THE JWANENG LTPP EXPERIMENT: PERFORMANCE OVER 14 YEARS AND A COMPARISON BETWEEN KALAHARI SAND-ASPHALT AND CALCRETE BASE COURSES

F NETTERBERG[1] and MI PINARD[2]

[1]79 Charles Jackson Street, Weavind Park 0184 Pretoria, South Africa
Tel: +2712 846 7051; Email: frank.netterberg@gmail.com
[2]InfraAfrica (Pty) Ltd, Private Bag 00426, Gaborone, Botswana
Tel: +267 397 1281; Email: mipinard@global.bw

ABSTRACT

The Jwaneng long-term pavement performance base course experiment on the Kanye-Jwaneng road in Botswana consisted of 12 test sections of wet-mix and foamed Kalahari sand-asphalt and 11 test sections of mostly substandard calcrete base course with two control sections of gravel base, all under a double surface treatment. The purpose of the experiment was to evaluate various alternative base material quality designs for roads in the Kalahari where good quality gravels are scarce. Although the performance of most of the sand-asphalts and some of the calcretes was marred by construction defects, monitoring for 13 years and 0,4 ME80 showed that both types of base course were viable options for at least 1,0 ME80 and that untreated calcretes previously regarded as too inferior could be used as base course. The performance of the cement, lime and mechanically stabilized calcretes was inferior to that of their untreated equivalents.

1. INTRODUCTION

Approximately 80% of Botswana is covered by fine Kalahari sand (Roads Department (BRD), (2010) in which areas conventional rock and gravel road construction materials are scarce to non-existent, the only other material usually being isolated occurrences of mostly poor quality calcrete (Lionjanga et al, 1987).

A set of long-term pavement performance (LTPP) experimental sections comprising both Kalahari sand-asphalt and calcrete base courses was therefore constructed as part of the new Kanye-Jwaneng road in 1979 in order to evaluate such materials for their potential use in Botswana.

This road is a 1982 Botswana Road Design Manual (BRDM) Category II (Roads Department, 1982) and a TRH4:1996 Category C (COLTO, 1996) road with a designed structural capacity of 0,5 million equivalent standard 80 kN axles (ME80 or MESA) As the sand-asphalt sections have already been described by Netterberg and Pinard (This Conf.) and the calcrete sections by Lionjanga et al (1987) and Greening and Rolt (1997, 2014) and briefly reviewed by Gourley and Greening (1999), it is the purpose of this paper only to provide a comparative summary of their performance up to 1993, after which the whole experiment was rehabilitated, with a minimum of background information.

2. THE SITE

The experiment was located in flat, sand-covered terrain on the Kanye-Jwaneng road in Botswana about 7 km from Jwaneng. The area has a semiarid warm climate and lies within the 1982 Botswana road design manual and the TRH4:1996 Dry Macroclimatic Region for pavement and seal design purposes. The annual rainfall at Jwaneng varies between about 200 and 800 mm, with a mean of about 420 mm, falling mostly between October and April.

The roadbed consisted of a reddish-brown fine-grained Kalahari sand extending to a depth of at least 5 m below natural ground level classifying as an AASHTO M-145 (1995) A-2-4(0) soil rather than as an A-3 single-sized sand. The permanent water table was believed to lie at a depth of about 110 m, but a temporary perched water table during the rainy season at a depth of about 1,0 m appeared likely.

3. PAVEMENT DESIGN, LAYOUT AND AS-BUILT LAYER PROPERTIES

The road and pavement design details were as follows:

- Cross-section: 2,5% fall on seal, 3,5% on shoulders.
- Surfacing: 6,7 m-wide with yellow edge lines; 9,5/19 mm double seal (80/100 pen.) plus fog spray (cationic emulsion) except on seal experiments.
- Prime: 7,0 m wide MC-30 at 0,75 l/m^2 on Sections 1 – 6; at 0,98 l/m^2 on Sections 7 – 23
- Base courses: Gravel on Sections A and B – D compacted to 98%, sand-asphalts to 95% MAASHO; calcretes to 97% BS Heavy (BSH).
- Shoulders: 1,85 m-wide, as for base on Sections A, B, C and D (all sealed) and calcretes (unsealed); preconstructed, unsealed, calcified clayey sand on the sand-asphalts, all compacted to 95% MAASHO.
- Subbase: Gravel on sections A, B, C and D and calcified clayey sand on Sections 1 and 2 compacted to 95% MAASHO and Kalahari sand “subgrade” compacted to 93% MAASHO on others. The sand subbase was primed on Sections 3 – 7.
- Subgrade and fill: Side-borrowed Kalahari sand compacted to 93%; fill to 90% MAASH0
- Roadbed: Kalahari sand compacted to 90% MAASHO to 1,25 m below top of subgrade.

The layout and some of the as-built properties are shown in Table 1.

The whole experiment consisted of 12 sections of sand-asphalt and 11 of calcrete bases of which two (21 and 22) were left unsealed as wearing course experiments plus two seal experiments B (Kalahari sand seal) and C (single 9,5 mm chip seal) and a control section of normal construction at each end (A and D). Each section was 100 m long. The thickness of all base sections was intended to be 150 mm except for Sections 8 (100 mm), 9 (75 mm), 10 (75 mm) and 11 (100 mm).

The purpose of the experimental cement and lime stabilization was to improve the poorest calcrete, the mechanical stabilization with Kalahari sand to lower the PI of an otherwise good but scarce nodular calcrete and also to make it go further, compaction at less than moptimum (OMC) to use less scarce water, and drying back to determine if this would improve the performance.

The purpose of the sand-asphalts was to provide for alternative designs where suitable calcretes could not be found. The vane shear method (Marais 1980) was used for the design and the binder contents were the percentages by mass of the whole binder (i.e. including the cutback volatiles) of the dry sand.

Table 1: Layout and layer properties of Jwaneng experiment [1]

← To Kanye　　　　To Jwaneng →

Section No.	A	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	B	C	D
TRL No. [2]	A	-	-	-	-	-	-	-	-	-	-	-	-	1	2	3	-	-	-	4	5	6	7	8	B	C	D
Process / Material	Nat. Gravel	← In-situ wet process →						← Foamed asphalt →						Powder calcrete		Calcified sand			Nodular calcrete				Hardpan calcrete		Crushed gravel		
															[3]		[4]	[5]	[6]		[7]	[8]	[8]				
Base [9]																											
Binder Type	-	RC-250	RTH 35/40		RTH 30/35 +1,5%PVC	RTL 35/40	RC-250	60/70 pen.			RTH 55/60			-	--	-	Cem.	Lime	Sand	-	-	-	-	-	-	-	-
Design (%)	-	4,5	5,0	5,0	5,0	5,0	4,5	3,5	3,5	3,5	4,5	4,5	4,5	-	--	-	3	3	1:1	-	-	-	-	-	-	-	-
Actual (%)	-	3,4	5,2	5,2	5,0	5,0	3,6	3,9	3,0	4,1	4,9	4,1	4,6	-	--	-	-	-	-	-	-	-	-	-	-	-	-
Thickness Actual (mm)	(150)	140	140	140	140	140	140	150	90	70	40	70	120	155	142	150	166	167	166	198	198	168	154	170	(150)	(150)	(150)
Compaction MAASH0 [10] (%)	≥ 98	90	99	96	96	95	87	91	93	90	89	90	87	85	87	95	97	97	95	99	98	100	97	91	(98)	(98)	≥98
Density (kg/m³)	-	1866	1960	1906	1920	1879	1740	-	-	-	-	-	-	1233	1266	1750	1741	1659	1958	1946	1923	1958	1917	1791	-	-	-
Strength Vane [11] (kPa)		510	380	340	300	330	380	320	310	390	170	210	190	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CBR [12] (%)	61	-	-	-	-	-	-	-	-	-	-	-	-	60	-	23	120	95	48	85	-	-	-	80	(120)	(120)	120
GM	(2,0)	-	-	-	-	-	-	-	-	-	-	-	-	1,43	1,2	1,13	1,20	1,20	1,58	2,12	1,9	2,0	2,3	2,05			(2,3)
P425 (%)	38	-	-	-	-	-	-	-	-	-	-	-	-	56	-	76	75	75	62	30	-	-	-	36	(23)	(23)	23
PI (%)	5	-	-	-	-	-	-	-	-	-	-	-	-	10	7	20	4	5	12	27	23	29	11	9	(NP)	(NP)	NP
MDD (kg/m³)	2190	2085	1990	1990	2000	1980	2000	-	-	-	-	-	-	1440	-	1860	1791	1703	2058	1960	-	-	-	1950	-	-	2200
OFC/OMC [13] (%)	7,1	6,5	7,0	7,0	5,5	6,5	7,0	-	-	-	-	-	-	25,5	-	12,1	9,5	9,4	7,4	10,2	10,2	-	-	10,7	-	-	5,7
Subbase [14]	Gravel	Cal. clay sand		← Kalahari sand "subgrade" to 93 % MAASHO →										← Kalahari sand "subgrade" to 93 % BSH →											← Gravel →		
(150 mm) Compaction (%	[15] ≥ 95	100	102	106	98	96	104	90	97	97	98	95	93	-	-	-	97	96	100	98	95	96	101	99	-	-	[15] ≥95
Fill [14]	≥93	← Kalahari sand to 93 % MAASHO(mean 96 % achieved) →												← Mean 97 % BSH achieved →													≥92
Roadbed [14]	≥90	← Kalahari sand to 90 % MAASHO (mean 96 % achieved) →												← Mean 94 % BSH achieved →													≥90

SV 67 + 100
km 113,900

SV 68+400
km 115,200

SV 60+700
km116,500

Notes:

[1] Bases constructed in April – May 1979, sand-asphalt primed with MC-30 within 2 weeks; calcrete Sections 16 – 18 immediately, 22 – 22 not primed, others within 2 days, sealed in Oct 1979, opened to traffic 1979/11/07, closed 1980/02/02, reopened 1980/03/28. Cumulative E80 as at June 1980 20 000 in Jwaneng lane, 5 000 in Kanye lane. Jwaneng lane west (Jwaneng)-bound, Kanye lane (Kanye)-bound, Culverts at joints between Sections 11 & 12 and 19 & 20 and cattle crossing between 22 and 23

[2] Greening & Rolt (1997, 2014)

[3] Section 14 compacted at < OMC

[4] Ordinary portland cement? ; primed within 24 h but only sealed six months later

[5] Marvello magnesian lime ; primed within 24 h but only sealed six months later

[6] NP Kalahari sand

[7] Section 20 to be dried back before priming and sealing (however, all dried back to about 0,5 OMC even if primed)

[8] Initially unprimed & unsurfaced as wearing course experiments. In early 1981 Section 20 reconstructed with nodular calcrete with single seal; 21 with powder calcrete with double seal

[9] Actual percentages binder, thicknesses , compactions, etc., are means, figures in brackets are estimates

[10] Specified : 98 % MAASHO for gravel base controls, 95 % for gravel subbase controls, 95 % for sand -asphalt base, 95 % for calcified clayey sand subbase, 93 % for sand "subgrade" (subbase); 97 % BSH for calcrete bases

[11] 7-Day mean in-situ vane shear at 40 °C (design spec. 200 kPa at 100 % MAASHO)

[12] Calcrete samples after compaction or mostly from road in 1989. BS 1377:1975 test methods, BSH CBR & compaction data. Samples for Sections 15 and 16 taken after field mixing (CBRs are BSH means of two after 7 days curing. CBRs after 28 days 165 and 160, respectively.)

[13] OFC for max. shear strength 1,5 – 3,0 % < OFC for max. density for sand-asphalts

[14] Kalahari sand relative to MAASHO compaction on controls and sand-asphalt sections, BSH on calcrete sections

[15] Gravel subbase CBR 70 at 95 %, PI 6

4. MATERIALS

4.1 Sands

The Kalahari sand used for the sand-asphalt, subbase and embankment was a mostly nonplastic, reddish-brown, silty, fine sand with a grading modulus (GM) of about 0,87 classifying as an A-2-4 (0) material according to AASHTO M-145-91 (1995), and as a G7 in the 1982 BRDM and TRH 14:1985 (National Institute for Transport and Road Research (NITRR, 1985), and the COLTO (1998) specifications for state roads in South Africa. This sand had a soaked CBR of 90 compacted at the BS1377:1975 heavy effort (BSH).

4.2 Calcretes

The calcretes were selected from different borrow pits to represent four typical Kalahari calcretes of different type (Netterberg, 1971) and quality representative of those found along the proposed Trans-Kalahari road to Namibia, either marginal or inferior in some respect to the normal BRDM requirement for base course. Some of them were even inferior to the relaxations previously found possible in South Africa (Netterberg, 1971, 1982) and in Botswana (Netterberg and Pinard, 1991) (Table 2).

Table 2: Some properties of the sand and calcretes used

Material type	Source	GM	PI %		BSH CBR (%)			APV	CaCO$_3$ (%)	
					Soaked		@ OMC [1]		Total	<425 µm
					Pit	Road	Road			
			Mean	Min. – Max.		-		%	%	%
Kalahari sand	Side	0,9	NP	NP – 2	90 [3]	-	110 [3]	-	Nil	Nil
Calcified sand	BG4	1,2	15	13–23	40	23	90	28	16	15
Powder calcrete	BG3	1,9	9	7–16	50	60	75	6	38	32
Nodular calcrete	BG2	2,1	20	13–40	120	85	140	53	32	22
Hardpan calcrete	BG1	2,2	7	5–11	150	80	90	23	40	29
Standard base	-	≥ 2,0	≤ 6	0–6	≥ 80 [2]	≥ 80 [2]	-	-	-	

Notes: [1] Calcretes all ≥ 120 and approx twice soaked CBR after drying to approx. 0,5 OMC except calc. sand (>150 and six times). [2] At 98 % MAASHO. [3] Side borrow

With average dry/soaked 10% FACT (TFV) values of only 20/10 kN for the hardpan calcrete and a dry value of 40 kN for the nodular calcrete the aggregate strength of even the best calcretes was very low and far below the traditional minima of 110/83 for a crushed base, and even lower than the soaked 50 kN successfully used in Zimbabwe for a gravel base (Mitchell et al, 1975) and the 50/40 dry/soaked minima suggested by Netterberg (1982) for calcrete bases to carry up to 500 vpd.

The samples of calcified sand and nodular calcrete contained insufficient coarse aggregate for a TFV determination and the dry APVs (Aggregate Pliers Value) (Netterberg, 1971, 1982) of all except the nodular calcrete were less than the minimum of 50 suggested by him. However, only the powder calcrete broke down significantly after compaction, the GM decreasing from a mean of 1,9 to 1,4, and the others by no more than 0,1.

5. CONSTRUCTION

The sand-asphalts proved more difficult to construct than expected, with low binder contents, inadequate mixing, densities and thicknesses on a number of Sections (Table 1).

The bagged cement and lime for the calcrete Sections 16 and 17 were spread by hand on the prewatered material, mixed with a Rex Pulvimixer and rewatered again, all of which took about 3,5 hours. Compaction followed without delay and both sections were primed with MC-30 within 24 hours.

The bases were constructed in April – May 1979, the calcretes primed within 24–48 hours and the sand-asphalts within two weeks of construction. However, they were only surfaced in October 1979 due to a shortage of surfacing chippings. The control Section A was constructed and surfaced in October 1979 and Section D only in March 1980. No traffic was permitted on the sand-asphalt bases before surfacing, but cattle damaged the primed surface on Sections 7–12. After three months under traffic the sections were closed and reopened to traffic on the 28 March 1980 when the road to Jwaneng was completed.

6. MAINTENANCE

In June 1981 the shoulders were regravelled with a ferruginised, weathered granite gravel over Sections 1–12, 15–17 and 20 and the side slopes flattened from 1 in 4 to 1 in 6 due to severe rainfall erosion of the unsatisfactory calcified sand shoulders and the bare sand sideslopes. In 1983 the shoulders of Sections 13, 14, 18 and 19 were regravelled.

Distress, mostly in the transition zones between the sections, was apparent on most of the sand-asphalt sections soon after opening to traffic and most required some patching.

Sections A and D received a fog spray in July 1984, all sections were resealed with 10 mm chips and crusher dust in 1984, whilst Sections A and D received a slurry seal in 1990.

7. TRAFFIC

Details of the traffic history of the experiment have been provided by Lionjanga et al (1987) and Greening and Rolt (2014). The cumulative ME80 using a load equivalency exponent of 4,5 is shown in Figure 1 (courtesy Mr PAK Greening of TRL).

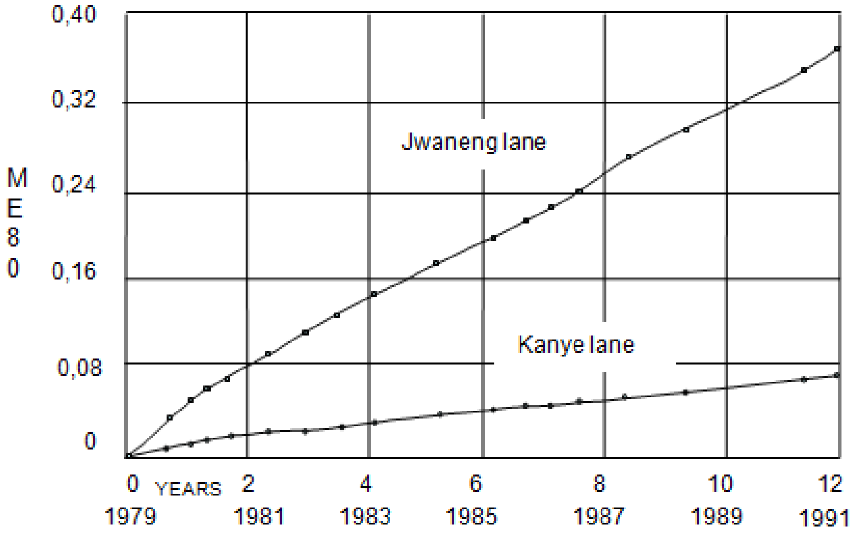

Figure 1: Cumulative axle loads (courtesy PAK Greening)

Although the conventional damage exponent of 4,5 has been used, a comparison of the observed damage (rut depths) showed that the actual exponent was about 2,5 for all the calcrete sections (Greening and Rolt, 2014) Similar calculations have not been made for the sand-asphalt or the controls.

8. MONITORING

Visual inspections (Table 3) by a panel consisting of representatives of the BRD, TRL and NITRR (usually Dr F Netterberg) were held regularly until March 1993, supplemented by stringline and 2 m-long straight edge and 20 mm-wide wedge rut depth measurements.

Table 3: Jwaneng panel overall pavement condition ratings compared with TMH9:1992 [1]

Degree	Description (Panel) [2]	Description (TMH9: 1992)
Very good	No distress: Nearly perfect, no cracks or deformation. Ruts ≤ 10 mm, normally ≤ 6mm	Very few or no defects. Degree of defects <3 < warning
Good	Minor distress: Only "sound" TRH12 ratings, no significant defects, i.e. ≤ Degree 2 (TRH6). Ruts ≤ 10 mm	Few defects. Degree of structural defects mostly < warning
Fair	Significant distress : Generally not severe, but ruts can be 10 – 20 mm	Few defects and seldom severe. Extent only local if degree is severe (excluding surfacing defects)
Poor	Considerable distress : Severe deformation, patching or rutting, or warning PSI. Ruts can be > 20 mm but no shears. (Ruts max. 30 mm added 1992-03-03)	General occurrence of particularly structural defects with degrees warning to severe
Very poor	Failed: Severe deformation, patching, rutting and/or PSI. One or more serious types of defects ≥ Degree 4. However, rutting alone not required	Many defects. Degree of majority of structural defects severe and extent predominantly general to extensive

Notes:
[1] Ratings are averages for the central 50 m of the section. [2] In general agreement with threefold TRL system (Kennedy and Lister, 1978). See TRH6:1985: & TRH12:1984 for details, and use appropriate percentiles for ruts and TRH12 for extent

More comprehensive monitoring including rut depth, riding quality and deflection using the TRL transient deflection method with a 62 kN axle load (80 kN is now usual) and 590 kPa tyre pressure (Smith and Jones, 1980) were also carried out and, in the initial unavailability of a vehicle-mounted system, smoothness using a TRL rolling straight edge (Young, 1979). One falling weight deflectometer (FWD) survey was carried out in September 1990. The control sections were unfortunately not measured.

Ad-hoc investigations of failures or distress were also carried out as necessary by all parties, and these reports have been freely drawn upon in this paper.

9. RESULTS

The results of the first condition survey made within six months of construction showed that most of the sections were considerably more uneven both longitudinally and transversely towards their construction joints (not shown). Only data representative of the middle 50 m of each 100 m section were therefore considered in an attempt to eliminate the effects of the much rougher transition zones between the sections. However, even this central section was unacceptably rough on Sections A, 18–20 and 23, and was presumed to have mostly been built-in.

The survey also showed that by early 1980 after only about 0,07 ME80, the sand-asphalt Sections 1, 7, 8, 10, 11 and the calcrete Section 17 had all developed ruts of 10 – 15 mm, rather more than the 3–5 mm bedding-down expected as in the others, and the zero on the control Section A. Because of this and other distress the sand-asphalt Sections 10 and 11 and the calcrete Section 17 were already only rated as in a fair condition and by May 1982 Sections 1 and 10 were considered as failed.

Table 4: Mean condition of central 50 m of each section in June 1986 after about 8 years and about 0,22 ME80 in Jwaneng- bound lane [1]

←To Kanye Jwaneng→

Section			A	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	B	C	D
Parameter	Base		Nat. gravel	Wet mix sand-asphalt						Foamed sand- asphalt						Powder calcrete		Calcified sand			Nodular calcrete				Hardpan calcrete		Crushed gravel		
	Lane/position [2]			RC-250	35/40 RTH		30/ 35H PVC	35/40 RTL	RC-250	60/70 pen. bitumen			55/60 RTH tar					Nat.	+ 3 %		1:1	Natural							
																			cem.	lime	sand			[3]	[3]				
Deflection (31 kN) [4] (*n* = 3 or 5) (mm x 10^{-2})	Kanye	Inner	35	73	54	28	28	39	35	45	39	46	39	42	40	51	64	88	55	84	31	29	24	21	42	32	27	32	29
		Outer	33	46	33	29	30	33	37	32	37	34	37	44	39	64	59	41	81	84	19	27	24	23	43	36	31	24	32
	Jwaneng	Inner	43	63	55	32	31	42	29	38	43	42	46	52	49	46	51	79	87	71	46	37	29	26	40	41	26	31	30
		Outer	40	43	27	26	27	35	43	26	33	28	34	41	39	54	53	39	79	80	24	28	26	25	52	35	24	33	32
Cross-section deviations (*n* = 5) (3 m str. [5] edge) (mm)	Kanye	Inner	5	6	6	5	6	2	4	8	9	11	9	16	11	9	9	10	9	7	3	5	5	6	8	7	6	4	5
		Midlane	2	3	0	1	1	0	1	3	1	1	2	0	3	2	1	3	2	4	3	9	7	4	0	5	0	1	2
		Outer	7	9	5	3	2	2	4	4	7	14	11	7	9	5	10	9	7	13	9	5	6	3	3	5	6	6	7
	Jwaneng	Inner	17	5	8	4	12	10	8	12	19	16	8	13	11	10	10	10	11	9	12	17	9	9	11	6	5	4	6
		Midlane	2	4	2	2	0	0	3	1	0	0	7*	1	5	0	1	3	2	3	1	2	2	2	1	6	2	4	4
		Outer	4	4	1	4	4	2	4	4	9	26	21*	13	11	3	10	11	12	15	21	6	7	5	2	7	6	5	5
Smoothness (rolling straight edge) [6] (No. of deviations >6 & 10 mm)	Kanye outer	> 6mm	4	10	0	2	0	3	2	7	3	3	0	3	1	6	3	6	2	6	14	10	16	6	4	14	3	0	4
		> 10 m	1	4	0	0	0	1	0	2	0	0	0	0	0	0	1	1	0	0	2	1	2	0	0	2	0	0	0
	Jwaneng outer	> 6mm	1	7	2	2	0	1	8	1	2	0	7	12	2	0	0	2	3	5	12	17	18	5	0	15	2	2	2
		> 10 m	0	3	0	0	0	0	4	0	0	0	5	6	1	0	0	0	0	0	1	2	2	0	0	3	0	0	0
Rut depth [7] (*n* = 5) (mm)	Kanye	Outer	5	7	3	2	1	2	2	2	4	14	10	6	11	2	6	5	7	9	7	4	6	1	1	4	3	5	7
	Jwaneng	Outer	4	7	2	3	4	5	2	4	9	18	25	19	12	4	11	9	12	17	22	6	5	3	1	4	5	7	5
Riding quality (LDI) (*n* = 3) [8]	Kanye	QI	17	38	20	26	15	20	20	32	28	25	29	34	26	22	17	25	17	24	35	35	31	17	17	32	20	24	16
		PSI	3,7	2,6	3,5	3,2	3,9	3,5	3,5	2,9	3,1	3,3	3,0	2,8	3,2	3,4	3,7	3,4	3,7	3,3	2,7	2,7	3,0	3,7	3,7	2,9	3,5	3,3	3,8
	Jwaneng	QI	25	28	22	28	24	19	25	29	28	31	34	64	32	19	16	26	19	26	27	31	44	19	17	32	17	16	17
		PSI	3,3	3,1	3,4	3,1	3,3	3,6	3,3	3,0	3,1	3,0	2,8	1,7	2,9	3,6	3,8	3,2	3,6	3,2	3,1	3,0	2,4	3,6	3,7	2,9	3,7	3,8	3,7
General pavement condition [9]	Kanye	Lane	VG	V P	G	F	VG	VG	F	VG	VG	F	F	F	G	VG	G	G	VG	G	G	VG	G	VG	G	VG	F	VG	VG
	Jwaneng	Lane	VG	F	G	F	VG	VG	P	G	F	F	P	P	F	VG	G	F	F	F	P	VG	G	VG	G	VG	F	VG	VG

Notes:

[1] Kanye-bound lane cumulative 0,04 ME80

[2] Inner = wheelpath nearer centreline, outer = wheelpath nearer shoulder

[3] Reconstructed and sealed in 1981

[4] Deflections at three points on Sections A, B-D and 1-12, and five on Sections 13-23, not corrected for temperature

[5] One end of 3 m straight edge placed on centreline and held down when necessary; max. dev. in inner, midlane and approx. outer wheelpath, * = Patch

[6] Continuous over central 50m, outer wheelpath taken as 0,8 m from edge of chippings

[7] Stringline and wedge, *n* = 5

[8] Mean of three runs in each direction at 80 km/h

[9] Panel method

Mean assessment criteria used for BRDM Category II / TRH4 C road (adapted from references shown)

Measurement	Units	Base	Sound	Warning	Severe	Ref. [1]
Deflection (31 kN) [2]	mm x 10^{-2}	BTB	< 40	40–80	> 80	(1,2)
		Gravel	< 50	50–100	>100	(1,2)
Cross-section devs [3]	mm	Gravel	≤10	-	-	(3)
Smoothness (per 50m) [4]	No. ≥ 6mm	Gravel	<10	10 – 20	> 20	-
	No. > 10mm	Gravel	< 5	5 – 15	> 15	-
Rut depth [5]	mm	-	< 10	10 –20	> 20	(1)
	mm	-	< 15	15 – 25	> 25	(2)
Riding quality [6]	PSI	Cat. C	> 2,0	2,0–1,5	< 1,5	(1)
Visual condition [7]	Rating	-	VG, G	Fair	P, VP	(1)

Notes

[1] References (1) TRH12:1997. (2) Roads Dept (2000). (3) COLTO (1998, Clause 3405).

[2] 0,78 x 40 kN limits in refs; usually a percentile, but mean here. [3] For new construction, 3 m straight edge, one end on centreline. [4] In-service (this paper). [5] 2m Straight edge, one end on seal edge; usually a percentile, but mean here. [6] Equivalent to IRI limits in refs 1 and 2. [7] Panel method

The riding quality in 1986 (Table 4), as measured by a vehicle-mounted linear displacement integrator (LDI) (Visser and Curtayne, 1982) and presented as a Quarter Car Index (QI) and the South African Present Serviceability Index (PSI) of mostly 20–35 and 3,5–2,7 respectively, were all sound for a TRH12: 1997 Category C (PSI) > 2,0), or Botswana Category II road with only the Jwaneng lane of Section 11 with a PSI of 1,7 in a warning condition. (Other methods were also used but are not presented here.)

The pavement condition in 1986, 1989 and as at the final inspection in 1993 after 13 years under traffic and about 0,4 ME80 in the Jwaneng lane and 0,1 ME80 in the Kanye lane together with the FWD base layer index (BLI) and rut depths are shown in Table 5.

Table 5: Summary of visual condition in 1986, 1989 and 1993 and inspection panel maintenance recommendations in 1993 after 13 years

Sect.	Jwaneng Lane								Kanye Lane					
	FWD 0,33 ME80 In 11 y [2]		Rut Depth OWP 0,36 M in 12 y [4] (80 %) mm	General Pavement Condition after ME80 in years [5, 6]				Minimum Maintenance Recommended by Panel in March 1993 after 13 years		General Pavement Condition after ME80 in years [5, 6]				Rut Depth OWP 0,08M In 12 y [4] (80 %) mm
[1]	BLI mean µm	Condn mean [3]		Panel			TMH9			Panel			TMH9	
				0,22	0,30	0,40	0,40			0,04	0,06	0,09	0,09	
No.				6	9	13	13			6	9	13	13	
A	**-**	**-**	**6**	**VG**	**G**	**G**	**VG**	**None**	**None**	**VG**	**G**	**G**	**VG**	**8**
1	740	Severe	18	F	P	VP	VP	Patch, reseal	Reseal	VP	F	VP	VP	14
2	510	Severe	6	G	G	F	F	Reseal	Reseal	G	G	F	F	6
3	370	Warn	14	F	G	F	F	Reseal	Reseal	F	G	F	F	5
4	300	Warn	10	VG	G	F	G	Fog	Fog	VG	G	F	G	5
5	310	Warn	10	VG	F	F	G	Fog	Fog	VG	G	F	G	8
6	430	Severe	10	P	P	P	F	Patch, reseal	Patch, reseal	F	G	P	P	21
7	420	Severe	25	G	F	P	P	Fill rut, reseal	Fill rut, reseal	VG	G	P	P	24
8	340	Warn	33	F	P	VP	VP	Fill rut, reseal	Fill rut, reseal	VG	F	P	P	26
9	380	Warn	48	F	P	VP	VP	Fill rut, reseal	Fill rut, reseal	F	F	VP	P	38
10	370	Warn	53	P	P	VP	VP	Fill rut, reseal	Fill rut, reseal	F	F	P	P	27
11	340	Warn	40	P	P	VP	VP	Fill rut, reseal	Fill rut, reseal	F	F	P	P	23
12	420	Severe	31	F	F	VP	P	Fill rut, reseal	Fill rut, reseal	G	G	P	P	27
13	670	Severe	11	VG	VG	F	G	Slurry	Slurry	VG	G	F	F	12
14	720	Severe	33	G	F	VP	P	Fill rut, slurry	Slurry	G	G	F	G	13
15	880	Severe	19	F	P	P	F	Fill rut, slurry	Slurry	G	VG	F	G	13
16	750	Severe	29	F	P	VP	P	Fill rut, slurry	Slurry	VG	F	F	F	16
17	720	Severe	32	F	P	VP	P	Fill rut, slurry	Fill rut, slurry	G	F	P	F	22
18	470	Severe	47	P	P	VP	VP	Fill rut, slurry	Fill rut, slurry	G	P	P	F	23
19	470	Severe	20	VG	F	P	F	Fill rut, slurry	Slurry	VG	F	F	G	13
20	290	Warn	11	G	F	F	G	Slurry	Slurry	G	F	F	G	10
21 A	250	Warn	5	VG	VG	F	G	Patch, slurry	Patch, slurry	VG	VG	G	VG	7
21 B	230	Warn		VG	VG	F	F	Patch, slurry	Patch, slurry	VG	G	F	F	
22 A	650	Severe	7	G	G	F	F	Patch, slurry	Patch, slurry	G	G	F	F	6
22 B	490	Severe		G	G	F	F	Patch, slurry	Patch, slurry	G	G	F	F	
23	510	Severe	13	VG	F	F	G	Fog	Fog	VG	VG	VG	VG	8
B	-	-	10	F	G	F	G	Reseal	Reseal	F	G	VG	VG	7
C	-	-	8	VG	F	F	G	None or reseal	None	VG	G	VG	VG	8
D	**-**	**-**	**8**	**VG**	**VG**	**G**	**VG**	**None**	**None**	**VG**	**VG**	**VG**	**VG**	**8**

Notes:

[1] Sections 1 – 12 sand-asphalt, 13 – 23 calcrete: 21 & 22 initially unsealed, reconstructed in 1981 and sealed : 21A : 13 mm calcrete single seal, without fog, 21B and 22A : 10 mm red granite single; 22B 9,5 mm quartzite plus sand. A & D gravel controls. B Kalahari sand seal & C single 9,5 mm quartzite seal on gravel bases. [2] In Sept. 1990, normalised to 40 kN, mean of 3 points at 25, 50 and 75 m except for Sections 21 and 22 (mean of points at 13, 25 and 38 m for A and 63, 75 and 88 m for B). [3] Severe >400 µm, Warning 200-400 µm for both granular and bitumen-treated bases (Horak, 2008). [4] Over central 50 m in Oct. 1991 *n* = 21; t-distribution assumed for 80%-ile. [5] Best average over central 50 m of section except for Sections 21 and 22 seal expts (13–38 & 63–88 m). Mostly structural condition assessed from visuals and rut depths. Panel and TMH 9:1992 methods: VG = Very good, G = good, F = fair, P = poor, VP = very poor. [6] In June 1986, Feb. 1989, March 1993

Ratings in 1993 according to both the panel and TMH9:1992 methods are shown. Those according to the panel criteria were usually slightly more severe than those by TMH9.

Distress in the form of rippling and shoving of the surfacing, depressions and/or rutting and even shear failures up to 15 mm in depth were noticed on most of the sand-asphalts, although most of these were in the construction transition zones,

Most of the calcrete sections were in a better condition although by 1986 the sand-stabilized nodular calcrete Section 18 had developed a mean rut depth of 22 mm in the Jwaneng lane which had deepened to a dangerous 80%-ile of 47 mm after 0,4 ME80.

The cement- and lime-stabilized calcified sand Sections 16 and 17 failed to develop the expected strengths during the six months before sealing and had also developed mean rut depths of 12 and 17 mm respectively (Table 4) with maxima of 16 and 24 mm (not shown), in comparison with a mean of 9 mm for the adjacent Section 15 of similar untreated material. By 1991 the rutting had deepened to an 80%-ile of 29 and 32 mm, respectively.

Field testing in 1982 by the phenolphthalein method (Netterberg, 1984) indicated that both sections were completely carbonated and confirmed by the high gaseous $C0_2$ contents found, which were greater than atmospheric and indicative of untreated material.

10. DISCUSSION

10.1 Sand-asphalts

Only Sections 4 (5,2% PVC tar) and 5 (5,0% RTL 35/40) gave a good performance comparable with the calcrete Sections 13 (CBR 60, PI 10 powder calcrete), 20 (CBR 85, PI 23 nodular) and 23 (CBR 80, PI 9 hardpan) and only inferior to the gravel control sections A and D, and probably could have carried up to about 1,0 ME80 in 20 years.

Sections 2 (5,2% RTH 35 / 40 on a plastic calcified sand subbase), and 3 (5,2% RTH 35/ 40) on a sand subbase) gave a fairly good performance and should have exceeded 0,5 ME80. Section 6 (3,6% RC-250 on a sand subbase) also gave a fairly good performance in the more heavily trafficked Jwaneng lane but exhibited terminal rutting of 21 mm in the Kanye lane, possibly because of a lower binder content and/or lower density in this lane.

The performance of the foamed asphalts (Sections 7 – 12) was generally inferior to that of the cold wet-mixed sections and most of them failed in terms of a terminal rut depth of 20 mm at about 0,1 – 0,2 ME80.

Agreement between either one of the 9- or- 13 year visual condition ratings (strongly influenced by rut depth) and those according to the BLI (Horak, 2008) at 11 years shown in Table 5 was fair, with agreement in 7 of the 12 cases (58 %) Disagreement included Sections 8 – 11 with poor or very poor visual ratings and rut depths of 33 – 53 mm but only a warning BLI of 340 – 380 µm, whereas the two best Sections 4 and 5, both with a rut depth of only 10 mm and rated fair or good also had a (slightly better) warning rating. However, if allowance in made for likely optimistic results at the end of the dry season, then the warning ratings for Sections 8 -11 might be correct.

The causes of the premature distress of the sand-asphalts have been discussed by Netterberg and Pinard (This Conf.) and were mostly construction defects**.** In all cases the distress appeared to be confined to the base course and should be preventable by the application of modern guidelines such as those of the Asphalt Academy (2009).

10.2 Calcretes

Apart from some shear failures at 0,22 ME80 in the outer wheelpath of the weakest section (15: CBR 23, GM 1,1; PI 20 calcified sand) during the 1987/1988 rainy season due to poor shoulder drainage, premature distress of the calcretes was largely limited to the unexpectedly poorer performance of the stabilized sections in comparison to their unstabilized counterparts. In all cases the rutting was confined to the base course.

The lack of strength development of the cement- and lime- treated sections, in spite of good laboratory strengths having been achieved at both 7 and 28 days on road samples taken after mixing and their total carbonation within three years of construction was a surprise. Subsequent work (summarised by Netterberg, 1991) showed that carbonation usually proceeds downwards on exposed surfaces at the rate of 0,5 – 2 mm / day whether or not the layer is primed and upwards from below in service at 2 – 50 mm / year, and lose on average about half of their strength. At 1 mm/day, as also found on lime- stabilized unconfined compressive strength specimens of this calcrete (Motswagole, 1994), the unfortunate six months of exposure were probably sufficient to account for all or most of the carbonation-induced loss of strength and the subsequent upward carbonation could have accounted for the rest. The excessive time taken for mixing and compaction would have lowered both the MDDs and field densities obtainable. Although 97% compaction was achieved (Table 1), this was off low MDDs and their low field densities would also have made them more susceptible to carbonation and subsequent rutting.

Laboratory work on calcrete from this experiment showed mellowing, delay between compaction and sealing, and carbonation to be highly detrimental to strength development, that these effects were additive, and that exposure to air for even two hours appeared to stop the lime-soil reaction (Motswagole, 1994).

It is now known that it is essential to seal a cement- or lime- stabilized material – especially when the raw material is of such low quality as this – from the air as soon as possible in order to minimise downward carbonation.

The mechanically stabilized 1:1 nodular calcrete:sand Section 18 was also not a success. Although the addition of the fine sand had lowered the PI from the 27 of the untreated material to 12 and increased the MDD from 1 960 to 2 058 kg/m^3, it had also lowered the GM from 2,1 to 1,6 and the CBR from 85 to 48, and possibly lowered the $CaCO_3$ content of the P425 to below the 10% (Netterberg, 1971) thought necessary for a calcrete.

Agreement between the visual condition ratings and those according to the BLI was better in the case of the calcretes, with agreement in 9 out of the 13 cases (69%). Disagreement was greatest in the case of four of the five best sections (13, 22A, 22B and 23) with fair to very good ratings and rut depths of 7 – 13 mm which were all rated as severe in terms of the BLI ratings. Also, although both Sections 12 and 13 were rated as severe according to both their BLI and maximum deflections (D_O, not shown), the actual BLI on the poor sand-asphalt Section 12 with a rut depth of 31 mm was lower than that on the far better adjacent calcrete Section 13.

Whilst some of this disagreement might be attributable to the deflection survey having being carried out in late September at the end of the dry season and further analysis is warranted, too much must not be expected from such surveys (Horak, 2008).

The performance of these calcretes in a dry environment is best understood in terms of soil suction and fabric (Toll, 1991, Toll et al, 1991), in particular the advantage of the high fines of the powder calcrete when unsaturated and the dilatency of the hardpan when saturated.

10.3 Value of sealed shoulders

Shear failures and rutting on some calcrete sections during the summer rainy season indicated that sealing the shoulders would be advantageous. Although a comparison of the September 1990 FWD results in the outer wheelpath and the midlane (i.e. about 1,7 m from the seal edge) – at the end of the dry season – only suggested an average additional capacity of about 0,05 ME80 for the sand-asphalts and 0,10 ME80 for the calcretes, this varied considerably from section to section. For example, an increase in capacity from 0,6 to 1,6 ME80 for the sand-asphalt Section 4 and from 0,25 to 2,5 ME80 for the calcrete Section 18 is predicted if a 1,0m-wide sealed shoulder were to be provided.

Sealed shoulders were recommended for the calcretes by Greening and Rolt (2014) on both performance and economic grounds and also in general by SADC (2003).

11. DERIVED KALAHARI SAND-ASPHALT AND CALCRETE BASE COURSE DESIGNS

11.1 Sand-asphalts

Table 6 shows the base course designs using the vane shear method for a TRH4 Category C or BRDM Category II road with an expected terminal 80%-ile rut depth of 20 (TRH4) or 25 (Roads Dept, 2000) mm or a total area of 20% of patching and severe distress and a TRH4 Category D road in a dry environment with a rut depth of 30 mm or 50% of patching and severe distress derived from the experiment (Netterberg and Pinard, This Conf.). They are neither a criticism of a particular binder nor of the process used, but simply what could be derived from the results available, which were complicated by construction defects. However, they appear compatible with designs for a BSM3 material on a >15 foundation CBR for up to 0,3 and 1,0 ME80 in the Asphalt Academy (2009) guide.

Table 6: Derived Kalahari sand-asphalt designs

Cumulative Max. ME80 / lane Distress [1]		**Thick-ness**	**In-Situ 7-day Vane Shear Strength @ 40°C**		**Represented by**		
					Section	**Binder [2]**	
			Min.	Mean			
20 %	50 %	mm	kPa	kPa	No.	Type	%
0,1	0,2	50	100	200	10, 11 9	RTH 55/60 60/70 pen.	4,9; 4,1 4,1
0,2	0,3	75	150	200	8, 9 11	60/70 pen. RTH 55/60	3,5 4,1
		100	250	300	7, 8	60/70 pen.	3,9; 3,0
		150	150	200	12	RTH 55/60	4,6
		150	250	300	6, 1	RC-250	3,6; 3,4
0,5	0,7	150	250	300	3, 2	RTH 35/40	5,2; 5,2
0,6	0,8	150	250	300	5	RTL 35/40	5,0
0,8	1,0	150	250	300	4	RTH 30/35 PVC	5,0

Notes :

[1] Max. 80 %-ile rut depth 20 or 30 mm or 20 or 50 % total area of patching and severe distress in 20 years, respectively

[2] Residual binder (total binder less volatiles for cutbacks), min. 2,0 % actually attained for 0,1/0,2 and 0,2/0,3 classes

Sand to be treated and for untreated subbase and subgrade: AASHTO M145 class: A-2-4(0) with P075 10-20 %, PI NP-3.

Compaction: Min. 95 % MAASHO for sand-asphalt for all traffic classes

Compaction for subbase and lower layers for A-2-4(0) Kalahari sand (100% MAASHO for A-3 sand for fill and upper 0,5 m of roadbed) :

Traffic category (ME80) :	≤ 0,5	≥ 0,5
Minimum subbase compaction	93	95
Minimum subgrade & fill compaction	90	93
Minimum roadbed compaction	90% in top 0,5m	90% in top 0,5 m, 85% from 0,5-1,0m

Shoulders : Gravel or sealed sand-asphalt

11.2 Calcretes

Table 7 shows the specifications for Kalahari calcrete base course derived from the results of this experiment extrapolated to a maximum of 1,5 ME80 (Greening and Rolt, 2014). They permit even greater relaxations in grading and plasticity for calcretes than those proposed by Netterberg (1971, 1982) and Netterberg and Pinard (1991) provided that a reasonable soaked CBR is obtained. However, users of these should be aware that they were derived from the results of testing according to BS 1377:1975 which may yield results which differ significantly from others such as TMH1:1986 (Pinard and Netterberg, 2012). Users should also ensure that the material has been properly identified as a calcrete and also has a minimum $CaCO_3$ content of 12 % in the P425 (Lionjanga et al, 1987).

This minimum should also be applied if a calcrete is mechanically stabilized with fine sand and the soil constants still exceed those normally allowed (e.g. a PI of 6).

Table 7: Derived specifications for BRDM Category II / TRH4 Category C calcrete road bases (adapted from Greening and Rolt, 2014)

Maximum traffic (ME80)	0,3	0,5	0,7	1,0	1,5
Traffic category (ORN 31) [1]	**T1**	**-**	**T2**	**-**	**T3**
Max. particle size (mm)	75	75	75	75	75
Max. P425 [2] (%)	80	65	65	45	30
Max. P063 [3] (%)	30	30	25	20	15
Max. LL (%)	60	55	50	40	30
Max. PI (%)	25	20	15	12	10
Max. Bar LS (%)	12	12	8	6	5
Max. LS x P425	800	700	550	400	200
Max. LS x P063	300	300	300	200	100
Min. soaked CBR [4] (%)	40	50	60	60	80

Notes
[1] Overseas Road Note 31 (TRL, 1993). [2] P425 = percentage passing 425 μm sieve [3] P063 = percentage passing 063 μm sieve [4] At 100 % BS heavy compaction and using BS 1377 for all testing

11.3 Subbase

Both the sand-asphalt and the calcrete designs assume a very well compacted Kalahari sand subbase and lower layers. The September 1990 FWD survey yielded a mean sound (< 50 μm) lower layer index (LLI) of 41 μm and a warning (100 – 200 μm) middle layer index (MLI) of 158 μm for the whole experiment (not shown). Good drainage, seal and shoulder maintenance is also assumed – at these traffic levels more than half of the performance is due to the environment rather than the traffic (SADC, 2003).

12. RELATIVE COSTS

As the relative costs in the Kalahari of the designs evaluated are expected to be (from highest to lowest) crushed stone > sand-asphalt > lime- stabilized calcrete > cement-stabilized calcrete > unstabilized calcrete and are substantial, it is clear that substantial savings are possible by making the best use of untreated calcretes. For example, neglecting any effect of different test methods, on account of their high PI the 0,3 and 0,5 ME80 calcretes in Table 7 only classify as COLTO (1998) G10 materials and, according to TRH4:1996, are usable only as roadbed or subgrade – and also not as raw material for a cemented material. Similarly, the 0,7, 1,0 and 1,5 ME80 calcretes only classify as G5 and should only be usable as base course for a Category C road to carry up to 0,3 ME80 and a Category D road for 1,0 ME80.

The construction of an untreated calcrete base is also simpler and less expensive in that no binders, specialised equipment, construction time constraints, heating, curing, or aeration are necessary, and they can be compacted in one lift.

13. CONCLUSIONS

1. The experiment has shown that both pavements consisting of a double seal on either a Kalahari sand-asphalt or an untreated, inferior calcrete base course on a well-compacted Kalahari A-2-4(0) sand subbase and lower layers with a structural capacity of at least 1,0 ME80 are viable.
2. In general, the untreated calcrete sections performed better than the sand-asphalts and the cold wet-mix sections better than the foamed asphalt. However, the performance of most of the sand-asphalts and some of the calcretes was marred by construction defects.
3. The best sand-asphalts were those with 5,0% RTH 30/35 with 1,5% PVC, or 5,0% RTL 35/40, 140 mm thick, compacted to 95 – 96% MAASHO and with mean 7-day in-situ vane shear strengths of 300 kPa or more.
4. The best calcretes were a hardpan calcrete with a BSH CBR of 80 and PI of 9 compacted to 91% BSH, a nodular calcrete with a CBR of 85 and PI of 23 compacted to 98%, and a powder calcrete with a CBR of 60 and a PI of 10 compacted to only 85%, all about 150 mm thick.
5. The performance of the cement- and lime- stabilized calcified sand was worse than the similar material used untreated, probably due both to the excessive time taken for mixing and compaction, and the unfortunate delay before sealing, which led to complete carbonation of the layer.
6. Despite halving the PI, mechanical stabilization of a relatively good nodular calcrete gravel with fine sand was not a success, probably because it also halved the CBR and may also have reduced the fine $CaCO_3$ content below some critical value.
7. The greatest savings will be made in the location and use of untreated calcretes.
8. A well-compacted (at least 97% MAASHO) A-2-4(0) Kalahari sand can be used as subbase. The ease which this sand could be compacted indicates that 100% should be specified, at which a laboratory CBR of over 80 and in-situ DCP CBRs of 45 or more were obtained.

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