THE BIESIESVLEI LONG-TERM PLASTIC CALCRETE BASE EXPERIMENT: PERFORMANCE OVER 30 YEARS UNTIL FAILURE

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ABSTRACT

Calcretes are probably the most widely used road construction materials in southern Africa, rank second after dolerites in relative importance in South Africa and are often the only available materials in the vast area covered by Kalahari sands. After a back-analysis of some old calcrete-based roads in the Western and Eastern Cape in the 1960s indicated that substantial relaxations in plasticity, grading and even CBR might be possible, purpose-built LTPP experimental sections were constructed in Botswana, Namibia and South Africa in order to test this hypothesis. The performance of one of these – the Biesiesvlei plastic calcrete base experiment constructed in 1976 on the now N14-11 in the North West Province – until failure after 0,5 MESA in 30 years is described. Three simple specifications for a similar calcrete base for a Category C road in dry and borderline moderate macroclimatic regions for structural capacities of 0,3; 0,5 and 0,8 MESA were derived empirically from the comprehensive test and performance data collected. These all require a GM of 1,7 – 2,5 and, depending on capacity, a maximum PI of 16 – 14, a maximum LSM of 320 – 260, and a minimum 98% soaked CBR of 40 – 60.

1. INTRODUCTION

Calcretes in southern Africa usable in road construction occur mostly in areas receiving a mean annual rainfall of less than about 550 mm (Netterberg, 1971). In this arid to semiarid area comprising some two-thirds of southern Africa calcretes are by far the most widely used road material and – in the vast area covered by Kalahari sand – are usually the only sources of gravel. In the 1960s an evaluation of old, unstabilized, calcrete-based roads on the Cape Flats and in the Gqeberha (Port Elizabeth) area – on which there were no failures at that time – indicated that the traditional grading envelope requirements could be dispensed with and the grading modulus (GM) of a calcrete base to carry up to about 5 000 vehicles per day (vpd) [probably about 1 – 3 MESA] relaxed from the usual minimum of 2,0 to a minimum of 1,5 **and**, depending on traffic, the plasticity index (PI) could **also** be relaxed from the traditional maximum of 6, to 8 for up to 5 000 vpd and to as high as 15 for up to 500 vpd [probably about 0,2 MESA] (Netterberg, 1971, 1982). Moreover, the minimum CBR could **also** be relaxed to 60 for 500 vpd, but retained at the traditional minimum of 80 for higher traffic.

The Biesiesvlei long-term pavement performance (LTPP) experiment on the Coligny-Biesiesvlei road in the North West Province (NWP) was therefore constructed in 1976 order to test the light traffic (< 500 vpd) calcrete base course specification against similar material stabilized with cement – as it would then normally have been used. The typical calcrete natural gravel used was what would now mostly classify as of Committee of Land

Transport Officials (COLTO):1998 G5 – G6 quality, but with as-built PIs of up to 16, i.e. only a G7. The control sections were nominally the same material stabilized with 4% portland blast furnace cement (PBFC), assumed to have been equivalent to a COLTO:1996 (TRH4:1996), 1998 C3 material, both on a 2% PBFC stabilized calcrete subbase, assumed to have been a equivalent to a C4, as was used over much of the rest of the Coligny – Biesiesvlei road.

It is the purpose of this report only briefly to describe the layout, testing and performance over 30 years of the Biesiesvlei LTPP experiment and to derive empirical performance-related material quality specifications for an untreated calcrete base from them.

2. LOCATION AND LAYOUT

The 900 m-long Biesiesvlei calcrete base course experiment was located on the N14-11 (formerly R375/DR 433) about 32 km west of Coligny and 7,0 km east of its intersection with the R52/P34/3 at Biesiesvlei in the North West Province of South Africa (Table 1).

Table 1: Experimental layout and summary of as-built material test results [1]

← **Coligny (RHS)**	7,4 m-Wide double seal with prime		**Biesiesvlei (LHS)** →
Section no..	1 (Control)	2 (Test)	3 (Control)
150 mm Calcrete [2] Comp. (% MAASHO) PI/GM/CBR @ 98 (1976/7) (1993) COLTO **calcrete** classif.	C3 (4 %PBFC) - - NP – **11** / 2,0 – 2,2 / 52;67 (C3)	G6 92 – 103 8 – 12 / 1,9 – 2,4 / (160) [3] 8 – 16 / 1,7 – 2,4 / 46 – 78 **G6 – G8**	C3 (4 % PBFC) 100 NP /2,4 / – NP – **7** / 1,6 – 2,7 / 77 (C3)
125mm Calcrete [2] PI/GM (1993) COLTO classification	C4 (2 % PBFC) SP – **14** / 1,7 – 2,2 (C4)	C4 (2 % PBFC) NP – **11** / 1,8 – 1,9 (C4)	C4 (2 % PBFC) NP – **11** / 1,8 – 2,2 (C4)
150mm R Br soil PI/GM (1993) COLTO classification	G7 12 – 13 / 1,7 (G6 – G7)	G7 10 – 14 / 1,7 – 1,8 (G6 – G7)	G7 9 / 1,6 – 1,7 (G6)

SV (km + m)	14+200	14+500	14+800	15+100
NWP Log (km)	29,557	29,857	30,157	0,457
Sanral Log (km)	26,542	26,242	25,942	25,642
Lat. ºS	26,38006			26,37775
Long. ºE	28,97297			25,96433
Altitude	1444,4 m			1442,6 m

Notes:
[1] Test results on disturbed samples outside the wheelpaths and year taken.
[2] In 1993 the calcrete was found to be a mixture of calcrete and some weathered andesite.
[3] CBR probably too high because all oversize crushed in.
[4] Roadbed: Brown clayey sand (assumed G8 – G9) under 0,3 – 0,5 m G7 Kalahari sand

Unless stated otherwise, the **calcrete** COLTO:1998 classification is used throughout this paper for all untreated calcrete. This classification allows certain relaxations based upon the author’s earlier work (Netterberg, 1971, 1982). The draft Committee of Transport Officials (COTO): October 2020 classification is only considered later.

3. CLIMATE

The macroclimatic classification for TRH4:1996 pavement design purposes is 'moderate' (borderline dry). The mean annual rainfall at Biesiesvlei village is 570 mm, with a standard deviation (SD) of 150 mm. Because the site lies at approximately the wet limit of the occurrence of calcrete usable in road construction, the results of the experiment should be conservatively applicable to calcretes anywhere in southern Africa.

4. PHYSIOGRAPHY, SOILS AND DRAINAGE

The topography of the area is flat with only about a 1º fall towards Biesiesvlei in the west.

The roadbed was both potentially collapsing at a shallow depth and potentially expansive below, as well as possessing a perched water table. From the point of view of experimental design the roadbed was therefore not unusually favourable. According to local information the permanent water table in the vicinity of the road is at a depth of about 12 m and does not vary greatly. With a culvert at the Coligny end and a fall of only about 100 mm in 300 m on Section 1, 1,1 m on Section 2 and 600 mm on Section 3, the drainage of Section 1 was considered to be the worst of the three sections. With the centreline about 1,0 m above the natural ground level and an invert level varying between about 0,5 and 1,3 m below the centreline the wide side drains were assessed as adequate, although with a thick grass cover and almost no fall water stood in there at times, especially along the side of the Coligny-bound lane. The roadbed moisture conditions were therefore average or even poor. By 1998 the road surface drainage was in a **warning** condition according to TMH9:1992 visual criteria due to the lack of shoulder maintenance.

5. GEOMETRIC ALIGNMENT AND CROSS-SECTION

All three sections were straight and practically horizontal with a fall of 1,8 m over the 900 m (i.e. 0,2 %) towards Biesiesvlei. The road consisted of a 7,4 m-wide seal without yellow edge-lining, with 2,7 m-wide calcrete gravel shoulders. The same coarse-grained, plastic, calcrete gravel used for the base course of Section 2 was used for the unsealed shoulders of all three sections. Both these and the side slopes became thickly covered with wild grass with time. The side slopes were wide, with a distance of about 12 – 14 m from the edges of the seal to the drain inverts. All three sections were supposedly on a new alignment to the right (i.e. north) of the old gravel road. A double crossfall of 2 % was probably intended on the surfacing but according to the Dynatest survey carried out in December 2006 after the Sanral patching the average crossfall was only 1,1% on both lanes on all three sections.

6. PAVEMENT DESIGN

The road was designed as a Class II two-lane road for what was regarded at that time as medium traffic of 30 – 150 hv/d at construction (Transvaal Roads Department (TRD), 1973). A natural gravel base was then only permitted for up to 30 hv/d but for 0,2 – 0,4 MESA lane in 1977 (TRD, 1978). In both cases it was required to possess a minimum 98% MAASHO CBR of 80, a minimum GM of 2,0, a maximum PI of 6, and to be compacted to at least 98% MAASHO. Such roads had a design life of 15 – 20 years and a traffic growth rate of 6% was generally assumed. The design philosophy was not that no local failure should occur over the structural design period, but that there should be a high degree of certainty that no structural rehabilitation would be required over this period (TRD, 1978).

In TRH4:1996 terms the road would have been a Category C surfaced rural secondary road with a structural design life of about 20 years and an analysis period of 30 years.

7. MATERIALS

On the base and subbase borrow pit design sheet the material was described as a white, nodular calcrete about 0,9 m thick overlying very hard, unpickable calcrete. On the basis of three samples only, this material had the properties shown in Table 2, i.e. a GM of 2,07 – 2,46, a PI of NP – 13, and a CBR @ 98% MAASHO of 50 – 140. With 4% cement the sample with a GM of 2,07 and a PI of 13 yielded a UCS at 97% MAASHO of 1,8 MPa and was slightly plastic (SP). The nonplastic (NP) sample with a GM of 2,52 yielded a UCS of 3,0 MPa. Only material which could be obtained by bulldozing with nominal ripping was used.

Table 2 also shows all the other test results on the base course taken during and from soon after construction up to 1993 in comparison with the specification to be evaluated, i.e. that of Netterberg (1971, 1982) for a calcrete base course to carry < 500 vpd (< 20% > 3 tons) at the end of its structural life. Also shown is the TRH4:1978 specification for a G4 base and the TRD (1973) specification of the time for a gravel base. A G4 was the lowest quality material permitted for use as base course at that time (TRH4:1978 and 1985), although a relaxation of the PI to 15 in the case of calcretes “appears permissible” (TRH:1970). According to TRH4:1996, a 125 mm – thick G5 base can be used in both dry and wet regions under a double seal for a Category C road for up to 0,3 MESA and a Category D road for up to I MESA. In 1973 the TRD only permitted a 150 mm gravel base to this specification to be used for less than an initial AADTT of 30.

Also shown is a preliminary specification for a calcrete base course derived from these results which should be adequate for at least 0,2 MESA at about which time (1993) both lanes of Section 2 were still in a TMH9:1992 **very good** overall condition and actually better than Sections 1 and 3, which were mostly only rated as fair due to stabilization cracking.

As special testing failed to show any potential for self-stabilization the results of this LTPP experiment should therefore be conservative as far as the material properties are concerned.

The calcrete was found to be largely composed of silica in the form of quartz, and Ca, Mg and carbonate in the form of mostly calcite with a small amount of dolomite, with palygorskite as the dominant clay mineral and was therefore not unusual among calcretes. The $CaCO_3$ content of the P425 fraction was also well in excess of the minimum of 5% CO_2 (10% $CaCO_3$) (Netterberg, 1971) thought necessary for a material to behave as a calcrete.

Table 2: Comparison of Netterberg (1971a) calcrete base and general TRH4:1978 and TRD (1973) specifications with borrow pit and as-built material test results for Section 2 unstabilized calcrete base course

Source / Date	Nomin-al Max. Size [1]	GM	P 425	LL [2]	PI [2]	LS	EC	CLASSIFICATION AASHTO M 145 – 95 [3] Classif.	GI	COLTO (1998) Calcrete [4]	LSM [5]	CBR @ % MAASHO 98 % 2,54 mm	98 % 5,08 mm	95 % 2,54 mm	Swell @ 100 % MAASHO	In-situ Compact ion MAASHO	MAASHO MDD	OWC	Remarks NITRR Sample No. / Position [6]
Units	mm	-	%	%	%	%	S/m	-	-	-	-	%	%	%	%	%	kg/m^3	%	m
Spec.																			
Netterberg (1971) calcrete	37,5	≥1,5	15-55	≤40	≤15	≤6,0	≤0,15	A-2-6 (worst)	0 [15]	-	≤320	≥60	≥80	-	≤0,5	≥98	-	-	End AADTT <100
TRH4:1978 All G4	63	(2,0 - 2,7) [14]	-	≤25	≤6	≤3	-	-	-	All G4	-	≥80	-	-	≤0,2	≥98	-	-	≤0,1 MESA [15]
TRD (1973)	63,0	≥2,0	-	-	≤6	-	-	-	-	-	-	≥80	-	-	-	≥98	-	-	<30 Initial AADTT
Results [7]																			
Borrow Pit No. 7	100 100	2,07 2,52	30 15	- -	13 NP	- -	- -	A-2-6 A-1-a	0 0	G6 G5	- -	70 50	- -	28 48	- -	- -	- -	- -	Consultant results
[8]	75,0	2,46	18	38	2	4,5	-	A-1-a	0	G6	177	140	-	65	-	-	1885	12,8	4487
After dumping on road (Aug. 1976) [9]	53,0	2,26	25	43	12	6,5	-	A-2-7	0	(G7)	163	-	-	-	-	-	-	-	6340
	75,0	2,36	21	42	13	6,5	-	A-2-7	0	(G7)	137	-	-	-	-	-	-	-	6341
	75,0	2,37	20	42	12	5,5	-	A-2-7	0	(G6)	110	-	-	-	-	-	-	-	6342
	75,0	2,35	22	40	15	6,5	-	A-2-6	0	(G7)	143	-	-	-	-	-	-	-	6343
	53,0	2,31	23	40	16	6,5	-	A-2-6	0	(G7)	150	-	-	-	-	-	-	-	6344
	63,0	2,43	18	45	14	6,5	-	A-2-7	0	(G7)	117	-	-	-	-	-	-	-	6345
	75,0	2,26	25	42	11	4,5	-	A-2-7	0	(G6)	113	-	-	-	-	-	-	-	6346
	75,0	2,35	22	42	13	6,0	-	A-2-7	0	(G6)	132	-	-	-	-	-	-	-	6347
Min.	53,0	2,26	18	40	11	4,5	-	A-2-6	0	G6	110	100	103	74	0,0	-	1811	14,5	1 no.com-bined CBR
Max.	75,0	2,43	25	45	16	6,5	-	A-2-7	0	(G7)	163								
After compaction (1976) [10]	75,0 100 75,0	2,42 2,29 2,13	17 23 28	38 38 39	8 12 9	3,5 6,5 5,5	0,05 0,04 0,04	A-2-4 A-2-6 A-2-4	0 0 0	(G6) (G7) (G6)	60 150 154	- - -	- - -	- - -	- - -	- - -	- - -	- - -	6348(ch 0) 6349 (ch 150) 6350 (ch 300)
After 10 months (1977) [11]	37,5 37,5 37,5	1,93 2,16 2,13	38 38 38	37 39 38	9 8 11	4,5 4,0 4,0	- - -	A-2-4 A-2-4 A-2-6	0 0 0	G6 (G6) (G6)	171 152 152	160 - -	- - -	95 - -	0,13 - -	93,4 92,3 103,1	1750 1750 1750	13,5 13,5 13,5	50 150 200
Min.	37,5	1,93	17	37	8	3,5	0,04	A-2-4	0	G6	60	160	-	95	0,13	92,3	1750	13,5	0-1 yr after
Max.	100	2,42	38	39	12	6,5	0,05	A-2-6	0	(G7)	171	-	-	-	-	103,1	1750	13,5	compaction

Table 2: Comparison of Netterberg (1971a) calcrete base and general TRH4:1978 and TRD (1973) specifications with borrow pit and as-built material test results for Section 2 unstabilized calcrete base course

Source / Date	Nomin -al Max. Size [1]	GM	P 425	LL [2]	PI [2]	LS	EC	CLASSIFICATION AASHTO M 145 – 95 [3] Classif.	GI	COLTO (1998) Calcrete [4]	LSM [5]	CBR @ % MAASHO 98 % 2,54 mm	98 % 5,08 mm	95 % 2,54 mm	Swell @ 100 % MAASHO	In-situ Compact ion MAASHO	MAASHO MDD	MAASHO OWC	Remarks NITRR Sample No. / Position [6]
Units	mm	-	%	%	%	%	S/m	-	-	-	-	%	%	%	%	%	kg/m³	%	m
17 years (1993) and 0,2 MESA in left lane [12]	37,5	1,79	47	44	14	6,0	-	A-2-7	0	(G6)	282	-	-	-	-	-	-	-	50C
	63,0	1,92	43	44	13	5,5	-	A-2-7	0	G6	237	57	-	40	0,1	-	1695	17,0	50C
	37,5	1,81	44	40	13	5,5	-	A-2-6	0	(G6)	242	-	-	-	-	-	-		90C
	26,5	1,84	44	41	11	4,5	-	A-2-7	0	(G6)	198	-	-	-	-	-	-	-	108C
	53,0	1,73	48	43	12	5,0	0,05	A-2-7	0	G6	240	78	-	60	0,0	-	1713	15,4	108C
	63,0	1,81	49	38	12	6,0	-	A-2-6	0	(G6)	294	-	-	-	-	-	-	-	150C
	37,5	1,73	47	38	16	7,0	-	A-2-6	1	G8	329	46	-	36	0,1	-	1832	14,9	150C
	53,0	2,18	30	38	14	6,5	-	A-2-6	0	(G7)	195	-	-	-	-	-	-	-	210C
Min.	26,5	1,73	30	38	11	5,0	-	A-2-6	0	G6	195	46	-	36	0,0	-	1695	14,9	
Max.	63,0	2,18	48	44	16	7,0	-	A-2-7	1	G8	329	78	-	60	0,1	-	1832	17,0	
All comp. Min.	26,5	1,73	17	37	8	3,5	0,04	A-2-4	0	G6	60	46	-	36	0,0	92,3	1695	13,5	0 – 17 yrs after
Max	100	2,42	48	44	16	7,0	0,05	A-2-7	1	G8	329	160	-	95	0,1	103,1	1832	17,0	compaction
Prelim-spec. [13]																			After compaction
Min.	26,5	1,7	15	-	-	-	-	A-1-a	0	-	60	45	-	35	0,0	98	1690	-	for ≥ 0,2
Max.	63,0	2,4	50	44	16	7,0	0,15	A-2-7	0	G8	330	-	-	-	0,2	-	-	17,0	MESA

Notes:

[1] Up to 10 % coarser permitted
[2] 4 Units have been subtracted from the NITRR LL and PI test results due to their use of a BS LL device
[3] AASHTO M 145-95 practice is to round off GI to nearest whole number, e.g. 0,4 is reported as 0 and 0,5 is reported as 1
[4] Brackets indicate potential classification on indicators only
[5] LSM = linear shrinkage modulus = LS x P425. PIM = plasticity index modulus = PI x P425 (not individually shown)
[6] Section "chainage", i.e. 0-250 m ; C = centreline. Only samples outside wheelpaths on centreline or midlane assumed to represent as-built condition
[7] All samples also complied with the P2,00 = 20 - 70 % requirement for a COLTO:1998 G5 but not with G4 grading envelope
[8] Sample supplied by TRD and tested at NITRR
[9] Sampled by TRD site staff in August 1976 over 40 m lengths in order from SV 15+520 to 14+800, i.e. section "chainage" 20 – 300 m. PIM = 240-368; mean 291
[10] Sampled by TRD site staff in August/Sept. 1976 at section "chainages" 0; 150 and 300m at unknown offsets and tested at NITRR. pH 7,9 – 8,4; moderate to strong reaction for CO_3^{2-}, no reaction for Cl^- or SO_4^{2-}
[11] TRD tests in May 1977 at unknown offsets. Sample No. P22/77. Field water contents 11,1; 10,9; 8,0 %, respectively
[12] Sampled by TRD and tested by commercial laboratory. PIM = 420-752; mean 576; or 551 if outlier of 752 at 150 C omitted
[13] Based mostly on results after compaction with minimal consideration of previous specs. For ≥0,2 M E80 after 17 years as both lanes still in very good condition in 1993
[14] G4 is lowest quality base permitted; grading envelope actually required
[15] Max. 0,1 MESA or 300 vpd for 150 mm G4 base / 150 mm G7 subbase /SG7

8. TRAFFIC

Table 3 summarises traffic data in terms of average annual daily traffic (AADT), heavy vehicles (trucks) (AADTT), equivalent standard 80 kN axle loads (E80s, ESA) and cumulative E80s estimated mostly from 12- hour hand counts. At the time of the pavement evaluations carried out in 2005 and 2007 the road had carried about 0,5 MESA. Multi-axle heavy vehicles were very evident on both occasions and the AADE had more than doubled from a measured 119 E80/d in 1997 to an estimated 275 in 2005, and tripled to a measured 367 in 2007.

Table 3: Traffic history

Year	Average annual daily and yearly traffic [1]						Cumulative [3]		
	AADT	AADTT [1]		LEF	AADE	AAE	Both directions [1]	To Biesiesvlei (LHS)	To Coligny (RHS)
	vpd	%	hv/d	[2] E80/hv	[2] E80/d	E80/y	E80	E80	E80
1977	132	41,7	55	(0,6)	(33)	12 045	12 045	7 227	4 818
1980	412	26,7	110	(0,6)	(66)	24 090	60 225	36 135	24 090
1982	275	22,5	62	(1,2)	(74)	27 010	111 325	66 795	44 530
1983	288	16,0	46	(1,2)	(55)	20 075	131 400	78 840	52 560
1989	292	17,1	50	(1,2)	(60)	21 900	253 675	152 205	101 470
1991	332	14,2	47	(1,2)	(56)	20 440	296 015	177 609	118 406
1992	260	14,2	37	(1,2)	(44)	16 060	312 075	185 639	126 436
1993	385	13,5	52	(1,2)	(62)	22 630	334 705	196 954	137 751
1997 [4]	582	17,1	100	1,2	119	43 435	446 030	252 617	193 413
1997 [5]	478	16,1	77	(1,2)	(92)	33 580	-	-	-
2004	448	18,1	81	(1,7)	(138)	50 370	757 010	408 107	348 903
2005	707	15,1	107	(2,5)	(275)	100 375	857 385	443 238	414 147
2007 [6]	729	13,4	98	3,8	367	133 955	1 091 715	525 253	566 462

Notes:
[1] For both directions. Opened to traffic in Nov. / Dec. 1976. Legal axle loads increased in 1996, e.g. for single dual wheel axle from 8 200 to 9 000 kg
[2] Figures in brackets are estimates
[3] Biesiesvlei : Coligny split 60 : 40 (1977–1991), 50 : 50 (1992–2004), 35 : 65 (2005–2007)
[4] Seven-day survey from 12-20 August 1997 using Truvelo TDL 500 logger with two Series 8 stick-on plates and a TEL 2CM with four-stick-on loops at km 34,0. Average E80/axle = 0,31, average no. axles/hv = 3,82; average axles > 8 t = 34 no./d (2,5%), i.e. 70 E80/d (59%)
[5] Manual count for comparison, WIM AAE used to calculate cumulatives
[6] One-month effective survey in Sept. - Oct. 2007 using loops, bending plate WIM sensors and a logger at km 31,40. Average E80/axle = 0,84; average no. axles/hv = 4,5; axles > 8t = 123 no./d (27%), i.e. 303 E80/d (83 %); axles> 9 t = 90 no./d (20%), i.e. 262 E80/d (71%)

As overloading is a major factor causing pavement damage, it is concluded that the experimental sections were not subjected to an unusually low degree of overloading.

9. MAINTENANCE

The maintenance applied to this experiment was as follows:

Nov. 1980 : Slurry seal because of oxidation of tar, and ravelling
Nov. 1986 : Due to misunderstanding **not** resealed with 9 mm single seal along with rest of road because of stabilization cracking and dry seal
1990 : 6,7 mm quartzite single seal
June 1994 : **Not** sprayed with diluted emulsion.

No patching was done except at sample sites until about 2003/2004 when a few shear failures and potholes appeared on Section 2. Sealing of the stabilization cracking on Sections 1 and 3 was carried out from time to time from at least 1986 onwards. The heavily grass-covered gravel shoulders were apparently never regravelled. It is therefore concluded that no unusual maintenance was necessary before 2003–2004, but that it probably should have had a reseal in 1986 and a fog in 1994 as for the rest of the road.

10. PERFORMANCE

Visual inspections were carried out in 1977, 1978, 1983, 1986, 1993, 2006 and 2007. Due to absence of funding no monitoring was carried out between 1993 and 2005.

A summary of only the two most important visual evaluations over the central 200 m (i.e. section ch 50-250 m) is shown in Table 4. Those for February 1998 and May 2005 are the most important because the first failures on Section 2 occurred sometime between these two inspections and there was little change after the Sanral patching in 2006 and the final evaluation in 2007. A second inspection in July 2005 was carried out after the failure and potholes seen on Section 2 in May had been patched.

Table 4: Summary of traffic, visuals, rut depths and maintenance recommendations

Year Month **Age** Seal [1]	Section No.	LHS (Biesiesvlei-bound) Lane				RHS (Coligny-bound) Lane			
		Traffic Cum. E80	General pavement condition, attention needed [1]	OWP/IWP[2] Rut (mm)		Traffic Cum. E80	General pavement condition, attention needed [1]	OWP/IWP[2] Rut (mm)	
				80% -ile	90% -ile			80% -ile	90% -ile
1998-02 **21 yrs** S2 +SL +S1	1	260k	GOOD Bleed D1/E5 Undul. D2/E5 (ridged over crack sealing under reseal) RQ fair – good **Routine (B)** (cut grass)	D2 D2	D2 D2	200k	GOOD Bleed D2/E5 Undul. D2/E5 (ridged over crack sealing under reseal) RQ fair - good **Routine (B)** (cut grass)	D2	D2
	2	260k	VERY GOOD Bleed D2/E5 Undul. D1/E5 RQ very good (better than Sects 1 and 2) **Routine (B)** (cut grass)	D2 D1	D2 D1	200k	GOOD Bleed D3/E5 Undul. D1/E5 RQ very good (better than Sects 1 and 2) **Routine (B)** regravel sh., cut grass	D2 D1	D2 D1
	3	260k	GOOD Bleed D1/E5 Undul. D2/E5 (ridged over crack sealing under reseal)	D2 D2	D2 D2	200k	GOOD Bleed D2/E5 Undul. D2/E5 (ridged over crack sealing under reseal)	D2	D2

Table 4: Summary of traffic, visuals, rut depths and maintenance recommendations

Year Month **Age** Seal [1]	Section No.	LHS (Biesiesvlei-bound) Lane				RHS (Coligny-bound) Lane			
		Traffic Cum. E80	General pavement condition, attention needed [1]	OWP/IWP[2] Rut (mm)		Traffic Cum. E80	General pavement condition, attention needed [1]	OWP/IWP[2] Rut (mm)	
				80% -ile	90% -ile			80% -ile	90% -ile
			RQ good **Routine B** (cut grass)				RQ good **Routine B** (cut grass)		
2005-05-03 /06 [3] **28 yrs** S2 +SL +S1 **Before** Sanral patch-ing	1	420k	GOOD Bleed D2/E5 C cracks D1/E5 Undul. D1/E5 RQ good **Routine (A)** (edge grass) **Reseal (A)**	8 6	10 6	370k	GOOD Bleed E2/E5 C cracks D3/E1 Undul. D1/E5 RQ good **Routine (A)** (edge grass) **Reseal (A)**	13 6	15 6
	2	420k	GOOD Bleed D3/E1 (sample sites) C cracks D3/E1 Patches D3/E1 (sample/failure) Pothole 1xD5/E1 RQ good **Routine (A)** (patch. sh. edge too high) **Reseal (A)**	7 5	8 5	370k	FAIR Bleed D3/E1 (sample sites) C cracks D3/E2 Patches D3/E3 (sample/ failure) Potholes 2 x D4/E1 Shear 1x D3/E1 RQ fair **Routine (A)** (patch. sh. edge too high) **Reseal (A)**	15 4	17 4
	3	420k	GOOD Bleed D2/E5 Ruts D1/E5 Undul. D1/E5 RQ good **Routine(A)** (grass) **Reseal (B)**	7 7	9 8	370k	GOOD Bleed D2/E5 Ruts D2/E5 Undul. D1/E5 RQ good **Routine(A)** (grass) **Reseal (B)**	10 6	12 7

Notes:
[1] TMH9:1992 nomenclature used. Seals : S2 = double (initial), S1 = single (reseal), Sl = slurry (reseal); D = Degree, Sp = Average Spacing in m; E = Extent; Bleed = bleeding; B = block cracks; C = crocodile; L = longitudinal; T = transverse; Undul. = undulations; RQ = riding quality ; Reseal ( ) = reseal recommended at (A, B or C) priority (see TMH9 : 1992). **Over central 200 m** (section ch 50 – 250 m) unless otherwise stated
[2] *n* = 21 **over central 100 m** (section ch.100 – 200 m): D1 = < 5 mm, D2 = 5 -10 mm
[3] At time of failure investigation with Gautrans (03-07 May 2005). Similar on 01 July 2005 except for appearance of D3 L cracks on Sections 2 and 3 due to clay roadbed concealed by sand cover

Occasional Degree 1 - 2 longitudinal cracks **outside the wheelpaths** characteristic of an slightly active clay roadbed were noticed on all sections on several occasions. Block cracking was noticed on the stabilized sections after priming, but was first noticed on the seal after two years during 1978. This caused them to be only rated as ‘fair’ in 1986 and 1993, in comparison to the unstabilized section which was still rated as ‘very good’.

The inner wheelpaths still exhibited neither cracking nor patching and 80 percentile rut depths of only 6 mm, indicating that sealing the shoulders should have extended the life.

Visual assessments of riding quality (RQ) were made at each inspection as in Table 4 and a few mechanised measurements made from April 1977 after opening to traffic in December 1976 until December 2006 after the initial Sanral patching (not shown). According to TRH12:1997 riding quality criteria the preliminary specification for the quality of the base course proposed in Table 2 was adequate for at least 0,2 MESA and the left lane should have had a structural capacity of about 0,5 MESA for a Category C road.

In October 2006 after about 0,5 MESA in 30 years a deflection survey of the unpatched areas in the outer wheelpaths of both lanes was carried out using a Carl Bro PRI 2100 Falling Weight Deflectometer (FWD) (not shown). Although according to Horak’s (2007) criteria **all three sections except the left lane of Section 3 would be regarded as having failed**, all the unpatched parts were still in a good condition, the rutting was still acceptable and only the riding quality was in the warning or severe range. This survey also showed Section 3 to be in a better structural condition than Section 1, to which it was supposed to be identical and that – according to **all** the deflection parameters – the left lane on all three sections was in a better structural condition than that of the right lane, to which it was supposed to have been identical. This finding effectively doubled the number of sections from three to six.

11. PAVEMENT EVALUATIONS IN 2005 AND 2007

After about 0,42 MESA the **left lane** was still in a **good** condition with a total of only 5 m of cracking (3% of the 200 m length) of Degree 3, 4 m of patching (2%) **not** coinciding with the sites of known previous sample points, and an 80 percentile rut depth of 7 mm (Table 4).

In contrast, the right lane, which had apparently carried only slightly less traffic (0,37 MESA) at that stage, was in a significantly **worse** condition and was only rated as **fair** due to an 80 percentile rut depth of 15 mm, 39 m of patching (20% of the 200 m length) **not** coinciding with known previous sample sites, 8 m of Degree 3 or worse crocodile cracking (4 % of the 200 m length), two Degree 4 potholes, and one Degree 3 shear failure. On the basis of the 20 percentage length of patching **the right lane of Section 2 was regarded as having reached a terminal condition** for a Category C road after about 0,4 MESA in 28 years. A second base course specification derived from this work is shown later in Table 5.

A final monitoring and pavement evaluation was carried out in May 2007 **after the patching**. At that time the experiment was **31 years old** and had carried an estimated 0,50 MESA in the Biesiesvlei and 0,52 MESA in the Coligny lane, i.e. **about 0,5 MESA in each lane.**

The overall structural condition of Sections 1 and 3 and the left lane of Section 2 was rated as **good**, but the right lane of Section 2 only as **fair** due to the extensive patching and poorer riding quality, which included the patches.

The remaining unpatched pavement was still in **good** condition after about 30 years and 0,5 MESA, and probably had a residual capacity of at least about 2,0M in the left and 0,5 MESA in the right lane. A further specification derived from it is shown later in Table 5.

12. DERIVED BASE COURSE SPECIFICATIONS

The specifications to follow for an untreated calcrete base have been derived empirically largely only from the results of this experiment, with minimal consideration of other specifications. Whilst they therefore strictly only apply to the conditions of the experiment, these were not unusually favourable and the specifications should actually be of much wider application. Although it is arguable whether the specifications are applicable to the situation where the **subbase** is not cemented, all layers of the old Western and Eastern Cape roads were unstabilized (Netterberg, 1971, 1982), and the Nata LTPP experiment in Botswana after 10 years and about 0,4 MESA (Netterberg and Pinard, 1991) and the TRH4:1996 design catalogue all indicate that it is.

The specifications for these calcrete base courses derived at various stages of the project are summarised in Table 5 in comparison with some local calcrete base course specifications. Also shown in Table 5 is the overall condition and rut depth of each lane at these stages, and the rut depth and number of test results from which the specifications were derived. The results of the experiment are in good agreement with those of previous work on calcrete bases and confirm that – for coarse material at least – much higher LLs, PIs and shrinkages can be allowed for these levels of traffic provided that a reasonable soaked CBR of about 50 or 60 – which is also less than the traditional 80 – is obtained (Table 6).

Perhaps the most radical and useful aspect of the findings of this project is that, provided the other requirements such as CBR are met, a calcrete G7 can be used for base course for at least 0,5 MESA and a calcrete G6 (which would only be a non-calcrete G7) for a projected 1,0 MESA, whereas according to TRH4 : 1996 none of these should be used as base course for any pavement, not even for less than 3 000 E80.

Although the specifications are deliberately conservative, bearing in mind the notoriously poor reproducibility of both the indicator and the CBR tests, it could be argued that the soil constants are all essentially the same and that the specification for the projected 1,0 MESA design should be applied in all cases, and especially where the quality of control testing is suspect. The range of GM and the swell requirement are considered sufficiently conservative in most cases, although the minimum GM could be raised to 2,0 and the maximum swell decreased to 0,2% when used for a 0,3-1,0 MESA Category B road.

The specifications should only be applied to **calcretes** and not to other whitish materials which contain little or not calcium carbonate, and the **soil fines** (P425) should contain at least about 10% $CaCO_3$ or its equivalent.

As the LS (and the derived LSM) are regarded as more reliable and definitive than the PI (and the derived PIM), it is essential that the LS be **determined** and not just estimated.

Table 5: Comparison of results and preliminary derived specifications from Biesiesvlei LTPP Expt with some local calcrete base specifications

Source	Rut depth (80 % -ile)	Nominal maximum size [1]	GM	P 425	LL	PI	LS	PIM [2]	LSM [3]	Classification [4]: AASHTO M145 - 95 [5]	Classification [4]: COLTO **Calcrete** [6]	Min. soaked CBR @ % MAASHO: 98, 2,54 mm	Min. soaked CBR @ % MAASHO: 98, 5,08 mm [7]	Min. soaked CBR @ % MAASHO: 95, 2,54 mm	MAASHO Swell, max.	DCP [8] BASE: DN max.	DCP [8] BASE: CBR min.	DCP [8]: DSN 800 min.	Traffic / Remarks
Spec.	mm	mm		%	%	%	%	-	-	**Worst**	**Worst**	%	%	%	%	mm/ blow	%	Blows	AADTT / Cum. M E80
Netterberg (1971,1982) Calcrete	- -	19 - 38 38 - 53	≥1,5 ≥1,5	15-55 15-55	≤40 ≤35	≤15 ≤12	≤6,0 ≤4,0	- -	≤320 ≤170	A-2-6 A-2-4	G6 G6	60 80	80 80	- -	0,5 0,5	- -	- -	- -	End AADTT <100 [12] End AADTT <200 [13]
COLTO G5 (1998) TRH4:1996 Calcrete G4	20 - -	63 53	1,5-2,5 (2,0-2,7) [10]	- 10-30	≤30 ≤25	≤15 ≤8	≤6 -	- -	≤320 ≤170	- -	G5 G4	- 80	- -	45 -	0,5 0,5	- -	- -	- -	≤ 0,3M (Cat. C); ≤1,0 (Cat. D) ≤1,0M (Cat. B,C,D)
Netterberg & Pinard (1991) Calcrete	 - -	(100) (100) [9]	2,0-2,6 2,0-2,6	- -	- -	≤15 ≤15	≤7,0 ≤7,0	- -	≤170 ≤170	- -	- -	60 80	- -	- -	0,5 0,2	(3,6) (2,9)	(80) (105)	(155) (170)	≤0,5M (Cat. B) [14] ≤1,0M (Cat. B) [14]
Table 2 @0,2MESA Both lanes very good	- 6 	75 26,5 -63	2,26-2,43 1,73-2,42	18-25 17-48	40-45 37-44	11-16 8-16	4,5 -6,5 3,5 -7,0	240 -368 136 -752	110 -163 60 -329	A-2-7 A-2-7	(G7) G8	100 45	103 (50)	74 35	0,0 0,2	- 1,8	- 200	- -	Before comp. [15] After comp; >0,2M in 17 years [16]
@ 0,42M Left lane good	7 -	63 63	2,15-2,41 2,25-2,41	21-31 21-25	≤34 <34	≤13 ≤13	≤7,0 <7,0	≤380 ≤330	≤210 ≤200	A-2-6 A-2-6	G7 G7	40 60	(45) (70)	30 45	0,5 0,5	4,0 2,5	(70) (130)	230 240	≤0,4M in 28 y ≥0,4M in 28 y [17]
@ 0,37M Right lane fair	15 -	63 63	2,07-2,41 2,07-2,51	17-25 17-25	≤41 ≤41	≤14 ≤14	≤7,0 ≤7,0	≤280 ≤280	≤160 ≤140	A-2-7 A-2-7	(G10) G7	50 60	(55) (70)	40 45	0,3 0,1	4,4 3,1	(63) (98)	200 280	≤0,4M in 28 y ≥0,5M in 28 y [18]
@ 0,5M Right fair Left good	 6 7	 63 63	 1,70-2,23 1,70-2,08	 28-47 28-47	 ≤43 ≤42	 ≤14 ≤14	 ≤7,0 ≤6,0	 ≤660 ≤560	 ≤300 ≤260	 A-2-7 A-2-7	 G7 G6	 50 60	 (55) (70)	 40 45	 0,5 0,5	 3,4 3,4	 (87) (87)	 (145) 170	[19] [20] ≤0,5M in 31 y ≤1,0M in 31 y

Notes for Table 5:

[1] Up to 10% coarser permitted.
[2] PIM = PI X P425.
[3] LSM = LS X P425.
[4] The classification is that of an individual sample and not necessarily that of the specification itself, i.e. it could be considered as an additional requirement.
[5] Or ASTM D3282. **Also, max. Group Index** (GI) **= 0**. GI rounded to nearest whole number.
[6] Brackets indicate potential classification on indicators only.
[7] Figures in brackets estimated from $CBR_{5,08}$ = $1,15CBR_{2,54}$.
[8] With DCP zero at top of **base.** The DN requirements for the 150 mm base are definitive, the in-situ CBR estimated from the Kleyn (1984) model CBR = $410DN^{-1,27}$ for DN>2 only indicative.
[9] For construction and also found in base (actual max. found 150 mm).
[10] Full grading envelope actually required for G4.
[11] DCP requirements in brackets for TRD (1994) Class II rural road for 0,1 – 0,3 MESA for optimum moisture regime and BN = 40 for comparison.
[12] Probably ≤ 0,2 MESA.
[13] Probably ≤ 1 MESA.
[14] DCP requirements estimated (not required by authors). Unstabilized subbase.
[15] On road **before compaction** : eight indicators, but only one combined CBR (probably too high because all >19mm crushed in).
[16] **After compaction** and up to 0,2 MESA (both lanes very good): :14 indicators, 6 CBRs, 3 in-situ densities, 3 DCPs (rest refused); OWP rut depth (mm) : $\bar{X}$ = 5, 80 %-ile = 6

Note	Lane	Condition	Rut depth(mm) *		MESA	Indicators	CBRs	FWCs	DCPs
			$\bar{X}$	Min. – Max.		No.	No.	No.	No.
[17]	Left	Good	8	4 - 16	0,42	6	6	6	6
[18]	Right	Fair	12	6 - 24	0,37	7	4	7	6
[19]	Right	Fair	5	0 - 8	0,5	5	4	4	5 (in dupl.)
[20]	Left	Good	6	0 - 9	0,5	5	3	5	5 (in dupl.)

* At sample / DCP sites

13. CONCLUSIONS

- The Biesiesvlei unstabilized, 150 mm-thick plastic, calcrete gravel base with a GM of 1,7 - 2,4, LL of 37 - 44, PI of 8 - 16 with a mean of 12, LS of 4,0 - 7,0, LS x P425 of 150 - 329, and a 98% CBR of 46 - 78, under a double seal and on a 125 mm-thick assumed C4 subbase on a 150 mm SP - NP G7 Kalahari sand selected subgrade, opened in November 1976, survived without significant distress until at least 2002 after about 0,3 MESA in 25 years, with reseals only in 1980 and 1990 and no patching.

- The first failures requiring patching occurred in 2002-2003 after about 0,3 MESA in 26 years in the right lane due to no shoulder maintenance and an overdue reseal.

- In 2005, after about 0,4 MESA in 28 years, the right lane was in a terminal condition with respect to the maximum 20 % length of patching allowed for a Category C road.

- In 2006, after about 0,5 MESA in 30 years, the left lane was also in a terminal condition for a Category C road with respect to the 20 % length of patching allowed.

- However, in 2007 DCP and other testing of the remaining unpatched pavement nearly all still in good condition indicated a residual capacity of at least about 2,0 MESA in the left and 0,5 MESA in the right lane.

- Monitoring over most of the full analysis period of 30 years by means of periodic visual, rut depth, deflection and roughness surveys, as well as pavement evaluations in 1993, 2005 and 2007 involving also DCPs, sampling and laboratory testing, enabled simple, performance-related material quality specifications to be derived for untreated calcrete base course for two proven and one projected level of traffic.

- The essentials of these specifications for a TRH4:1996 Category C road are :

GM	Max. PI	Max. LS x P425	Min. soaked 98% CBR	Max. Cum. MESA
1,7-2,5	16	320	40	≥0,2 proven; max. 0,3?
1,7-2,5	15	300	50	≥0,4 proven; max. 0,5?
1,7-2,5	14	260	60	≥0,5 proven; max. 0,8?

- Materials at the limiting values of these specifications would only classify as non-calcrete COLTO:1998 G7 materials and as G7 or G6 calcretes and could not be used as base course for any pavement according to TRH4:1996 designs.

- The conditions under which the experiment was carried out were not abnormally good.

- As the field water contents of the base course in May of both 2005 and 2006 were found to exceed MAASHO optimum it must be assumed that Section 2 was wet or even saturated for a significant part of at least these two years.

- The investigations showed the left lane to be unexpectedly both significantly stronger and to perform better than the right lane. Some of this was built-in and some due to the poorer seal edge drainage in the right lane.

- A more comprehensive version of this paper is available from the author.

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Table 6: Recommended calcrete base course specifications derived from the Biesiesvlei LTPP Experiment for Category C roads [1]

TRH4: 1996 Design structural capacity over 20 years	Nominal max. size [2]	GM [3]	P 425 [3]	LL max. [4]	PI max. [5]	LS max. [6]	PIM max. [7]	LSM max. [8]	Worst Classification		Min. soaked CBR @ MAASHO [11]			MAASHO CBR Swell max.	DCP [12]			Remarks [13]
									AASHTO M145 [9]	COLTO [10] Calcrete	98 %		95 %		150 mm Base		DSN 800	
											2,54 mm	5,08 mm	2,54 mm		DN max.	CBR min.	min.	MESA
MESA	mm	-	%	%	%	%	-	-	-	-	%	%	%	%	mm / blow	%	blows	
0,1 - 0,3	63	1,7-2,5	15-50	44	16	7,0	(700)	320	(A-2-7)(0)	(G7)	40	(45)	(30)	0,5	4,4	(63)	145	Good @ 0,2 Max. 0,3 ?
0,3- 1,0	63	1,7-2,5	15-50	43	15	7,0	(660)	300	(A-2-7)(0)	(G7)	50	(55)	(40)	0,5	3,4	(87)	145	Good @ 0,4 warning @ 0,5 Max. 0,5 ?
0,3 -1,0	63	1,7-2,5	15-50	42	14	6,0	(560)	260	(A-2-7)(0)	(G6)	60 [14]	(70)	(45)	0,5	3,4	(87)	170	Good @ 0,5; Projected to 1,0 Max 0,8 ?

NOTES:

[1] Figures in brackets and the DCP requirements are indicative and can – or should - be omitted if inappropriate
[2] Upto 10 % coarser permitted; 75 mm max. COTO:2020, 50 mm for G5 or G6 base
[3] By TMH 1 : 1986 Method A1-(a) or equivalent (e.g. SANS 3001-GR1)
[4] By TMH 1 : 1986 Method A2 two or three-point method or equivalent (e.g. SANS 3001 - GR11 or12)
[5] By TMH 1 : 1986 Method A3 or equivalent (e.g. SANS 3001 - GR10)
[6] By TMH 1 : 1979 Method A4 or equivalent (e.g. SANS 3001 - GR10)
[7] PIM = PI x P425. [8] LSM = LS x P425
[9] Or ASTM D3282; group index rounded to nearest whole number, e.g. < 0,5 = 0; i.e. max. = 0,4
[10] COLTO:1998 calcrete; COTO:2020 same except G5B for projected 1,0M. Non-calcrete COLTO classifications are all G7; COTO G7, G6 if GM = 2,5; G6, respectively
[11] TMH 1 : 1986 Method A7 and A8 or equivalent, (e.g. SANS 3001-GR 30 and 40) with a maximum of 30 % (by mass of the whole sample) plus 20 mm material crushed in as compensation for oversize
[12] By TMH 6 : 1984 Method ST6, but with zero at top of base and Kleyn model, e.g. as in Win DCP. Well – or averagely – balanced pavement and wet test conditions assumed
[13] Min. base course compaction 98 % MAASHO. Conservative max. MESA suggested
[14] If min. unsoaked CBR of 80 at OWC desired CBR must be determined after four days moisture equilibriation Netterberg, (2014b)

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