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TITLE The use of calcrete in paved roads in Botswana

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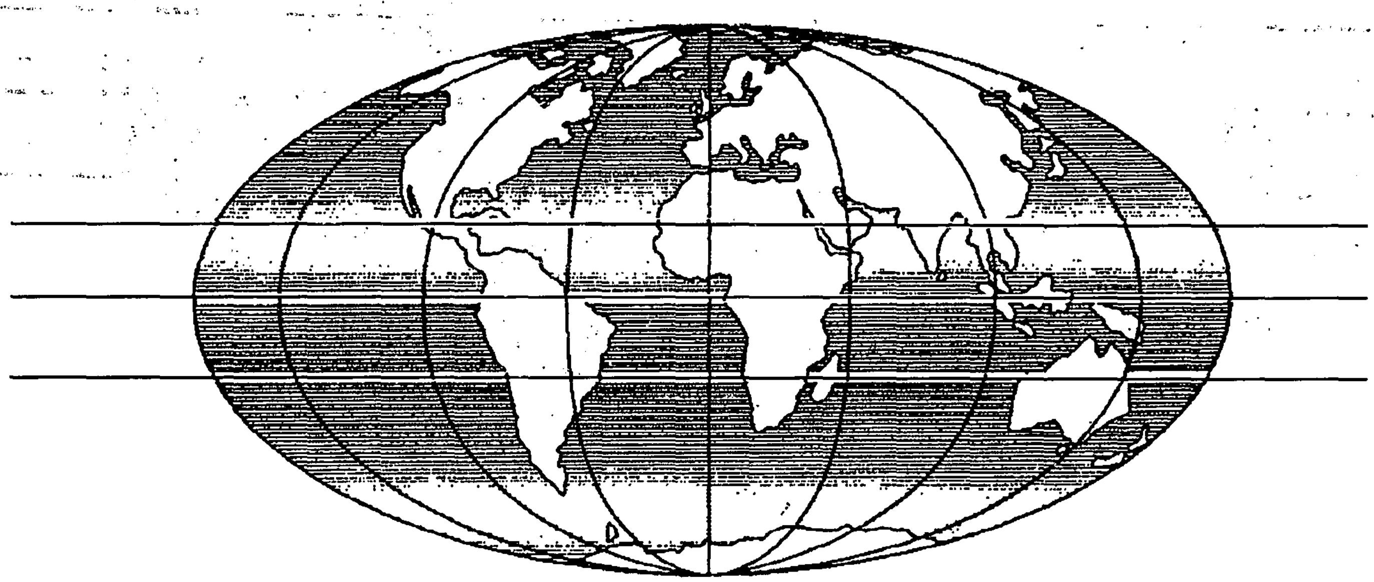

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The use of calcrete in paved roads in Botswana

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ABSTRACT: This paper describes the studies undertaken in Botswana which have led to the development of local specifications for the use of calcretes in paved road construction. The studies have examined their use as road bases, untreated shoulder materials and as surface dressing aggregates. A new specification for lightly-trafficked roads based on the findings of the studies is included.

The results of recent research concerning the use of cement and lime stabilisation is presented and recommendations made.

Finally, the results of the research will be applied to the construction of over 1200 km of road to be constructed in the Kalahari region over the next decade. This will enable massive cost savings to be made.

1 INTRODUCTION

Calcrete deposits exist as virtually the only sources of hard or gravelly materials available for use in pavement layer construction throughout most of the central and western areas of Botswana. Their occurrence is generally confined to those areas overlain by Kalahari sands although they are also found further east overlying older rocks and along drainage lines, (Mallick, Habgood and Skinner 1981).

The engineering properties of calcrete are extremely varied. They range from slightly calcified uniform sands and soft powdery deposits to hard gravel and rock layers. For use in pavement layer construction only the best deposits normally satisfy traditional specifications although the use of the softer types has been successfully demonstrated in low-volume roads (Overby 1982, Lawrence and Toole 1984).

A number of major paved roads are planned to be built in the next decade in the Kalahari region in which calcretes will be used. These projects are identified in Figure 1.

The completion of these routes will lead to an expansion of the paved road network from its current length of 2000 km to approximately 3200 km.

It is likely that calcrete will be used as the main pavement material in the construction of all routes. It may also provide a source of surfacing aggregate.

In the earlier development of the paved road network, calcrete was seldom used. The reason for this was the abundance of natural gravels and weathered rock deposits exposed in the east of the country where most of the road and economic development has taken place.

Whenever calcrete has been used as a base material on the main road network stabilisation by cement and/or lime has been undertaken. The main purpose of the stabilisation has been to reduce the plasticity of the calcrete. In each case the calcrete material has been relatively coarsely-graded prior to treatment.

The occurrence of the harder varieties of calcrete however is not widespread and has led to the need to develop experience in using marginal and low grade types.

In order to obtain the necessary experience and evidence to justify new design standards, the Botswana Ministry of Works and Communications (MOWC) has conducted research into the use of calcretes with a number of research organisations. This has led to the construction of four major full-scale road experiments in which calcretes ranging in classification from calcified sand to hardpan and boulder deposits are being examined as sub-bases, bases and surface dressing aggregates.

The construction of roads under Rural

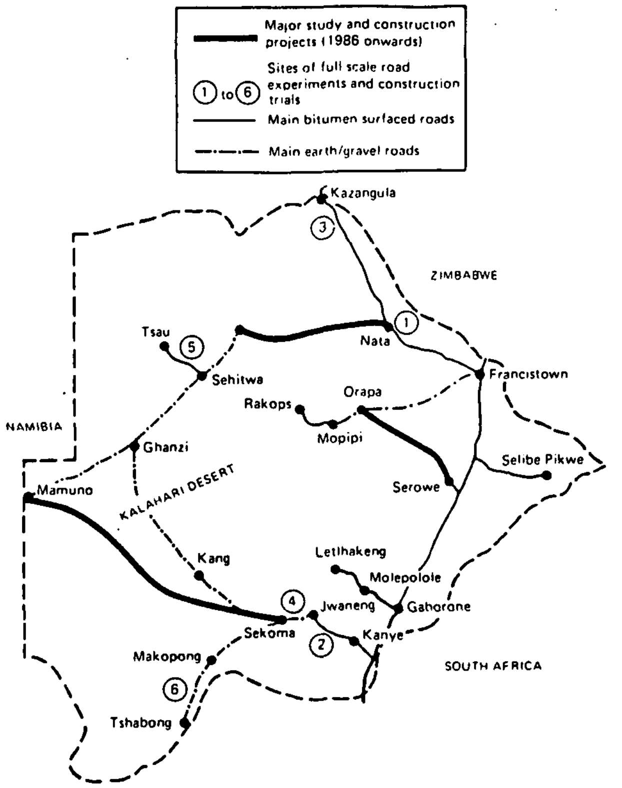

Fig. 1 Map of Botswana showing the location of the experiment

Roads Project (Overby 1982), in which untreated powder calcretes and calcified sands were used as roadbases, has also assisted in the development of local expertise.

The objective of this paper is to bring together past and recent experience in the use of calcretes in paved roads for the benefit of highway engineers involved in the design and construction of roads in calcrete areas.

2 THE OCCURRENCE AND DISTRIBUTION OF CALCRETES IN BOTSWANA

Calcrete deposits occur throughout the Kalahari region of Botswana, within the Kalahari sand. They are associated with topographic features of the sand surface such as pans, inter-dune hollows, topographical depressions and former drainage lines, but also occur in association with grey-coloured patches of Kalahari sand and with rocks near the surface. In the last case they occur as cappings to calcareous or basic igneous rocks, which form a local source of calcium carbonate.

Calcretes and the geological formations with which many are associated, have been mapped in Botswanta by the use of remote sensing techniques. Black and white aerial photographs have been used to map landforms associated with calcrete, and Landsat imagery has been used to map features showing colour differences. The "Photogeological Map of Botswana" (Mallick, Habgood and Skinner 1979) was produced in this way, and illustrates the main surface materials and exposed geology of Botswana. Figure 2 which is based on this map, shows the presence of calcretes and other materials that are potentially suitable for road pavement construction. The remarks in Fig 2 are based on field investigations conducted in the TRRL-MOWC study of the occurrence of calcretes (Lawrence and Toole 1984). As part of this latter study detailed maps of calcrete occurrence covering an area in the Central Kalahari, and which are suitable for estimating material resouces, were produced. Use was also made of natural colour aerial photography in mapping grey sand areas.

3 PREVIOUS USE OF CALCRETES IN PAVED ROADS

Calcrete has been used in the sub-base layers of sections of the main paved road network, in the Rural Roads Project roads built in the Kalahari region and in various experimental pavement sections. The road sections which incorporate calcrete in the road base are listed in Table 1.

Roads built as part of the main road network have been constructed with crushed or mechanically stabilised calcrete bases, lime modified calcretes or cement and lime stabilised calcretes. These roads have given good performance over periods up to ten years.

In the construction of these roads the pavement thickness designs and material standards have been based on either TRRL guidelines for tropical countries (TRRL 1977) or South African guidelines (National Institute for Transport and Road Research, 1980a, 1980b).

Roads built as part of the Rural Roads Project have used various thickness design guides. In the selection of pavement materials, trial specifications based on research conducted by NITRR (Netterberg 1971) and those developed following the 'forced-trafficking' of lengths of project roads have been used. These are described later in this paper.

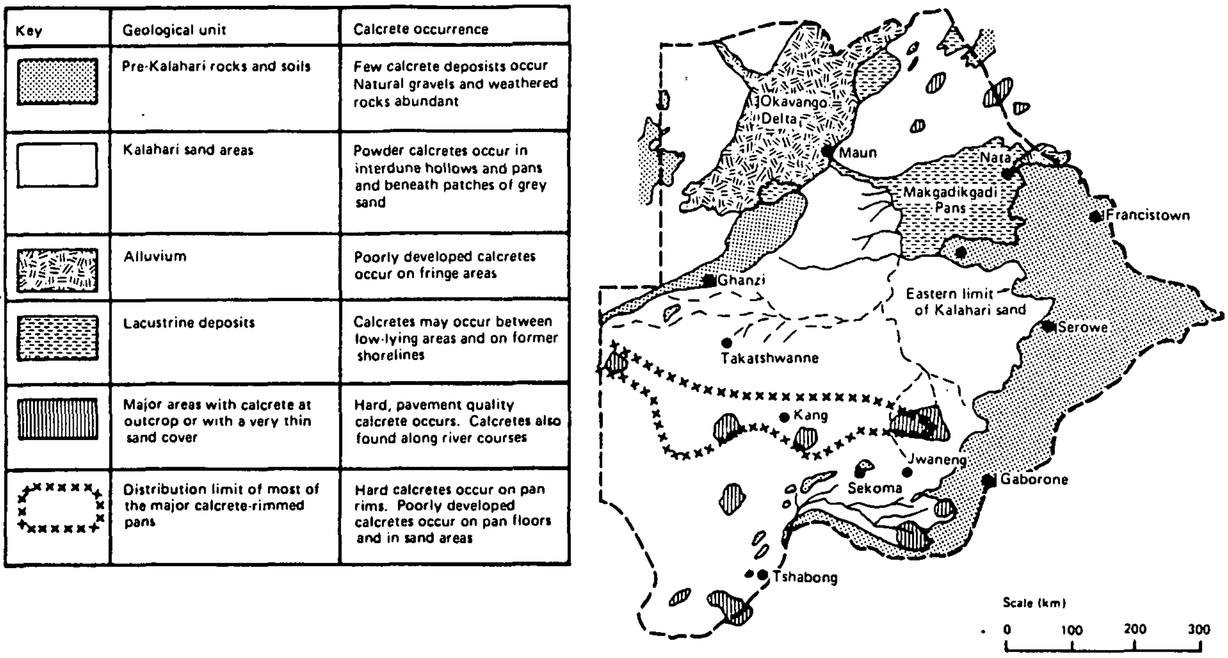

Fig. 2 Distribution of the main material types in Botswana (After Mallick, Habgood and Skinner 1979)

Table 1. Use of calcretes as road bases in Botswana

Project/Route	Length (km)	Type of construction
1. Main road network		
(a) Francistown - Nata	28	Lime stabilised calcrete base with a double surface dressing
(b) Palapye - Serowe	45	Two stage lime and cement stabilisation of a calcrete with a double surface dressing
(c) Nata - Kazangula	180	Lime stabilised calcrete with a double surface dressing
2. Rural road projects		
(a) Sehitwa - Tsau	50	Untreated calcified sand/powder calcrete with a double surface treatment of a graded seal and a sand seal
(b) Tsabong - Makopong	95	Untreated and mechanically stabilised calcrete base with a double surface treatment comprising a single graded aggregate or single sized aggregate followed by a sand seal
(c) Molepolole - Letlhakeng	50	Untreated calcrete base with a double surface dressing
(d) Mopipi - Rakops	50	Untreated calcrete base with a double surface dressing

4 THE CLASSIFICATION AND ENGINEERING PROPERTIES OF CALCRETES IN BOTSWANA

4.1 Description and classification

The calcretes which exist in Botswana are the result of a pedogenic soil forming process, in which carbonates of calcium (and often magnesium) have accumulated in the Kalahari sand. Solution and redeposition over time have given rise to a variety of calcareous deposits, all called calcrete, varying from loose, calcified sand to massive, hard "rock".

In Botswana a classification of the common calcrete types based on the South African groupings (Netterberg 1971) has been adopted and these are distinct both physically and in their engineering properties. The groups are; calcified (or calcareous) sand, powder calcrete, hardpan calcrete (including "boulder" calcrete) and nodular calcrete (Figs 3 and 4). They differ by the amount and type of carbonate present and its degree of crystallinity, the proportion and hardness of any gravel sized particles, and the degree of induration. They may also contain varying amounts of mineral fine material, eg water soluble salts and clay minerals.

4.2 Profile characteristics

Any one or a number of types of calcrete may be expected to occur in a calcrete profile. The thickness, position and hardness of the layers will also vary. Thicknesses from a few centimetres to over two metres have been recorded and these often determine the cost of production, the mechanical plant necessary for excavation and construction and whether a deposit is workable.

Because of the possibility of variable layer quality and thickness particular care needs to be exercised during excavation to prevent contamination and mixing of materials. The availability of an accurate description of in situ conditions and test data representative of the calcrete profile can assist in the identification of the most suitable deposits.

4.3 Properties of calcretes

4.3.1 Engineering tests

The properties of some Botswana calcretes related to their use in paved roads are shown in Table 2. Typical gradings for the four common types of calcrete

Fig. 3 Sampling calcified sand. Note the extreme looseness of the material. The upper part of the profile is more coherent, approaching soft powder calcrete

Fig. 4 Hardpan calcrete. The horizontal laminar structure is typical. The material grades downwards into tough powder calcrete at the bottom of the photograph

TABLE 2. Laboratory test properties of some Botswana calcrete related to use in road construction

Sample No	Soil constants PI	LL	LS	GM (1)	Passing 425 µm (%)	Passing 75 µm (%)	APV (2)	Soaked CBR mod at AASHTO	Calcrete type	Classification according to Botswana Road Design Manual (3)	Use in full-scale road experiments in Botswana
FN3 (4)	SP	-	-	2.6	20	-	70	172	Hardpan/Nod.	Road base (C4)	Road base: Francistown-Nata experiment (untreated and lime-modified)
FN1	11	-	5.3	2.5	21	-	70	67	Nodular	Subbase (G5) or lime-modified road base	Road base: Francistown-Nata experiment (untreated and lime-modified)
BG1	8	28	3.7	2.2	34	6	23	110	Hardpan	Subbase (G5) or lime-modified road base	Road base: Kanye-Jwaneng experiment
BG4	20	44	8.5	2.1	38	11	53	105	Nodular	Lime modified base	Road base: Kanye-Jwaneng experiment
JSSB	24	50	8.0	2.3	22	8	70	-	Nodular	Lime modified base or sub-base	Road base: Jwaneng-Sekoma experiment
Q91	12	49	8.3	2.3	23	2	43	103	Nodular	Sub-base (G5) or lime-modified base	-
BG6	7	36	2.9	1.9	44	15	6	90	Powder	Selected subgrade (G6)	Road base: Kanye-Jwaneng experiment
BG7	17	41	7.6	1.1	80	20	28	50	Plastic calcified sand	Fill (SG15)	Road base: Kanye-Jwaneng experiment (untreated and lime/cement stabilised)
BG5	19	38	9.0	1.5	70	18	-	42	Plastic Powder	Fill (SG15)	-
Q87	16	39	6.3	1.2	79	8	5	66	Powder	Fill (SG15)	-
JSBG4	26	49	10.6	1.1	73	28	-	56	Calcified sand	Fill (SG15)	Road base: Jwaneng-Sekoma experiment

Notes:
1. For definition of Grading Modulus (GM) $GM = \frac{300 - \text{sum of \% material passing } 2.0\text{ mm} + 0.425\text{ mm} + 0.075\text{ mm sieves}}{100}$
2. APV - Aggregate Pliers Value (Netterberg 1971)
3. Based on material standards and pavement categories in Chapters 5-107 and 5-307 (MOWC 1982)
4. The liquid limit values of sample nos FN3 and FN1 were determined using NITRR test methods and need correcting in accordance with Sampson and Netterberg (1984).

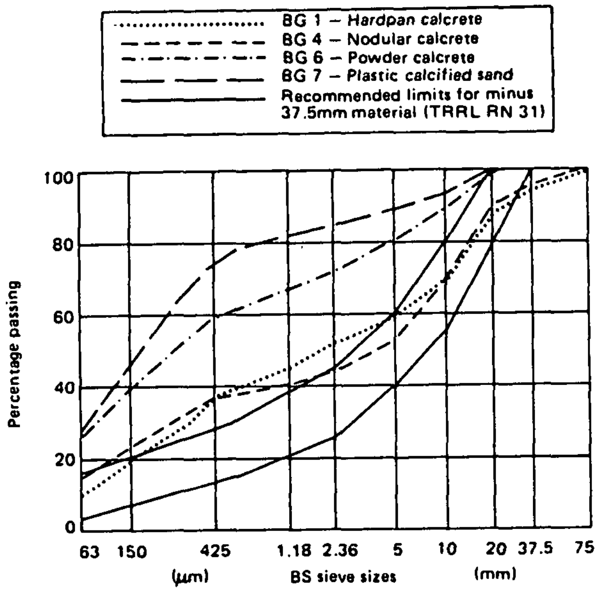

Fig. 5 Mean particle size distributions of samples of four of the common types of calcrete

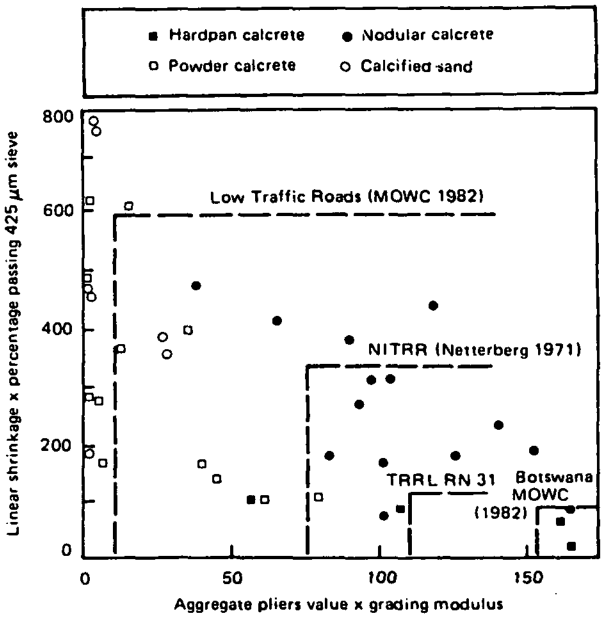

Fig. 6 Relationship between laboratory test properties of some Botswana calcretes and type (After Lawrance and Toole 1984)

Table 3. Results of testing calcrete aggregates used in bituminous surface dressings

Aggregate source	Modified Aggregate Impact Value (%)		10% Fines Aggregate Crushing Value (kN)		Water absorption (%)
	Dry	Soaked	Dry	Soaked	
Nata (used in Nata-Kazangula experiment)	22	23	270	210	-
Sekoma (used in Jwaneng-Sekoma experiment)	24-28	-	210-175	110-100	2.6-3.1

are shown in Fig 5. In comparison with conventional specifications for pavement materials the usefulness of the materials ranges from subgrade and embankment soil to road base quality (Ministry of Works and Communications 1982). As a result of research in Botswana however, their usefulness can be extended, particularly in low volume road construction.

Because of the variability of calcretes even within the recognised types it is suggested that the full range of laboratory tests be performed prior to selection. In common with traditional guidelines the properties which define the usefulness in road construction of a calcrete are its grading, the strength and proportion of the hard particles and the proportion and plasticity of the soil fines (material passing the 0.425 mm sieve). These four properties have been combined in Fig 6 in two composite expressions comprising the product of the linear shrinkage and the amount of material passing the 0.425 mm test sieve and the product of the grading modulus (Table 2) and the aggregate pliers value (Netterberg 1971) to illustrate the spread in properties obtained from testing the various types of calcrete. Superimposed on the figure are various acceptance limits for road bases (Netterberg 1971, Lawrence and Toole 1984, TRRL 1977).

Calcretes suitable for use as surfacing aggregates also exist in some parts of Botswana although their full potential is still being investigated. The test values of two such deposits are given in Table 3. These particular materials are currently being assessed as surface dressing aggregates in on-going road experiments.

4.3.2 Cement and lime stabilisation

In cases where untreated materials suitable for pavement layer construction are unavailable, or their use is not cost effective, local soils are often stabilised by the addition of low percentages of cement or lime to effect an improvement.

The purpose of the stabilisation needs to be clearly defined since the reaction of cement or lime is quite different. Lime (hydrated lime) is usually added to reduce the plasticity of a material by initiating a flocculation reaction with any clay minerals present. In some cases if additional lime remains available a pozzolanic reaction may follow. Cement is usually added to effect a direct gain in strength by creating cementitious bonds between soil particles. When measured in the laboratory after specified curing periods high strengths have been obtained with calcretes using either cement or lime. These can usually be maintained on soaking. In the field however, the success of stabilisation depends on a number of factors. These include the time between mixing and compaction, the efficiency of curing and effective sealing over long periods and the initial consumption of lime (ICL) of the unstabilised material.

The difficulties of compacting cement stabilised materials after long delays (usually greater than 3 hours) are well documented. It has been suggested that similar reaction times may occur with certain lime-stabilised calcretes due to the presence of non-plastic pozzolans in the form of reactive silica (Netterberg 1971). The only current means of determining the response of a material in this way is to perform a test programme whereby the density-strength-delay time relationship is determined. No specific examples are available from Botswana which demonstrate a rapid lime reaction although the data contained in Fig 7 illustrates the change in density achieved at constant compactive effort at different time delays. Corresponding cured

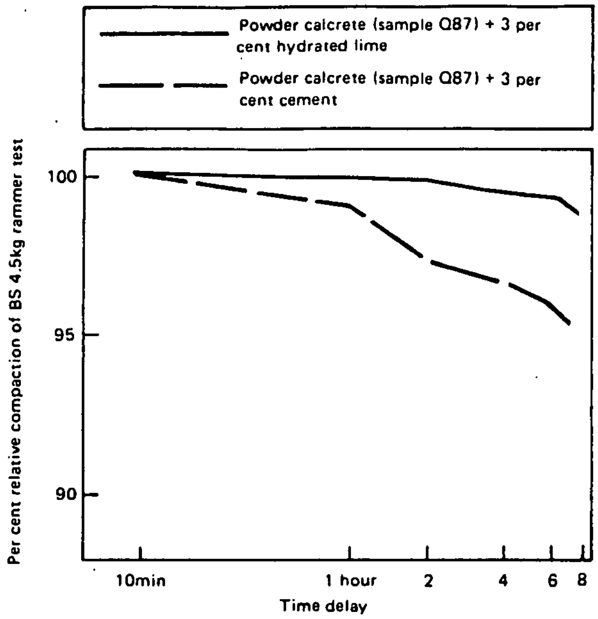

Fig. 7 Per cent relative compaction obtained after different time delays following the addition of the stabilising agent

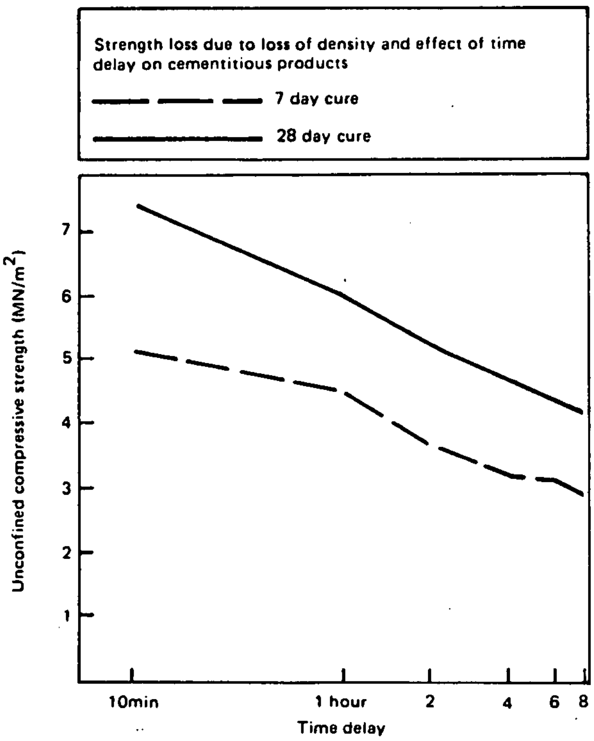

Fig. 8 Effect of time delay on the strength of cement stabilised stabilised calcrete: Powder calcrete (sample Q87) + 3 per cent cement

strengths at the likely compaction level are shown in Fig 8.

More recently problems related to the possible carbonation of stabilised layers have been brought to the attention of highway engineers (Paige-Green 1984). The carbonation reaction is most likely to occur beneath permeable surfacings in the tropics particularly in areas of low to medium humidity, and can take place in both cement and lime stabilised materials. Recent, as yet unpublished, research has shown that with calcretes carbonation can retard, and in extreme cases, reverse strength development in materials stabilised with cement and lime. It is not known however whether the initial flocculation reaction which is responsible for reducing the plasticity of soil-lime mixtures can be reversed in a similar manner. Evidence does exist however to show that poorly-graded calcretes which have flocculated to different degrees and failed to show a permanent strength gain are in fact less stable than untreated materials (Lionjanga, Toole and Newill (1987).

Good efficient curing techniques and early sealing are probably the best means to combating the problem and research is in progress to determine the most efficient techniques. The choice between cement and lime stabilisation may therefore depend on the initial design objectives ie modification of plastic components or cementing the material. In either case the same curing may be required.

A further consideration in stabilisation design is the initial lime consumption required to produce and maintain sufficiently high alkaline conditions for the formation of cementitious products. This is the minimum content required for long term durability (Klaus and Loudon, 1971). Often it is more efficient to introduce a two-part stabilisation process, first adding lime (at least up to the determined ICL value) and then adding cement. This however depends on costs particularly of double handling etc, weighed against material costs. With calcretes it is likely that the ICL would remain constant with time.

4.3.3 The role of calcium carbonate

Calcium carbonate is the main mineral component introduced into calcrete during its formation. The presence of the carbonate is thought to be one of the main mineralogical influences on the often satisfactory behaviour of some otherwise poorly-graded and plastic materials. It is believed that a minimum amount of carbonate is required to achieve the satisfactory response of a material. The calcium carbonate content of Botswana calcretes ranges from less than 10 per cent in calcified sands to over 50 per cent in some hardpan and powder calcretes.

Simple equipment can be used for the measurement of the carbonate content eg the "Collins" calcimeter (Road Research Laboratory 1952).

4.3.4 Soluble salts

Highly soluble salts such as sodium chloride may be present in some calcretes. The salt can migrate to the surface of a base layer and disrupt the bond with the prime and bituminous surfacing (Netterberg 1979). The various construction techniques available to deal with salt-related problems are discussed later in this paper.

The determination of the quantity of soluble salts present in a material is regularly undertaken when testing calcretes. A simple soil paste conductivity test is commonly used (National Institute for Transport and Road Research 1979). In Botswana provided that groundwater does not gain access to the road pavement and provide a source of salts after construction then testing of the intended base material with the required amount of the compaction water to be added is normally done.

5 EXISTING GUIDELINES FOR THE USE OF CALCRETES IN PAVED ROADS

Until recently the specifications used in the selection of calcretes for use in paved roads all derived from the adaption of European and North American specifications (eg TRRL 1977) or South African experience (NITRR 1980a, 1980b). They were neither calcrete-based nor were they derived exclusively for use in the semi-arid areas which extend across almost the whole of Botswana. The specifications generally require strict control of soil plasticity, grading, CBR and aggregate hardness (see Table 4).

As a result of studies of calcrete performance in South Africa and Namibia guidelines specific to their use in paved roads have been published by NITRR (Netterberg 1971). These are also contained in Table 4 and allow for the acceptance of materials with higher plasticity characteristics and poorer gradings than would normally be considered mechanically stable.

The latter specifications have been incorporated into the Botswana Road Design Manual (MOWC 1982) and have been applied in the construction of secondary and rural feeder roads receiving less than 200 000 equivalent standard axles (ESA) in a design period.

The lower calcrete specification however excludes the majority of calcrete deposits and may still be too stringent in many areas of Botswana where traffic levels are less than 100 vehicles per day (VPD) and design traffic levels can be as low as 100 000 ESA.

The development of locally-based specifications which take greater account of the traffic, climatic and subgrade conditions which exist in Botswana was therefore required. This need was met by undertaking studies to examine the use of locally available calcretes in all pavement layers and by developing appropriate construction techniques.

6 THE DEVELOPMENT OF APPROPRIATE SPECIFICATIONS AND CONSTRUCTION TECHNIQUES

Local expertise in the use of calcretes in paved roads has been obtained as a result of the construction of parts of the rural road network and through the construction and monitoring of four major full-scale road experiments constructed over the last ten years on the main road network. The projects are identified in Fig 1.

6.1 Full-scale road experiments

A summary of the design and performance of the four full-scale road experiments is presented below. Monitoring is carried out at regular intervals by means of measurements of surface deformation, cracking, longitudinal roughness and surface deflections. Panel inspections have also been conducted. In addition traffic and axle load surveys have been performed, climatic data recorded, and in some instances the density, moisture content and strength of the pavement layers and subgrade have been measured.

(1) Francistown-Nata. (Project 1 in Figure 1). Eight test sections were built which incorporate both lime stabilised and untreated calcretes as base materials. Calcretes were also used in the other pavement layers. Surfacing comprised a double surface dressing with a fog spray.

The base materials consist of coarsely graded nodular and hardpan calcretes (see Table 2). The worst material has a 4-day soaked CBR of 60-70 per cent and a PI

TABLE 4 Existing guideline specifications for the selection of light-trafficked calcrete bases

Test	TRRL Road Note 31 Design traffic 2.5 x 10^6ESA	NITRR Bulletin 10 (Netterberg 1971) Expected Traffic Category (VPD) < 20% > 3 tonnes			
		< 500	500-1000	1000-2000	2000-4000
Maximum size of material (mm) or size range	37.5 (1)	19-37.5	37.5-53	37.5-53	37.5-53
Minimum grading modulus	Not specified (ns)	1.5	1.5	1.5	1.5
Percentage passing the 425µm sieve	12-25	15-55	15-55	15-55	15-55
Percentage passing the 63µm sieve	5-15	ns	ns	ns	ns
Maximum liquid limit (%)	25	40	35	30	25
Maximum plasticity index	6 (2)	15	12	10	8
Maximum linear shrinkage (LS) (%)	4	6	4	3	3
Maximum LS x % passing 425µm	Not specified	320	170	170	170
Minimum CBR after 4 days soaking (3)	80	60 at 2.5 mm 80 at 5.0 mm	80 at 2.5 mm 80 at 5.0 mm	80 at 2.5 mm 100 at 5.0 mm	80 at 2.5 mm 100 at 5.0 mm
Minimum dry 10% FACT value (KN)	Not specified	ns (6)	80	110	110
Minimum soaked 10% FACT value (KN)	50 (4)	ns	50	50	50
Minimum relative field compaction	100% BS (3)	98% mod AASHTO (5)			
Total soluble salts (%) (5)	Not specified	0.2	0.2	0.2	0.2

Notes.
1. Details of gradings and appropriate maximum sizes given in TRRL (1977)
2. Can be raised to 12 in arid and semi-arid areas (TRRL 1977)
3. At 100% BS, 2.5 kg rammer method. (In practise a higher field compaction of 97% BS 4.5 kg rammer method is often specified and CBR is based on this).
4. A minimum 10% Fines Aggregate Crushing Test value has been suggested by TRRL (Hosking and Tubey 1969), or alternatively a maximum Modified Aggregate Impact Value of 40% is suggested.
5. Test methods described in NITRR (1979).
6. An Aggregate Pliers Value of 50 per cent is usually specified.

between 9 and 16 determined using Casagrande apparatus (NITRR 1979).

The experiment has remained in a satisfactory structural condition since it was opened to traffic in 1977. The surfacing has however required maintenance following loss of stone, which led to the base becoming exposed. The cause of this is thought to be the progressive absorption of binder by the calcrete base. Remedial treatment has included the application of dilute emulsion in 1983, as a fog spray, with subsequent resealing in 1985.

Traffic volumes on this road are of the order of 100-200 VPD. The route is the main road link to north-west Botswana and Zambia. The estimated axle loading over the life of the road is in excess of 500 000 ESA.

(2) Kanye-Jwaneng. (Project 2 in Figure 1). Eleven experimental calcrete base sections and four control sections in which quartzite and granites are used in the base are incorporated into this experiment.

The surfacings include conventional double and single surface dressings and bituminous sand seals.

The four main types of calcrete were incorporated as base and unsurfaced shoulder materials. Their particle-size distributions are contained in Fig 3 and a summary of the results of laboratory tests in Table 2.

Two of the experimental base sections comprised a plastic calcified sand stabilised with Portland cement and hydrated lime. Another was constructed in which a nodular calcrete was mixed with an equal proportion of the local Kalahari sand to determine whether savings could be made in the haulage of materials. In addition a powder calcrete which possessed an optimum compaction moisture content of around 30 per cent was compacted at a moisture content considerably below the normally required level as a means to saving water in dry areas. A further section was constructed in which a nodular calcrete was left unsurfaced for a number of months to determine whether any gain in strength on drying would be maintained in subsequent years.

From the results of the experiments so far, seven years after construction, the untreated road bases have performed satisfactorily when contained in the pavement. The poorest calcrete (the plastic calcified sand) however has not proved suitable as an unsurfaced shoulder material, having deteriorated badly within two years after construction.

Neither the mechanically-stabilised calcrete nor the cement or lime-stabilised calcrete have proved to be a success. Deep rutting has occurred in parts of each of these sections. The cement and lime-stabilised bases have also carbonated over their full depth. The failures have been attributed to the lack of stability in the base layer which in the case of the sand/calcrete mix is a result of an excessive gap in its grading and in the stabilised bases is a result of the stabilisation reaction producing a material which resembles a single-sized uniformly graded sand with a low amount of silt and clay particles. Since opening to traffic in 1979 all remaining road-bases have performed satisfactorily and have so far carried up to 160 000 ESA in the more heavily loaded traffic direction (Lionjanga et al 1987). Daily traffic flows have varied between 150 and 250 VPD.

The performance of different bituminous seals applied to two different calcrete bases was also examined. Sand seals using the local Kalahari sand have not performed wholly satisfactorily, being best on the better quality calcrete, which contained an appreciable quantity of coarse hard particles. These provide a surface finish that permits sufficient penetration of the binder film. Extensive potholing occurred on a powder calcrete with a sand seal. The single surface dressings performed reasonably well on both although they allow little margin for error in their design and their performance can be variable.

(3) Nata-Kazangula (Project 3 in Figure 1). This experiment comprises a total of four test sections which incorporate a crushed calcrete aggregate in the bituminous surfacing. The calcrete aggregates were applied in the following surface treatments to a primed crushed stone base:

(a) Double seal 13.2 mm first layer 6.7 mm second layer.
(b) Double seal 13.2 mm first layer, graded crusher waste second layer.
(c) Single seal 13.2 mm with a fog spray.
(d) Single seal 13.2 mm.

The mechanical properties of the aggregates are contained in Table 3.

The performance of the sections with the double seals and the single seal with a fog spray has been satisfactory. The section with a single seal only has suffered a substantial loss of stone as a result of the lack of a second binder spray to make up for the deficiencies in the condition of the primed base.

The experiment was opened in June 1983 and carries the heavily loaded traffic moving between Botswana, Zambia and Malawi. Vehicle flows are of the order of 40-70 VPD.

(4) Jwaneng-Sekoma. (Project 4 in Figure 1). This experiment comprises a total of eighteen test sections and calcretes are represented in the bituminous surfacing, base and sub-base.

In the experiment various surface dressings (both single and double) and graded aggregate seals (using the 'Otta' concept (Thurmann-Moe and Ruisten 1983)) were applied to both a plastic calcified sand base and a nodular calcrete base. The experiment has also examined the use of an armour course of large chippings (>20 mm) applied to the calcified sand base prior to priming and the application of a bituminous seal to the shoulders of the calcified sand sections.

The properties of the calcrete surfacing aggregate which was obtained from a Kalahari pan deposit, are contained in Table 3.

Of the 18 original sections, the 7 which received double surface treatments have performed reasonably well on both types of base although these sections required a fog spray after 15 months to enrich a binder-hungry surface. These consist of double surface dressings, using alternatively a single sized chipping or a crushed waste in the second seal, and double 'graded aggregate seals'. The remaining 11 test sections have been extensively patched and a slurry seal applied.

The experiment has identified a number of factors not adequately covered in existing guides. These include the need to take account of absorptive aggregates and the absorption of surfacing binder by a primed base. An analytical basis for the design of graded aggregate surfacings needs also to be pursued.

The experiment has shown that the construction of an armoured base is particularly difficult and costly and a similar design effect can be achieved successfully at a lower cost using a double surface treatment.

The experiment has also highlighted the need to take into account the slow curing properties of diesel cutbacks when used as surfacing binders.

Since completion of the construction in 1984 the shoulders of the plastic calcified sand sections have performed well having received a bituminous seal incorporating a graded crusher waste.

The traffic on the experiment has varied between 40-80 VPD.

6.2 Construction of rural roads

During the construction of roads built under the Rural Roads Project (Overby 1982) trials using different material specifications and construction techniques have been undertaken. These were necessary to enable economic solutions to be developed in areas where conventional materials were absent. Four project roads in the Kalahari region were constructed using calcretes (see Table 1). Of these, two projects have been more closely examined and reported.

(1) Sehitwa-Tsau. (Project 5 in Figure 1). The construction of this road was preceded by the construction and "forced-trafficking" of trial sections. In the area only poorly-developed, slightly plastic, calcified sands existed and experience of their use was previously confined to unpaved roads. The purpose of the trials was therefore to determine whether they could be used successfully as a base material, both untreated and following stabilisation with lime. Sections were also constructed where an "armour-course" was applied to the untreated base prior to priming and sealing. The surfacing of the experiment comprised a double seal using a graded aggregate in the first layer (an 'Otta'-type seal), followed by a bituminous sand seal as the second seal.

Following the construction of the trials in December 1980 35 000 ESA were applied by "forced trafficking". This was considered to be equivalent to ten years traffic. No differences in performance were observed during this period. As a result, the local calcified sands were used as road-base material for the construction of the road. The surfacing adopted comprised the graded aggregate seal followed by a light sand seal.

The road has been monitored at regular intervals since construction and the performance of the test sections and the main road project has remained satisfactory over a period of six years although a crack pattern, possibly associated with seasonal and long term moisture changes, of a rectangular form has developed on the unstabilised sections. No surface deformation has been observed.

(2) Tsabong-Makopong. (Project 6 in Figure 1). This road was constructed commencing in 1980 and the road base material comprised a mechanically-stabilised hardpan/nodular calcrete mixed with Kalahari sand. CBR values were in excess of 80 per cent after four days soaking and the material was of low plasticity.

Problems encountered on the project were associated with high amounts of soluble salt in the calcretes bases. The soluble salt contents ranged between 0.1% and 0.5%, and various techniques were used to remedy the problems of surface disintegration which occurred. The most successful technique was to use an MC70 grade prime sprayed at 1.3 litres/m^2 immediately after base construction and to complete the surfacing as soon as possible thereafter. If delays occurred to the priming operation the alternative method used was to skim the top of the base by a grading operation once the salts had migrated to the surface. This latter method resulted in a rough surface and required extensive patching.

7 RECOMMENDATIONS FOR THE USE OF CALCRETE IN PAVED ROADS

(1) Untreated or lime-modified road bases. The results of the studies have shown that a wider range of calcretes can be recommended for use in lightly trafficked roads than those specified previously (see Table 1). A revised specification which applies to a cumulative traffic loading of 160 000 ESA is shown in Table 5 and is based on a more critical examination of

the performance of calcified sands, powder calcretes and gap-graded materials examined in Botswana (see Lionjanga et al 1987). In particular the importance of the distribution of sizes in the soil fines is highlighted. A minimum calcium carbonate content is also recommended which may help to classify calcretes further although the role of calcium carbonate in the performance of calcrete as a road building material is not fully understood. There has been no evidence to suggest that self-stabilisation occurs as has been suggested elsewhere (Netterberg 1971).

For higher traffic levels it would appear that the maximum plasticity in the base material could be increased up to a plasticity index of 15. It is not known however whether grading requirements and CBR criteria could also be relaxed. Untreated and lime modified calcretes which satisfy the specifications of TRRL Road Note 31, provided that the criteria for aggregate hardness and soluble salts are also met, should be suitable for traffic levels up to 2.5 x 10^6 ESA.

(2) Cement and lime-stabilised road bases. Specifications exist in Botswana for cement and lime-stabilised bases. They are largely based on South African design guides (NITRR 1980a, 1980b). They have however been applied in circumstances where the untreated materials were relatively well-graded to begin with and in these cases they have generally met with success. In an efficient design process more poorly-graded materials would normally be used, particularly at current design traffic levels in Botswana. A number of factors can however affect the success of the stabilisation and these include: inefficient curing, which can lead to poor hydration of the cemented material, carbonation and delays between initial mixing and compaction. To ensure that some amount of mechanical stability is maintained a minimum grading modulus of 1.5 and a coefficient of uniformity greater than 5, and preferably greater than 10, is recommended. A minimum unconfined crushing strength of 1.7 MPa at field density is also recommended. The curing period should be 7 days for cement-stabilised materials and 28 days when lime is used.

(3) Shoulder materials. As a result of the unsatisfactory performance of some calcified sands as unsurfaced shoulder materials separate guidelines for their use are required. For low volume roads these are contained in Table 6 and include restrictions on the maximum allowable amount of material passing the 425 μm sieve and a minimum calcium carbonate content.

Where shoulders receive a protective bituminous seal the appropriate base materials for the design traffic level given in Table 5 should be used. At higher traffic levels (as covered in Table 1) the base should be extended through the shoulder either unsealed or sealed. This latter consideration will depend on local policy.

(4) Surfacing materials. Hard calcretes which satisfy normal aggregate requirements can be used successfully in bituminous surfacings up to high traffic levels. They should possess a minimum Ten Per Cent Fines Aggregate Crushing Value of 210 kN in the dry test and 160 kN after a period of soaking (NITRR 1980b). For low-volume roads those calcretes with lower particle strengths (eg a wet 10% FACT of 100 kN) and which often possess a high water absorption value may still be used although they may give a more variable performance as a result of the variation in the strength of individual particles.

Calcrete bases often require more bituminous prime to adequately seal the surface than other road base materials. Studies have shown that trials may be necessary at the time of construction to choose the correct type and application rate. Coarsely-graded calcretes are often the most "hungry" materials.

A conventional double surface treatment provides an adequate surfacing for all calcrete bases and from evidence in Botswana this can last for between five and seven years. Following this the application of a fog spray, to rejuvenate the surfacing, may add a few years to the life of a seal.

Single surface dressings and sand seals are not suitable for surfacing all types of base and require high maintenance and resealing within 2-3 years.

The use of graded aggregate seals has been successfully demonstrated on rural road projects using conventional aggregates although a quantitative design method does not exist and site trials are necessary to establish the technique to be used.

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Table 5. Revised guideline specifications for lightly trafficked calcrete bases (Note 1)

Test	Percentage passing the 425 µm sieve (2)		
	10-50	50-65	65-85
Maximum particle size range (mm)	75-10	75-10	75-10
% passing 63 µm sieve	5-25	15-35	20-35
Maximum ratio of % passing 425 µm and 63 µm	Not specified	3.5	3.5
Linear shrinkage (%)	<10	<6	<6
Plasticity index	<25	<15	<15
Maximum LS x % passing 425 µm	600	500	500
LS x % passing 63 µm	Not specified	30-150	120-210
Minimum 4-day soaked CBR at field density (%)	40	40	40
Minimum calcium carbonate content (%) of the material passing 425 µm	12	12	12

Notes. (1) Up to a design traffic level of 160 000 ESA
(2) After compaction using wet sieve analysis methods

Table 6. Guideline specifications for unsurfaced calcrete shoulder materials in lightly trafficked roads

Test	Percentage passing the 425 µm sieve (1)	
	10-50	50-65
Maximum particle size range (mm)	75-10	75-10
% passing 63 µm sieve	5-25	15-35
Maximum ratio of % passing 425 µm and 63 µm	Not specified	3.5
Linear shrinkage (%)	<10	<6
Plasticity index	<25	<15
Maximum LS x % passing 425 µm	600	500
LS x % passing 63 µm	Not specified	30-150
Minimum 4-day soaked CBR at field density (%)	50	50
Minimum calcium carbonate content (%) of the material passing 425 µm	25	25

Notes. (1) After compaction using wet sieve analysis methods

Any views expressed are not necessarily those of the British Government's Department of Transport, nor the Overseas Development Administration.

9 REFERENCES

BSI 1975. Methods of tests for soils for civil engineering purposes. BS 1377. London: British Standards Institution.

Hosking, J.R. & L.W.Tubey 1969. Research on low-grade and unsound aggregates. TRRL Laboratory Report 293. Crowthorne: Transport and Road Research Laboratory.

Klaus, K.A. & P.A.Loudon 1971. The influence of the initial consumption of lime on the stabilisation of South African road materials. Proc. 5th Reg. Conf. for Africa on Soil Mech. and Fndn. Engn: Launda.

Lawrence, C.J. & T.Toole 1984. The location, selection and use of calcrete for bituminous road construction in Botswana. TRRL Laboratory Report 1122. Crowthorne: Transport and Road Research Laboratory.

Lionjanga, A.V., Toole, T. & D.Newill 1987. The development of specifications for the use of calcretes in lightly-

trafficked roads in Botswana. 4th Intl. Conf. on Low Volume Roads, New York: Transportation Research Board.
Mallick, D.I.J., Habgood, F. & A.C.Skinner 1979. A geological interpretation of Lansat imagery and air photography of and air photography of Botswana. Overseas Geology and Mineral Resources No. 56. London: Institute of Geological Sciences.
Ministry of Works and Communications 1982. Road design manual. Roads Department, MOWC, Gaborone, Botswana.
NITRR 1979. Standard methods of testing road construction materials. NITRR TMH1. Pretoria: National Institute for Transport and Road Research.
NITRR 1980a. Structural design of interurban and rural road pavements. NITRR Draft TRH4. Pretoria: National Institute for Transport and Road Research.
NITRR 1980b. Standards for road construction materials. NITRR Draft TRH 14. Pretoria: National Institute for Transport and Road Research.
Netterberg, F. 1971. Calcrete in road construction. NITRR Bulletin 10. Pretoria: National Institute for Transport and Road Research.
Netterberg, F. 1979. Salt damage to roads - an interim guide to its diagnosis, prevention and repair. Pretoria: National Institute for Transport and Road Research.
Overby, C. 1982. Material and pavement design for sealed low traffic roads in Botswana. NRRL Internal Report No. 1042. Oslo: Public Roads Administration.
Paige-Green, P. 1984. A laboratory investigation into the influence of carbonation on the strength of lime-stabilised materials. Proc. 8th Reg. Conf. for Africa on Soil Mech. & Fndn. Engn. Harare, 1, 403-406.
Road Research Laboratory 1952. Soil Mechanics for road engineers. London: HM Stationery Office.
Sampson, L.R. & F.Netterberg 1984. A cone penetration method for measuring the liquid limits of South African soils and its implications. Proc. 8th Reg. Conf. for Africa on Soil Mech. & Fndn. Engn. Harare, 1, 105-114.
Thurmann-Moe, T. & H.Ruistuen 1983. Graded gravel seal (Otta surfacing). Proc. 3rd Intl. Conf. on Low Volume Roads. Tempe: Transportation Research Board.
TRRL 1977. A guide to the structural design of bitumen-surfaced roads in tropical and sub-tropical countries. TRRL Road Note 31. Crowthorne: Transport and Road Research Laboratory.