Requirements and Properties of Wearing Course Materials for Unpaved Roads in Relation to Their Performance

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A study of the influence of the properties of wearing course materials on the performance of unpaved roads in the Transvaal province of South Africa is in progress. The experiment involves the regular monitoring of 91 sections of road that cover six geological material groups, three climatic regions, and two traffic categories. The results of the field observations and preliminary analyses are discussed in terms of observed requirements for wearing course materials. The major contributors to road roughness are oversized material, potholes, corrugations, and surface erosion, all of which can be reduced by careful material selection and improved construction. Many of the sections under study have performed acceptably, even under reduced maintenance programs.

INTRODUCTION

South Africa, like much of the developing and developed world, uses an important network of unpaved roads. These roads comprise about 75 percent of the total road network in the Republic of South Africa and substantially more of the network of southern Africa as a whole. Previous major studies of unpaved road performance have been performed in Kenya, Brazil, and Ghana (*1-3*). The prime objective of these studies was to evaluate maintenance strategies; little attention was paid to material characteristics and performance. In contrast, the prime objective of the present investigation is to define the material characteristics that influence the performance of unpaved roads in general. The only other local study that was published was limited to one material subtype (calcrete) and a qualitative appraisal of performance (*4*). The present study involves the sampling, testing, and routine monitoring of 91 sections of unpaved road over a period of 3 yr in the Transvaal province of South Africa and 18 sections in south West Africa (Namibia). The main objectives of the project are to develop reliable, performance-related materials standards for unpaved roads and to assess the applicability of the Brazil study to local conditions (*2*). Secondary objectives include improved maintenance techniques and a better understanding of corrugations and the effect of geological material type on road performance. This work was performed from January 1984 to January 1987. The purpose of this paper is to briefly describe the results of the sampling and initial monitoring of the Transvaal sections and to provide a preliminary analysis of their properties and performance in relation to the idealized requirements for wearing course materials.

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EXPERIMENTAL DESIGN

The experiment utilized a factorial design; geological material type, climate, and traffic were the selected factors. Material types were grouped into six categories, each of which consisted of materials of common mineralogy and weathering characteristics irrespective of genesis (*5*). These groups were classified as acid crystalline (granite, felsite, and gneiss), basic crystalline (diabase, dolerite, and basalt), high silica (quartzite and quartz porphyry), arenaceous (sandstone), argillaceous (shale and mudrock), and pedocretes (calcrete (caliche) and ferricrete (laterite)). Each of these material types, except pedocretes, represents materials that range from mostly residual rocks in various stages of weathering (with or without a small admixture of the overlying transported soil binder) to residual soils. Calcretes and ferricretes are soils that are variably cemented or replaced by calcium carbonate and iron oxides, respectively.

The Weinert N-value was thought to be the most suitable climatic descriptor:

$$N = 12\ E_J / P_a \qquad (1)$$

where

E_J = calculated average evaporation in the warmest month (January), and
P_a = average annual rainfall (*5*).

Besides taking rainfall into account, the N-value correlates closely with the products formed during weathering. N-values of 2 and 5 correspond approximately with normal annual rainfalls of 500 and 800 mm, respectively. The Transvaal has a semiarid to subhumid warm climate, and road damage from freezing and thawing is unknown. The normal annual rainfall varies from less than about 400 mm in the north and west to over 1 500 mm in the mountainous parts of the east.

Two levels of traffic (greater and less than 100 vehicles per day) were considered to be the categories that were most suitable for local conditions. The traffic counts indicated were obtained from the most recent provincial records.

The design matrix is shown in Figure 1, in which the road numbers are listed in each cell and the average daily traffic and percentage of heavy vehicles are indicated for each road. All of the roads selected were constructed of the best material available near the road. A clustered, stratified random selection procedure was used to select the sites. Whenever possible, two sections were selected in each cell; one was a straight, level section and the other was on either a vertical grade or a horizontal curve. Each section was 300-m long.

CLIMATE	TRAFFIC	1 ACID CRYSTALLINE	2 BASIC CRYSTALLINE	3 HIGH SILICA	4 ARENACEOUS	5 ARGILLACEOUS	6 PEDOCRETE
N < 2	< 100 vpd	576 (28/13)	796 (40/38) 1298 (20/23)	625 (15/43) 421 (64/70)		210 (79/15) 1008 (26/28)	1110 (47/30)
	> 100 vpd	1560 (140/46) 219 (105/61)	383 (214/53)	P8-4 (112/29)		210 (102/32)	268 (653/40) 1266 (108/36)
2 < N < 5	< 100 vpd	1439 (5/20)	1561 (61/20) 685 (48/15)	1886 (20/5)	178 (26/25) P175-1 (97/25)	1342 (58/14)	1717 (31/27) 942 (18/7)
	> 100 vpd	024 (427/17)	1161 (200/10) 685 (251/22)	420 (197/20)	522 (173/14)	771 (388/9)	327 (152/22)
N > 5	< 100 vpd	017 (58/25)	437 (90/26) 14 (22/27)	1479 (20/26)	1141 (30/44) 508 (72/28)	508 (26/11)	167 (56/15) 1216 (11/22)
	> 100 vpd	502 (112/13) 433 (109/22)	912 (127/20)	509 (156/16)	611 (100/23)	146 (265/16)	1401 (200/50) 611 (110/30)

FIGURE 1 Experimental design matrix for the sampling and monitoring of unpaved roads in the Transvaal region of South Africa.

MEASUREMENT OF PERFORMANCE CRITERIA

Roughness

The roughness, or riding quality, of the sections was measured using Opel Rekord stationwagons that were fitted with Linear Displacement Integrators (LDIs) that were regularly calibrated against a set of standard control sections (*6*). The LDI value was then converted to a Quarter Car Index (QI) using a correlation between the LDI calibration and the QI calculated for the control sections after rod and level surveys (*7*). Roughness was measured in triplicate in both directions at 80 and 50 km/hr. In cases in which the geometrics or riding quality were such that the vehicle could not travel safely at 80 km/hr, the measurements were made at 50 and 30 km/hr. Measurements were generally taken every 3 weeks for each section. The QI scale typically increases with roughness over the range of 10 counts/km (very smooth, PSI about 4.0) to more than 100 counts/km (very rough, PSI less than 1.0).

Gravel Loss

The gravel loss measurements followed the method adopted in Kenya (*1*). Level measurements were taken at about six monthly intervals on a grid of 1-m intervals across the road and 5 m along the road over a length of 50 m. The measurements were compared with standard benchmarks located in the subgrade to indicate the average decrease in the thickness of the wearing course over the section.

Rut Depths

Longitudinal rut depths were measured using an AASHO road experiment rut depth gauge with a base length of 1.22 m. Rut depths were initially measured on all sections every 3 weeks but it soon became obvious that very few of the roads actually rutted under the prevailing conditions. Ruts were subsequently only measured when obvious wheel tracks with distinct ruts were evident.

Corrugations

In cases in which transverse corrugations or washboards were evident, their depth was measured with the rut depth gauge and their wavelength, extent, and width were measured or estimated. This data was collected to build a data base for a further investigation into their cause and prevention.

General Condition

Other factors that influenced the performance of the road were dust, stoniness, potholes, cracks, loose material, skid resistance in wet and dry conditions, wet weather trafficability, surface drainage (including ponding of water), and maximum in-place stone size. Each of these factors, except the maximum in-place stone size, which was measured, was visually rated by the two separate, independent parameters of both severity and extent on a five-point scale (Table 1) according to the general principles

TABLE 1 RATING OF FACTORS BY SEVERITY AND EXTENT

Severity		Extent	
Degree	Description	Extent (%)	Rating
1	Absent or negligible	0-20	1
2	Of minor importance	20-40	2
3	Significant, but acceptable with respect to consequences	40-60	3
4	Of major importance; may require evasive action	60-80	4
5	Totally unacceptable in regard to consequences	80-100	5

of the National Institute for Road Research (*8*). For example, significant but acceptable cracking that extended over the whole section would be coded as Degree 3, Extent 5.

The depth and diameter of the most severe potholes were measured on each section. These measurements and ratings were performed for each section after riding quality measurements were taken every 3 weeks.

Maintenance

Normal maintenance procedures were followed for the first 5 months of the monitoring, after which grader blading was reduced to about once every 4 months where conditions permitted. This procedure was adhered to for most of the sections.

RESULTS

The results of the more important material properties are summarized in Table 2. All results, except the in-place maximum size, density, moisture content, and relative compaction refer to determinations made in the laboratory on disturbed samples removed from the road. Most of the sections that were investigated were constructed or regraveled after 1973.

REQUIREMENTS OF WEARING COURSES FOR UNPAVED ROADS AND COMPLIANCE OF TEST SECTIONS

An ideal wearing course for unpaved roads should have the following attributes:

- An ability to provide an acceptably smooth and safe ride without excessive maintenance;
- Stability, in terms of resistance to deformation under both wet and dry conditions;
- An ability to shed water without excessive erosion or scouring;
- Resistance to the abrasive action of traffic;
- Freedom from excessive dust in dry weather;
- Freedom from excessive slipperiness in wet weather without excessive tire wear; and
- Low cost and ease of maintenance (*13*).

The generalized and observed properties that affect these attributes are summarized in Table 3. In addition, acceptability criteria for most of these properties are given together with the percentage of sections in which these criteria are within acceptable limits. The acceptability criteria are based primarily on the authors' experience of driving more than 70 000 km on unpaved roads during the routine monitoring of unpaved roads.

Ability to Provide an Acceptably Smooth Ride

The ability of the road to provide an acceptably smooth ride is one of the most important requirements and depends on a number of factors. A regression of the average riding quality (QI) per section in both directions against the average condition and material properties yields Equation 2, which accounts for 72 percent of the variance ($r = 0.85$; 95 percent confidence limits $\pm$ 28.6). The range of experimentally measured and generally possible values for the individual variables, arranged in order of their maximum effect calculated from the maximum value measured in the Transvaal, is shown in Table 4.

$$\begin{aligned} QI = &+ 23.57\ CORR + 1.47\ STONES + 4.91\ POT \\ &+ 0.79\ PO75 + 3.86\ SURDR - 0.55\ P2 \\ &- 0.08\ AADT - 0.20\ AFV \\ &- 1.50\ N \ldots \text{Counts/km} \end{aligned} \quad (2)$$

Each of these variables is significant at the 0.1 percent level except *N*, which is significant at the 2 percent level. Not all variables are entirely independent and some overlap exists in some cases, such as between surface drainage and potholes.

The condition parameters of surface drainage, corrugations, and stoniness are the first three variables to enter a forward stepwise regression; potholes enter at step 6 out of 21 possible variables. The surface drainage parameter includes all aspects that affect surface drainage, including erosion runnels, ruts, and potholes. The climate and traffic variables are not unexpected in this equation. However, the three material parameters, the two grading parameters and the AFV, which is a simple particle strength test that correlates well with more sophisticated strength tests, that were included at the expense of plasticity index or grading modulus are somewhat surprising. The negative influence that was attributed to annual average daily traffic (AADT) was probably due to the fact that highly trafficked roads were graded more frequently.

TABLE 2 SUMMARY OF PROPERTIES OF WEARING COURSE MATERIALS

	Values				
Property[a]	Mean ($\bar{x}$)	Standard Deviation (σ)	Maximum	Minimum	n
In place maximum size (mm)	323.0	152.0	920	60.0	3,729
Laboratory maximum size (mm)	30.4	14.5	63	4.8	182
Percent passing sieve					
4.75 mm	77.0	16.0	100	30.0	182
2.00 mm	63.0	16.0	100	22.0	182
0.425 mm	44.0	15.0	93	15.0	182
0.075 mm	22.0	12.0	76	9.0	182
Percent clay (< 0.002 mm)[b]	9.0	7.0	48	1.0	182
Grading modulus (GM)[c]	1.72	0.37	2.52	0.3	182
Dust ratio (PO75/P425)	0.48	0.16	0.95	0.22	182
Liquid limit (%)	27.0	7.5	50	NP	182
Plasticity index (%)	7.5	5.2	33.0	0	182
Linear shrinkage (%)	3.9	2.7	16.0	0	182
Proctor maximum dry density (kg/m^3)	1,972	122	2,209	1,613	162
Optimum moisture content (%)	11.6	3.0	24.0	7.0	162
In-place density (kg/m^3)	1,917	145	2,195	1,507	161
In-place moisture (%)	5.7	2.7	14.2	1.0	162
In-place relative compaction (% Proctor)	98.0	4.0	108	87	145
Soaked 0.1 in. CBR (% Proctor)[d]	26.0	20.0	99	0	162
Unsoaked 0.1 in CBR (% Proctor)[d]	35.0	27.0	205	3	162
Aggregate fingers value (AFV) (%)[e]	67.0	18.0	100	13	130
Aggregate pliers value (APV) (%)[f]	23.0	18.0	82	0	130

[a]South African standard test methods followed except where indicated (*9*).

[b]Hydrometer analysis by NITRR method (*10*).

[c]GM = cumulative percentage retained on 2.00, 0.425 and 0.075 mm sieve divided by 100 (*11*).

[d]CBR tests were performed on unsoaked specimens and specimens that were soaked for 4 days in the usual manner.

[e]AFV = total percentage number of 13-19 mm aggregate particles that were unbreakable in the fingers of both hands (*12*). The reproducibility of this simple test is about ± 10 percent of the AFV.

[f]APV = total percentage number of 13-19 mm aggregate particles that were unbreakable with 180-mm (7-in) engineer's pliers (Hazet type 1 850-3/7 in) when held in the concave, serrated portion of the jaws, using one hand (*12*). The reproducibility of this simple test is about ± 5 percent of the APV.

The stoniness of a road can be easily controlled by careful material selection and construction techniques. In developing areas, the hand picking of oversize material should be considered to provide temporary employment and produce a marked improvement in riding quality. The removal of oversize material also results in a reduction in the potholes that are formed during grader blading. The selection of a material with a smaller erosion potential, or greater cohesion, will reduce erosion runnels and probably inhibit the formation of corrugations; however, more potholes may form.

It can be seen from Table 3 that 50 percent of the sections had an acceptable riding quality, even after the maintenance frequency was reduced, whereas between 62 and 86 percent of the sections were acceptable in regard to corrugations, potholes, and surface erosion. Very few roads showed noticeable corrugations during the wet season. Potholes and erosion channels were avoided by vehicles once they developed and they did not significantly deteriorate during the dry season.

Stability

Neither the wearing course nor the subgrade, to a lesser extent, should deform under applied loads in either wet or dry conditions. A lack of stability results in potholes, rutting, and general deformation. An adequate material strength, for instance soaked CBR, and gravel thickness are necessary to ensure stability. None of the sections exhibited significant deformation even though 31 percent of the sections had materials with soaked Proctor CBR values of less than 15. It would therefore appear that either very few vehicles use these roads during prolonged wet periods or that such values are satisfactory in these particular cases.

Ability to Shed Water

If water is retained on the wearing course, the reduction of strength in localized areas because of soaking will probably

TABLE 3 PROPERTIES THAT AFFECT THE REQUIREMENTS OF WEARING COURSE GRAVELS AND THE ACCEPTABILITY OF SECTIONS

	Property Grading												
Requirements	Boulders	Gravel	Sand	Silt	Clay	Plasticity	Aggregate Strength	Soaked CBR	Traffic	Climate	Grade	Acceptability Criteria	Percentage of Sections Acceptable
Smooth ride												Mean QI < 80	50
Corrugations			+			+			+	+		Mean rating < 2.5	83
Stoniness	+						+		+	+		Mean rating < 3.0	62
Potholes	+	+					+	+	+	+	+	Mean rating < 3.0	86
Erosion				+		+		+		+	+	No observed erosion	64
Stability Deformation		+			+	+		+	+	+		Observed deformation	100
Ability to shed water Potholes	+	+					+		+	+		Mean rating < 3.0	86
Erosion				+		+		+		+	+	Mean rating < 3.0	64
Shape									+	+	+		
Resistance to abrasion		+	+		+	++	+	+	+	++		Gravel loss <21 mm/y	84
Freedom from dust				+	+	+			+	+		Mean rating < 4.0	53
Freedom from slipperiness Wet		+			+	+	+	+	+	+		Mean rating < 3.0	88
Dry		+				+	+					Mean rating < 2.0	100
Low cost and ease of maintenance Initial cost	+						+		+				
Maintenance cost	+								+	+	+		

TABLE 4 VARIABLES THAT AFFECT ROAD ROUGHNESS

Variable				
		Value		Maximum Measured Effect on QI
Code	Description	Measured	Possible	Counts/km
CORR	Degree of corrugation severity	1-5	1-5	+118
STONES	3 (degree of stoniness severity) X rating of stoniness extent	3-75	3-75	+110
POT	Degree of pothole severity X rating of pothole extent	1-20	1-25	+98
F075	Percentage passing 0.075 mm	10-30	5-50?	+24
SURDR	Degree of surface drainage severity	2- 5	1- 5	+19
P2	Percentage passing 2.00 mm	22-100	10-100?	-55
AADT	Annual average daily traffic (vehicles per daylight day)	5-653	0-1000	-52
AFV	Aggregate fingers value (%)	13-100	0-100	-20
N	Weinert's climatic N-value	1.3-8	0.5-100	-12

result in the formation of potholes and depressions. Of greater concern is the formation of transverse erosion channels in certain materials because of excessive water flow rates along the crossfall. Longitudinal erosion has less of an influence on riding quality but is important from the aspects of material loss, maintenance, and safety. Longitudinal erosion usually results from ruts or wider trough-like areas of excessive wear in the middle of a road in which only three wheel paths become surface drains during intense rainfall. Well-executed routine maintenance results in an adequate water shedding capability. Erosion was observed to be a significant problem on slopes greater than about 4 percent or those with crossfalls of about 4 percent.

Resistance to Abrasive Action of Traffic

The abrasive action of traffic results in the development of ruts, the generation of loose material, and an overall loss of material with time, which necessitates regraveling, which is the most costly maintenance operation. Adequate cohesion and routine maintenance are required to reduce the abrasive action of traffic. The worked material should be moistened and compacted after maintenance blading is performed to keep gravel loss to a minimum or the cohesionless material will be rapidly lost under traffic action. The actual gravel loss depends mainly on the traffic volume. Only 16 percent of the sections showed gravel losses of more than 21 mm/yr, which is the amount of loss that is usually estimated. The rule of thumb for gravel loss is usually 150 mm in 7 years.

Freedom From Excessive Dust

Excessive dust is primarily undesirable from the point of view of safety, but it also affects mechanical wear, driver discomfort, and roadside vegetation and crops. This investigation has shown that all materials produce excessive dust at some stage, usually after blading during the months of low rainfall. Fifty-three percent of the sections investigated showed unacceptably high dust ratings when about 40 observations were averaged.

Freedom From Excessive Slipperiness Without Excessive Tire Wear

The road should not be slippery when dry or become slippery when wet. Slipperiness is generally overcome by the presence of a well-graded fines and aggregate mix. The aggregate, however, should not be of such a size that it is excessively rough on tires. All of the roads investigated could be safely negotiated at speeds in excess of 80 km/hr under dry conditions, whereas 12 percent were periodically slippery after a number of vehicle passes under prolonged rainfall. The presence of loose material after blading exacerbated the condition by negating the effect of the underlying aggregate.

Low Cost and Ease of Maintenance

Local materials are required to keep construction costs low. Maintenance of most roads is not a problem unless there is an excess of oversize material. However, the frequency of blading should be determined by its necessity and should not follow a fixed program. Excessive blading can actually aggravate the problems of dust, wear, and slipperiness. Routine blading is seldom successful in restoring the shape of an eroded, badly worn, or potholed road.

DISCUSSION AND RECOMMENDATIONS FOR IMPROVING UNPAVED ROADS

Many of the sections that were studied have provided and continue to provide perfectly adequate service, even after no maintenance was performed for extended periods. Further research into the development of specifications from these observations is currently being performed.

However, those roads that do not perform acceptably can often be substantially improved by paying more attention to the following:

- Hard stones larger than about 75 or 100 mm lead to a marked deterioration in riding quality and maintenance procedures. Any stones of this size or larger that cannot be broken down under grid rolling should be removed by screening or handpicking, if necessary. The latter solution is especially recommended in developing areas with an unemployment problem.
- Erosion, especially transverse erosion, should be reduced as much as possible by better compaction, flatter crossfalls, better drainage, and the selection of a material that is less prone to erosion (i.e., more cohesion and fines).
- Potholes can be reduced by eliminating large stones from the wearing course and using material with an adequate soaked strength.
- Corrugations are primarily formed in materials that have low cohesion and in particular on bends and areas of acceleration or deceleration. Roads that contain a large number of large stones are also prone to the formation of corrugations because of the oscillatory motion of the vehicles over the stones.
- Carefully managed maintenance programs with well-executed maintenance operations result in far more satisfactory roads.
- Grader blading should be performed shortly after wet periods and loose material should be compacted to produce a smooth, stable finish.

CONCLUSIONS

Many of the sections perform acceptably even after no maintenance is performed for prolonged periods. It is evident that maintenance programs should be devised to allow those roads with high traffic and steep grades to be maintained more frequently than those that show little deterioration even after 4 or 5 months.

The selection of materials with low boulder contents and adequate cohesion should result in a significant improvement in riding quality. If excessive boulders cannot be broken down by grid rolling, they should be removed from the layer manually. The common practice of pushing boulders into the layer should be discouraged because they project through the surface soon after the wearing course gravel is lost.

Further research into actual values for reliable, simple specifications is warranted. Existing specifications obviously exclude many materials that are actually satisfactory in practice. The revision and simplification of these specifications would probably result in their greater implementation, which would in turn result in an improvement of riding quality and lower maintenance requirements.

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