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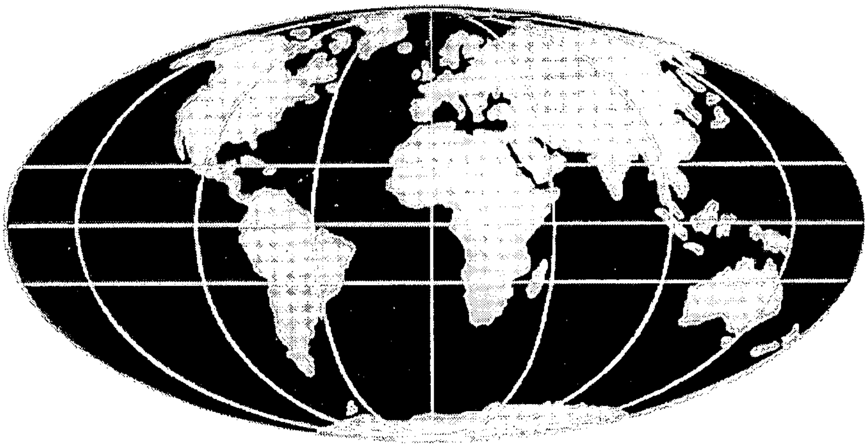

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The use of marginal materials for road bases in the Kalahari region of southern Africa

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ABSTRACT

The calcareous materials and sands available for road construction in the Kalahari often fail to meet the required specifications for base and sub-base layers respectively, in road pavements. Four different sources of calcretes were selected for the road base together with two different types of Kalahari sand. None of the materials complied with the normal requirements specified in the Botswana Design Manual. Road trials were constructed and performance monitored for almost 15 years. The main mode of deterioration was deformation within the road base. The results confirmed that the standard of a minimum 4-day soaked CBR of 80 per cent is inappropriately high for road bases on low-volume roads in the Kalahari and the suitability of Kalahari sand as a sub-base material. The strength/moisture profiles indicated that, with sealed shoulders, the performance of the outer wheelpath could be expected to be greatly improved. The different traffic loading in the two directions has been used to demonstrate that the effective exponent of the damage law for the sections was between 2 and 3. The project showed that large savings can be made on road construction projects in Botswana where these materials occur.

1. INTRODUCTION

Good quality road-building materials in the Kalahari region of southern Africa are scarce. Apart from sand, the principal road building material is calcrete which is historically regarded by engineers as a poor quality gravel. Some use has been made of the better calcretes for low volume roads in South Africa but this has not led to the general acceptance of calcrete. Nevertheless, since the haulage of good quality material from elsewhere is prohibitively expensive, it was important to establish reliable guidelines for its use. To do so, a joint research project was set up between TRL and the Roads Department of the Ministry of Works and Communications of Botswana. The approach adopted was to construct experimental sections of road using different types of calcrete as roadbases. The road between Kanye and Jwaneng was selected for the trials, partly because of the relatively high levels of traffic that were expected, and it was always intended that the trials would be monitored until they were close to the end of their useful life.

2. LOCATION OF CALCRETES

A preliminary but essential part of the programme was the location and mapping of calcareous deposits and an investigation of their engineering properties (Lionjanga et al., 1987). The scarce deposits of road-building materials are notoriously difficult to locate in the Kalahari by surface surveying but remote sensing techniques using aerial photography and satellite imagery proved particularly useful in the location of the calcrete deposits (see Lawrance, Byard and Beaven, 1993).

The four sources of calcretes selected for this project covered the range of materials found in Botswana. These can be sub-divided into four main groups namely hardpan calcrete (HC), nodular calcrete (NC), powder calcrete (PC) and calcified sand (CS). The principal properties of the samples are summarised in Tables 1, 2 and 3. All of the calcretes failed to meet at least one of the normal requirements specified in the Botswana Road Design Manual for strength, plasticity and grading. However HC-1 and NC-2 both met the minimum 4-day soaked California Bearing Capacity (CBR) requirement of 80% for roadbases and were potentially much better road-building materials than PC-3 and CS-4. As well as basic strength, sensitivity to moisture is an important aspect influencing their potential performance. The ratio of CBR at optimum moisture content to the CBR in the soaked state is a measure of this sensitivity (Table 2). The sensitivity of the calcified sand is noteworthy. The test results illustrate the high variability in properties that are found in most calcrete deposits. To use calcretes satisfactorily, great care is needed in quarrying, stockpiling, sampling and testing. Compaction trials are also recommended to determine the as-built properties of the materials when they are incorporated within a road.

Table 1: Properties of project calcretes compared with Botswana road Design Manual (BRDM) recommendations (samples from borrow pits)

Material property	Original BRDM	Project calcretes (mean values)			
		HC-1	NC-2	PC-3	CS-4
Grading modulus (min)	2.0	2.2	2.1	1.9	1.2
Maximum size	53	75	75	75	37.5
Passing 0.425mm sieve (max)	10-30	39	37	62	81
Passing 0.063mm sieve (max)	5-15(1)	12	14	33	28
Liquid limit (max)	25	25	44	39	36
Plasticity index (max)	6	7	20	9	15
Linear shrinkage (max)	3	4	9	4	6
LS x % passing 0.425mm sieve (max)	170	156	333	248	486
Minimum CBR (4 days soaked)	80(2)	150(3)	120(3)	50(3)	40(3)

[1] 0.075mm sieve in Botswana/South Africa. [2] At 98% Mod.AASHTO compaction (AASHTO T180, 1986).

[3] At BS heavy compaction (BS 1377 Part 4, 1990)

Table 2: Laboratory CBR (samples from the road)

Material	Average CBR (std dev)			Ratio	
	4-day soaked	At OMC	Dried back	Optimum/Soaked	Dried/Soaked
Hardpan calcrete HC-1	80 (24)	90 (7)	>150 (67)	1.1	2.4
Nodular calcrete NC-2	85 (41)	140 (27)	>150 (24)	1.6	2.9
Powder calcrete PC-3	60 (9)	75 (9)	120 (12)	1.3	1.6
Calcified sand CS-4	23 (12)	90 (11)	>150 (40)	3.9	10.0

3. ROAD TRIALS

The design traffic for the Jwaneng-Kanye road was 0.5 million equivalent standard axles (esas) but the traffic in the direction towards Jwaneng was much heavier than in the lane towards Kanye thereby providing an opportunity to examine the applicability of the 4th power axle load/pavement damage law to these materials and this type of construction in Botswana. Eight test sections with calcrete roadbases were constructed with four controls as part of a larger series of experimental sections looking at other topics. Laboratory results indicated that the Kalahari sands have potential for use in the lower pavement layers where they are constrained by the embankment and roadbase and therefore sand was used as the sub-base material throughout the trial.

4. ROAD PERFORMANCE

The main mode of deterioration was deformation due to shear failures within the roadbase, primarily in the vergeside wheelpath of the Jwaneng lane. The evidence from numerous moisture/strength profiles has led to the conclusion that the deformation was caused by a moisture-induced loss in strength.

4.1 Performance models

The primary measure of pavement performance is the traffic that the pavement is able to carry before reaching a defined "failure" or "terminal" condition at which repairs other than periodic or routine maintenance are required. In this experiment many of the trial sections did not reach a terminal condition and therefore, although not ideal from a statistical and scientific point of view, an assessment of their potential traffic carrying capacity could only be based on extrapolations of their performance history to date. To do so, simple performance models were developed relating rut depth statistics to traffic and/or age for each section and, where possible, for each direction of travel (Figure 1). The cumulative traffic in the Jwaneng direction by the end of the study had reached 450,000 esa and therefore traffic levels above this are extrapolations. These models predict the rut depths to better than 10% of the measured value. The actual or predicted traffic carrying capacities of the four roadbase materials to different 80th percentile rut depths are shown in Table 4.

Table 3: Typical aggregate tests on calcrete road base materials (borrow pit samples)

Sample	10% Fines Crushing Value (KN)		Modified Aggregate Impact Value (%)	
	Dry	Soaked	Dry	Soaked
Hardpan calcrete HC-1	18-20	9-11	96-130	120-150
Nodular calcrete NC-2	37-42	43	42-84	40-87

NOTE: *The powder calcrete and the calcified sand were too weak for these tests.*

Table 4: Traffic to the 80th percentile terminal rut depths (10^6 ESA)

Material	Section	Traffic to achieve Terminal Rut Depth (mm)			
		15mm	20mm	25mm	30mm
Hardpan calcrete HC-1	8	0.5	0.65	0.8	1.0
Nodular calcrete NC-2	4	0.4	0.5	0.6	0.75
Powder calcrete PC-3	1	0.6	0.8	1.0	1.15
Calcified sand CS-4	3	0.2	0.3	0.35	0.45

4.2 Roadbases

The moisture content of the middle two thirds of the pavements constructed with HC-1 and NC-2 was typically 50-70% of the optimum moisture content. The figures were higher for PC-3 and CS-4. From the moisture/strength profiles across the sections, it can be assumed that if the shoulders on the trials had been sealed then the moisture regime in the roadbase in the vergeside wheelpath would have been similar to that of the inside wheelpath. Under these conditions the vergeside wheelpath should perform better than in the trials, though not as well as the inside wheelpaths themselves. This confirmed evidence by Pinard and Jackalas (1987) from a weathered basalt roadbase that demonstrated the structural benefit of sealing shoulders, especially in materials with high plasticity. Research conducted by Emery (1984) has shown that there is generally an overall maintenance benefit in whole-life cost terms from sealing the shoulders of pavements constructed with natural gravel roadbases and this would appear to be particularly true for the calcretes. The test sections are discussed in order of improving performance.

Section 3: Calcified sand (CS-4): From the results of laboratory tests, the calcified sand would normally be considered suitable only for sub-base. Its potential for use as roadbase material in arid conditions stems from the relatively high strengths obtained in the laboratory when the material is tested at optimum moisture content (CBR=90%) and in the dried-back state typical of the middle two thirds of the pavement (CBR >150%). Conversely, the material was the most sensitive to moisture with a large reduction in strength when wet (Table 2). Over time, large variations in deflection have occurred in the vergeside wheelpath of this section (0.6-1.0mm). Deflections in the inside wheelpath position were generally 0.3-0.4mm. These results are also indicative of the difference in moisture condition of the pavement at these positions. The vergeside wheelpath of the Jwaneng lane developed an average rut of 20mm after the passage of about 350,000 esas.

Section 4: Nodular calcrete (NC-2): In terms of strength, the NC-2 material satisfied the general requirements for the higher traffic categories for unbound gravel roadbases given in Overseas Road Note 31 (TRL, 1993). However, the high plasticity index and the high percentage of material passing the 0.425mm sieve (Table 1) showed that the material failed to meet the Botswana specification. Despite this, high values of in situ CBR were recorded consistently across the whole paved area of the section. The mean rut depth in the vergeside wheelpath reached 12mm after the passage of 400,000 esa and the models of average rut depth and traffic indicate that the failure rut depth (20mm) would be reached at a traffic level of about 600,000 esas. Thus its use in conditions similar to those of the trial could be acceptable for traffic levels of around 500,000 esa's (Table 4). No significant rutting developed in the inside wheelpath. Moisture contents were typically less than 60% of optimum and in situ CBRs were in excess of 100%. Deflections were consistently less than 0.4mm in both wheelpaths.

Section 8: Hardpan calcrete (HC-1): HC-1 was the best of the materials used in the trials in terms of suitability for roadbase. It easily met the GB3 category in Overseas Road Note 31 (TRL, 1993) for roadbase in terms of strength although it did not satisfy the plasticity requirements. Deflections in the vergeside wheelpath of the Jwaneng lane averaged 0.4mm and were less (typically 0.3mm) in the other wheelpaths. The deformation in the vergeside wheelpath of the Jwaneng lane increased but at a relatively slow rate. The last measurements showed an average rut of 12mm.

Section 1: Powder calcrete (PC-3): The performance of this section was the most difficult to explain. The average in situ CBR values measured with a dynamic cone penetrometer were low, averaging 24% in 1991, and this is reflected in a low radius of curvature. The moisture content has increased since construction to values above optimum across the whole of the paved area. In 1994 the rut depths averaged 9mm in the vergeside wheelpath of the Jwaneng lane but this is an increase of less than 4mm since the road was opened to general traffic. This combination of low strength and low deformation is unusual and seems to indicate that the material possesses a greater resistance to shear than is evident from the CBR test, although the reasons for this are uncertain.

Table 5: Equivalent traffic damage based on different exponents

Lane	Exponent					
	1.0	2.0	3.0	4.0	4.5	5.0
Jwaneng	300 000	276 000	287 000	322 000	350 000	385 000
Kanye	138 000	103 000	73 300	66 500	70 500	77 900
RATIO	2.18	2.69	3.91	4.84	4.96	4.94

4.3 Sub-base

The moisture content of the sand sub-base was always less than the optimum for compaction. The ratio of Field Moisture Content to OMC varied from 0.3-0.8, reflecting the variations occurring in the roadbases above. The average overall *in-situ* strengths for each section also mirrored the strengths of the roadbases, the strongest sub-bases being associated with the strongest roadbases. The sub-base of Section 1 was the weakest at CBR 42% and Section 8 was the strongest at over

100%. The values in the vergeside wheelpath were very similar for Sections 1, 3 and 4, namely 45, 55 and 50% respectively, whereas the value on Section 8 was 95%.

4.4 Subgrade

Strength tests carried out on the subgrade shortly after pavement construction gave in situ CBR ranging from 11-22% (mean value = 16%). The predominantly dry and free-draining conditions yielded relatively high strengths in the sand subgrade and the results of subsequent measurements were consistently higher than at construction because the subgrade had dried back. The mean CBR at 550mm depth for all sections except Section 4 was above 30%, the value for Section 4 being 14%. As expected, the centre of the pavement was always stronger.

Table 6: Traffic categories for the calcretes used in the trials

Maximum Traffic	0.3m ESA's		0.5m ESA's		0.7m ESA's		1.0m ESA's		1.5m ESA's	
Shoulder(1)	U	S	U	S	U	S	U	S	U	S
Material type	CS-4	CS-4	--	CS-4	--	--	--	--	--	--
	PC-3	PC-3	PC-3	PC-3	--	PC-3	--	--	--	--
	NC-2	NC-2	NC-2	NC-2	(NC-2)	NC-2	--	(NC-2)	--	--
	HC-1	HC-1	HC-1	HC-1	HC-1	HC-1	(HC-1)	HC-1	(HC-1)	HC-1

(1) U=unsealed, S=sealed. Figures in brackets indicate that the materials may be used but there is insufficient evidence from this study to predict their performance at these higher levels of traffic.

4.5 Shoulders and embankments

The trials demonstrated that calcified sand is unsuitable as shoulder material because of its susceptibility to erosion. The coarse-grained calcretes performed well as shoulder material but the unsealed shoulders, when wet, acted as a potential source of moisture which infiltrated the roadbase layer and influenced the performance of some of the calcrete roadbases. When used as embankment material, Kalahari sand was susceptible to erosion but this was greatly reduced by modifying the embankment slopes from 1:4 to 1:6.

5. PAVEMENT DAMAGE LAW

The results show that for all sections the damage between different axle loads was less than that predicted by using the standard exponent of 4.5. This means that either the traffic in the Jwaneng direction was less damaging than expected from the 4.5 power law or that the traffic in the Kanye direction was more damaging. It is impossible to say which, but it is of little consequence since roads will always be designed on the basis of the most heavily loaded direction and, provided both the traffic assessment and the design charts are based on the correct law, then the designs will be economical. Consideration should therefore be given to using the revised damage law for these conditions. Most of the sections had damage ratios between the two directions of travel in the range 3.2 to 3.5 which is equivalent to an exponent of about 2.5 (Table 5).

6. SPECIFICATIONS

Suggested traffic limits for the four different types of calcrete roadbases used in this experiment are shown in Table 6. These are based on a combination of the projected traffic which will produce an 80th percentile value of rut depth of 20mm, the engineering properties of the materials, and other factors described in the full report which were shown to influence performance. Revised specifications based on five traffic categories are given in Table 7. It is not expected that any given material will meet all the limits specified for any given traffic category but, in order that the material can carry the predicted traffic, it must meet the limits of CBR and placticity. The thickness requirements are those specified in Road Note 31 for the quoted traffic levels and for an S6 (30% CBR) subgrade. It must be borne in mind that these have been distilled from the properties of the calcretes used in the trials and therefore relaxation of the specifications is permitted only within the bounds set by the actual properties for each calcrete type.

Table 7: Traffic categories for the calcretes used in the trials

Maximum traffic (ESA x 10^6)	0.3	0.5	0.7	1.0	1.5
Maximum particle size (mm)	75	75	75	75	75
Max % passing 0.425mm sieve	80	65	65	45	30
Max % passing 0.063mm sieve	30	30	25	20	15
Liquid limit (maximum)	60	55	50	40	30
Plasticity index (maximum)	25	20	15	12	10
Linear shrinkage (%)(maximum)	12	12	8	6	5
LS x % passing 0.425mm sieve (max)	800	700	550	400	200
LS x % passing 0.063mm sieve (max)	300	300	300	200	100
Minimum soaked CBR(1)	40	50	60	60	80

7. ECONOMICS

A survey of seven contracts in Botswana indicated that the cost of a constructed natural gravel roadbase was between 10 and 16 Pula per m^3 (£1=Pula 3.5) compared with 80-100 Pula per m^3 for crushed stone. This is equivalent to savings of about £30,000 per kilometre on the cost of the roadbase. If there is a need to seal the shoulders in order to guarantee a drier environment in the roadbase then the extra costs will be about £33,000 per kilometre although savings on shoulder regravelling costs will reduce this figure.

Fig 1. Actual versus predicted rut depths

The use of sand as sub-base material has also resulted in considerable savings. Most of the calcretes are suitable for use in the sub-base but the use of the abundant sources of Kalahari sand has resulted in savings in haulage costs on recent projects. Savings of approximately £33,000 per kilometre can be expected where sub-base sand material is available adjacent to construction sites in the Kalahari. Further savings of approximately £34,000 per kilometre have also been made on a recent contract as a result of a separate collaborative research project in Botswana on the use of crushed calcrete for road surfacing (Woodbridge and Slater, 1995). Similar savings will be made on future road construction projects in the Kalahari region.

8. CONCLUSIONS

The principal outputs from the project are the road performance relationships and the revised set of roadbase specifications for using each of the main types of calcrete found in the Kalahari region of Southern Africa. The results combine with other research on natural gravel roadbase materials to provide substantial evidence to indicate that the almost universal standard of a minimum 4-day soaked CBR of 80% is inappropriately high for low volume roads in climatic areas where the moisture content in the roadbase is unlikely to attain a value above optimum. A cost effective method of helping to attain this condition would be to seal the shoulders. The axle loading of the traffic was markedly different in the two directions and has been used to show that for the calcrete roadbases the ratio of damage is less than predicted by the 4th power damage law. The effective exponent of the power law was shown to be between 2 and 3. The trials have demonstrated that the Kalahari sands can be used effectively as sub-base material. The high strength of the sand, when confined, has resulted in no deformation in the sub-base layer even when the overlying roadbase material had sheared. This project and other studies of calcareous materials have shown that considerable savings can be made on road construction projects in Botswana and elsewhere in the region where calcretes occur.

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