is one of the major objectives of the unpaved roads project^{5,65} being carried out at the Division of Roads and Transport Technology. As this major project is nearing completion no attempt is made in this paper to derive a specification based upon the data reviewed here. This will rather be considered together with the project data in due course. As an interim measure it is recommended that the apparently most suitable local specification (eg selected from Table 2 or 3) should be tempererd according to the information presented here.

DUST

Most unpaved roads produce dust to a varying degree. It is usually worst immediately after blading and at a minimum during the rainy months. However, the severity of the dust can be minimised by better selection of material and its proper compaction with water. Many calcretes and some ferricretes and granites develop a crust or 'blad' (Afrikaans) which is relatively dust-free while other materials such as sugar dolerites produce minimal dust. The maintenance grader operator should try to retain this crust by means of a loose cover of gravel or sand, even though it may temporarily increase the dust nuisance.

A variety of dust palliatives are available⁶⁹ but are seldom economic unless the material is a waste product used close to its source^{17,48}. A recent study⁷⁰ has confirmed this. Water (fresh or sea) or salt usually remains the only economic additive.

The well-known 'salt roads' along the coast of South West Africa are actually gypcrete gravels compacted with strongly saline (minimum salt content 12 per cent, preferably at least 22 per cent) water. A draft

South West African specification has been developed for these roads. Although vehicle corrosion is increased, these roads are highly effective, dust and corrugation-free in the coastal arid climate in which they are used.

CONCLUSIONS

- 1 Unpaved roads remain an important part of the southern African road infrastructure and will remain so for the foreseeable future.
- 2 The requirements of wearing courses are different from those for base courses, but have been reasonably well-defined in general terms.
- 3 Although a number of apparently good local specifications for wearing courses exist, it is difficult to judge their reliability and applicability to other areas as the basis for their derivation is usually obscure.
- 4 There is therefore scope for studies quantifying the performance of local wearing course materials. Such a study is in progress at the Division of Roads and Transport Technology.
- 5 The greatest problem is probably not the apparent lack of reliable specifications, but rather their insufficient application in practice. There is therefore probably much scope for improvement of our unpaved roads through the better selection of materials and their proper compaction, preferably with water.
- 6 This probably also means that more attention will have to be paid to more efficient location of the materials available.
- 7 Too much reliance appears to be placed upon Atterberg limit and theoretical grading criteria in specifications for wearing courses. Greater reliance should probably be placed upon tests such as the CBR and CBR swell, and a minimum field soaked CBR of about 40 seems to be

required for satisfactory performance. A cheaper alternative might be to use methods for estimating the CBR from grading and plasticity data.

- 8 Aggregate strength requirements vary widely and are generally only important in the coarser materials. Whilst a 10% FACT of about 110kN is required to prevent aggregate degradation under traffic, much lower values down to about 20 have been found to be satisfactory and are sometimes necessary in order to improve the grading.
- 9 Detailed grading requirements are probably seldom warranted and seldom attainable, and are probably often invalidated anyway by particle density variations. The maximum size should preferably be about 20 mm with no more than about 15 per cent coarser up to about 50 mm.
- 10 The Atterberg limits and linear shrinkage must always be considered in relation to the grading and the climate.
- 11 A minimum level of compaction of about 93 per cent Mod AASHO appears to be required.
- 12 There is probably scope for the use of simple laboratory and field tests for density, compacted strength, aggregate strength, clay content, plasticity and shrinkage.
- 13 The degree to which different geological and pedological materials require different specifications is uncertain, but the only local specification developed specifically for a particular material (calcrete) is significantly different from all the other specifications studied.
- 14 A local calcrete specification is available which is of apparently high reliability. The data available indicate that it rejects all unsatisfactory materials at the risk of rejecting 11 per cent of the

satisfactory ones.

15 Dust palliatives other than the occasional use of water or waste products close to their source are not generally economic.

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