HOW PLASTIC IS YOUR LIME?

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ABSTRACT

A case history is described in which a weathered, non-durable, basalt proposed for base course for the Trans – Caprivi Highway in the wettest area of Namibia could not be reduced to non-plastic with SANS 824-quality lime during construction as required, even after extended curing. Adding more lime simply increased the plasticity index. It was established that the excess plasticity was due to the high plasticity index of 17 of the lime used. After extended ICL and plasticity testing for up to 28 days and durability mill, methylene blue and X-ray diffraction tests it was judged safe to accept a PI higher than NP after treatment with 3 % of the same lime. However, the problems of routine site control, uncertainty and responsibility remain. As the plasticity of road lime is not controlled by SANS 824, it is recommended that the plasticity index of lime proposed for use in pavement stabilization be determined and that it be rejected if it exhibits excessive plasticity.

Keywords: Basalt, durability, lime, stabilization, plasticity

1. INTRODUCTION

The source of materials for base course for a section of the Trans – Caprivi Highway between Katima Mulilo and Ngoma in Namibia had to be changed during construction at short notice. The only material available was a weathered basalt indicated to be non-durable by means of laboratory testing and of dubious service history in neighbouring countries.

Weathered basic rocks are notorious for increasing in plasticity in service with consequent premature distress or even failure of the pavement. It is therefore good practice to build in a safety factor by modifying them down to non-plastic, especially in wet areas and for other than light duty.

It is the purpose of this paper to report on an unusual problem in which the plasticity index was increased and not decreased by the addition of road lime.

2. THE SITE

The section of road involved was the last 14 km of the new road constructed in the year 2000 between Katima Mulilo and Ngoma Bridge in the eastern Caprivi of Namibia.

The area probably receives a mean annual rainfall of about 630 mm (estimated from Mendelsohn and Roberts, 1997) and falls within the “moderate” macroclimatic region for pavement design purposes (Committee of Land Transport Officials (COLTO), 1996).

Because the Weinert climatic N-value of the area is about 2,7, caution is required in the use of basic rock as base and subbase (Weinert, 1980).

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3. PAVEMENT AND MATERIALS DESIGN

The pavement is designed for 350 vpd and 100 E 80/d and consists of a 7,4 m wide Cape seal on a 150 mm-thick G4 (COLTO, 1998), grid-rolled, weathered basalt gravel base on a 150 mm-thick G5 calcrete subbase on a subgrade, fill and roadbed of Kalahari sand. The 19 mm Cape seal was of the original “koffiemoer” type in which crusher dust asphalt is used as the top layer instead of a bituminous slurry.

The standard base course materials specification included requirements for the percentage passing 425µm (P425) of 10 – 35 %, a P075 of 5-15 %, and a maximum liquid limit (LL) of 30% and plasticity index (PI) of 6 %. (Table 1).

Table 1. Typical laboratory test results on proposed basalt base.

Property	Specification	Results
Percent Passing		
53,0 mm	100	70-100
37,5 mm	85-100	55-95
26,5 mm	72-95	40-80
19,0 mm	60-90	30-60
13,2 mm	52-83	20-45
4,75 mm	30-65	10-25
2,00 mm	20-50	5-15
0,425 mm	10-35	2-12
0,075 mm	5-15	1-6
G M	-	2,7-2,9
L L (%)	≤ 30	24-38
P I (%)	≤ 6	3-11
L S (%)	-	2,0-5,5
CBR at 98 MAASHO (%)	≥80	85-170
Gravel ICL (road lime) (%)	-	2,0 at 1h; 2,0 at 24 h:~6 at 28 d

4. THE BASALT

The only available base course material was a weathered basalt of the Kalkrand Formation (Drakensberg Group) of the Karoo Sequence. When weathered, this basalt has acquired a bad reputation as base course over a period of many years in the neighbouring countries of Botswana, Zambia and Zimbabwe, and similar problems are well known in South Africa and elsewhere.

Visually, the material varied from dark greyish, “fresh” basalt apparently suitable for surfacing chippings and crushed stone base to reddish and greenish weathered “intermediate” material, suspect for base where N is less than 5 according to Weinert’s (1980) classification. However, even the “fresh” material evinced black sooty spots indicating that it was of the rapid-weathering type. This and the absence of amygdales classified it as a Type 2 basalt according to the classification of Van Rooy (1991), which should not be used for road or concrete aggregate.

The bad reputation, dubious visual appraisals and the low N-value all indicated the need for great caution. However, nothing else was available, so a way of using the material had to be found.

Durability testing by means of glycol and sulphate soundness, methylene blue adsorption, water absorption, petrography and X-ray diffraction all indicated marginal to non-durable material, whilst the durability mill index (DMI) (Sampson and Netterberg, 1989) results of up to 120 exceeded the recommended limit of 100, indicating a potential for the material to increase in fines and/or plasticity in service to potential failure levels.

The treacherous nature of the basalt was for example well shown by the extremely good dry 10 % FACT results of 260-420 kN, but water/dry ratios of only 43-62 % and glycol/dry ratios of 31-70 %, all of which were below the usual limit for a water/dry ratio of 75 % (e.g. COLTO, 1998).

Typical mostly site laboratory test results on the basalt as-dug and/or after grid-rolling are shown in Table 1. The test methods used were those of the National Institute for Transport and Road Research (NITRR) (1986) except for the glycol-soaked 10 % FACT for which ethylene glycol was substituted for water for 24 hours and four days soaking according to a method originated by DR Rossmann (2000, pers. comm.), and the initial consumption of lime (ICL), for which the author's improved version of the South African Department of Transport

(1987) "gravel" method on the whole grading crushed to pass 19mm was used, with curing periods of one hour, 24 hours, 7 days and 28 days.

5. LIME MODIFICATION

The grading could have been improved by additional grid rolling and/or mechanical modification with calcrete and/or sand, the CBR was adequate, and the LL and PI were mostly just within the conventional specification requirements for base course of 30 and 6, respectively. However, because most were marginal and some excessive and they were not always sufficiently reduced by mechanical modification within the grading envelope, modification with lime appeared to be the obvious answer.

In view of all this and the warning in TRH 13 (NITRR, 1986) and requirement of the former Transvaal Roads Department (1978) that weathered basic rock for base or subbase of a major road be reduced to slightly plastic (SP) at most and, more recently, (Transvaal Provincial Administration 1994) to non-plastic (NP), it was considered necessary to carefully determine the lime requirements by thorough testing of plasticity and ICL for periods of up to 28 days with two types of hydrated lime and one of cement. A summary of the results of the plasticity testing with the high calcium road lime is shown in Table 2. Lime or cement was added in amounts of 1, 2, 3, 4 and 5 % by mass both to the full grading cured in CBR moulds and in equivalent amounts to the pure fines on the assumption that only 5 % fines were present and that the lime reacted only with the fines. For example, 20 % lime added to the pure fines was assumed to be equivalent to 1 % added to the full grading and 100 % (i.e. at a 1 : 1 lime: fines ratio) equivalent to 5 %.

The stabilizers evaluated were as follows:

- Road lime: hydrated calcium road lime produced according to SANS 824.
- Building lime: hydrated dolomitic Type A2P plastic building lime produced according to SANS 523.
- Portland limestone cement: CEM II A – L 32,5 produced according to SANS 50197 - 1/EN 197-1.
- Sand: Kalahari-type sand with P425 of about 100 %, P075 of about 1 % and NP on both fractions.

Table 2. Effect of road lime on index properties of Ngoma basalt.

Material	Curing time	Whole grading (1)					Soil fines (2)				
		Lime (3) %	LL %	PI Indiv. %	PI Mean (5) %	LS %	Lime (4) %	LL %	PI Indiv. %	PI Mean (5) %	LS %
Basalt	4 h	0	31;31	4;5	4,5	2;3	0	33	7	-	3,5
Basalt - lime	4 h	1	28	3	-	1,5	20	31	6	-	3,0
	24 h		27	2	-	1,0		33	4	-	2,0
	36 h		29	4	3,0	2,0		35	5	5,0	2,5
	48 h		28	1	-	0,5		-	-	-	-
	7 d		28	2	2,4	1,0		40	6	5,3	3,0
	28d		SP	SP		1,0		50	5	-	3,0
	4 h	2	31	4	-	2,0	40	33	8	-	3,5
	24 h		30	5	-	2,5		36	6	-	3,0
	36 h		32	5	4,7	2,5		39	7	7,0	3,0
	48 h		32	3	-	1,5		-	-	-	-
	7 d		29	3	4,0	1,5		41	7	7,0	3,5
	28 d		SP	SP	-	1,0		54	6	-	3,0
	4 h	3	31	5	-	2,5	60	35	9	-	4,0
	24 h		32	5	-	2,5		39	8	-	4,0
	36 h		34	6	5,3	3,0		41	8	8,3	4,0
	48 h		36	5	-	2,5		-	-	-	-
	7 d		34	4	5,0	2,0		43	9	8,5	4,0
	28 d		SP	SP	-	1,0		51	7	-	3,5
	4 h	4	34	6	-	3,0	80	37	10	-	4,5
	24 h		36	8	-	3,5		40	8	-	4,0
	36 h		35	6	6,7	3,0		46	10	9,3	4,5
	48 h		36	6	-	2,5		-	-	-	-
	7 d		39	6	6,4	2,5		46	9	9,3	4,0
	28 d		32	3	-	1,5		54	8	-	4,0
	4 h	5	39	9	-	4,0	100	37	11	-	4,5
	24 h		36	7	-	3,5		40	12	-	4,5
	36 h		36	7	7,7	3,5		45	12	11,7	5,0
	48 h		38	7	-	3,0		-	-	-	-
	7 d		40	8	7,6	3,0		45	9	11,0	4,0
	28 d		36	3	-	1,5		59	8	-	4,0
Road lime	4 h	Pure	59	17	-	6,0	Pure	59	17	-	6,0
	24 h		-	-	-	-		60	17	-	6,0
	36 h		-	-	-	-		60	17	17,0	6,0
	48 h		-	-	-	-		-	-	-	-
	7 d		-	-	-	-		59	18	17,3	6,0
	28 d		-	-	-	-		63	18	-	7,0

(1)Made up to contain 5 % soil fines. Crushed to pass 19 mm and cured in CBR moulds.
(2)Fraction passing 0,425 mm.
(3)Kilograms added to 100 kg of whole grading material sample.
(4)Grams lime added to 100 g soil fines so as to maintain the equivalent ratio of lime to soil fines as in the whole material sample containing 5 % soil fines.
(5)Mean for all PI results up to that time.

6. DISCUSSION

A limited study of the repeatability of the operator concerned showed that he was always able to repeat the LL to within 1 unit, the PI to within 2 units (and nearly always to within 1 unit) and the LS to within 0,5 units. Differences in excess of these were therefore regarded as significant.

Table 2 shows that there was an apparent tendency for the road lime to increase the plasticity over the normal curing or testing delay period of 4-48 h for modification and definitely at lime contents of 4 % or more (i.e. 80 % for the pure fines). With an equal amount of lime (i.e. 100% in Table 2) the LL of the fines rose as high as the road lime itself (59), although the PI never exceeded 12. Only with the whole material was a clear minimum PI of 1 and LS of 0,5 reached (with 1 % lime at 48 h). The lowest values of PI (4) and LS (2,0) with the pure fines were also obtained with this approximately equivalent amount of lime (i.e. 20 %) at 36 h (no tests were carried out at 48 h). The material could not be rendered non-plastic even after curing for 28 days – the best that could be achieved was SP with a LS of 1,0 at 28 days with 1, 2 and 3% lime in the whole material (Figure 1, taking SP = 2).

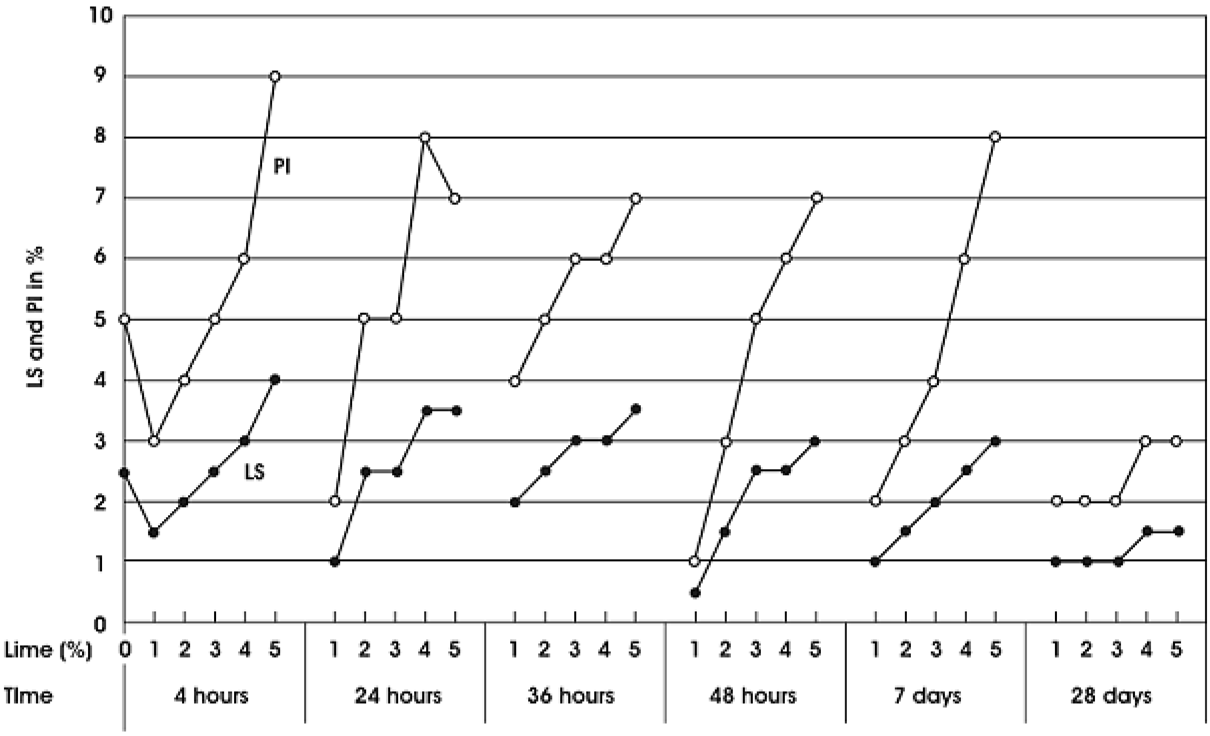

Figure 1. Effect of percentage road lime and curing time on linear shrinkage and plasticity index of basalt gravel base.

Tests on the pure fines were expected to give the most definitive result, but the lowest PI that could be achieved was 4, with a LS of 2,0 at 36 h with 20 % lime. Moreover, there was a disturbing increase in LL of up to 50 and a slight increase in PI and LS with time rather than the expected decrease. The addition of more lime simply increased the PI at all ages.

The plasticity of the lime was then determined together with the plastic building lime and a cement and it was then clear that the lime used was itself the cause of the high plasticity

(Table 3). The highly plastic nature of the lime was confirmed by the high Emley value exceeding 200, which qualified it as a plastic lime according to SANS 523. At lime contents above about 1 % up to 7 d one was apparently measuring the PI of the excess lime at that time. It is normal for lime to increase in plasticity with soaking (curing in this case) time, as shown in Tables 1 and 2 – and to decrease on carbonation (JE Kruger, 2000, pers. comm.). The effect of the building lime on the whole grading was much less marked (not shown). Only with 5 % was the PI increased significantly from the initial mean of 4,5 up to a maximum of 8 with a LS of 3,5. The initial LL rose to a maximum of 33 with 4 or 5 % lime. This lime also failed to render the material NP, but did render it SP with a LS of 1,0 at 28 days with all lime contents.

Table 3. Plasticity of stabilizers evaluated.

Stabilizer	Laboratory	LL %	PI %	LS %	Curing period	Emley plasticity (3)
Road lime	Site Pretoria	59 59	17 9	6,0 30	4 h (1) none (2)	- 224
Building lime	Site Pretoria	27-31 27	3-5 4	1,5-2,5 1,5	none (2) –4h (2)	- 182
CEM II A-L 32,5 cement	Site	21 36 SP SP SP	2 2 SP SP SP	1,0 1,0 1,0 1,0 1,0	4 h 24 h 36 h 7 d 28 d	- - - - -

(1) Increased to LL of 63, PI of 18 and LS of 7,0 % at 28 days (Table 2).

(2) Standard 10 minutes mixing only.

(3) According to SANS 523 after soaking for 30 minutes

The cement gave apparently rather more satisfactory results, 1- 5 % reducing the PI of the whole grading from 4,5 to SP or 2 with a LS of 1,0 at all times from 24 h, and NP with a LS of 0,0 at 28 days. Tests on the fines gave more variable results, with the PI being reduced from an initial 7 (LS of 3,5) to 1 - 3 (LS 0,5 – 1,5) at all cement contents after 4 h, and SP with a LS of 1,0 at 28 days: Thus, on an SP basis, if only 4 h curing had been used a minimum requirement of 5% cement would have been indicated, if 24 or 36 h 4 %, and 28 days 1 %. A disturbing feature at all cement contents was that the PI rose from 1-3 at 4 h to 4-6 with a LS of 2,0 – 2,5 at 7 days before reducing to SP (LS 1,0) at 28 days.

Mixtures of Kalahari sand with 1 - 5 % of road lime were NP with a LS of 0,0 at all ages. Mixtures of basalt and 20 % of sand were also NP, but it was feared that the PI would increase in service to potential failure levels.

Mixtures of basalt and sand treated with 2 % of cement looked promising and were only SP with a LS of less than 0,5 after 4 and 24 h, and NP with a LS of 0,0 after 7 days. However, methylene blue adsorption testing according to New Zealand Standard 4407 showed clay indices of 4,2, which were well in excess of the limit of 3,0 allowed in New Zealand for base course (R Dunlop, 1999, pers.comm.). This and X-ray diffraction testing proved that excessive amounts of smectite clay minerals were still present, but were not detected by conventional plasticity testing. Moreover, not even the ICL at 1h could be met with 2 or 3 % cement, and the use of larger amounts would probably have led to cracking.

Methylene blue testing of the soil fines and the fraction retained on the 0,425 mm sieve showed that smectite clay was still present which was not reflected in the plasticity testing. However, durability mill testing of whole grading material cured for 7 days in CBR moulds and then artificially carbonated indicated that the maximum PI likely to develop in service would be 5, with a durability mill index (DMI) of less than 100. This was judged safe in terms of the criteria developed by Sampson and Netterberg (1989).

Apart from some long term pavement performance (LTPP) sections of mixtures of basalt, calcrete, sand and lime or cement, the road was finally constructed using mixtures of basalt and sand or basalt and calcrete both treated with 3,0 % of the plastic road lime (as a percentage on the basalt), with average as-built (i.e. about 24 h) PIs of about 3. However, the unexpected plasticity of the lime and its inability to reduce the basalt to non-plastic - or even slightly plastic within a reasonable time led to a considerable amount of extra work and delay in decision-making during construction. The questions of uncertainty during routine site testing as to what exactly is being measured by the standard plasticity tests, uncertainty over long term performance and the question of responsibility also remain.

Unless the plasticity of road lime is controlled by SANS 824 it seems necessary to determine the PI of lime proposed for use when it is required to reduce the plasticity of a material to a very low level, and to reject limes of excessive plasticity. If rejection is not possible, testing of possible mixes should be continued after longer periods of curing and supplemented by other methods such as ICL and methylene blue, which can be done on site. The New Zealand methylene blue method NZS 4407: 1991 Test 3.5 for clay index was found to give clearer end points than the SANS methylene blue method 1243 : 1994. The use of the lime content indicated by a minimum PI appears risky, as in the case described this would have been 1%, whereas the ICL at 1 hour was 2%, and it increased to about 6% at 28 days.

It is uncertain how often a highly plastic lime is supplied as a road lime. Two other such cases have since been reported to the author. It seems that it is a particular problem when the content of soil fines is low, as in this case.

7. CONCLUSIONS

- In situations where the plasticity of a material must be reduced to a very low level the plasticity of the lime proposed for use should be determined and, if possible, lime which exhibits excessive plasticity rejected.
- If rejection is not possible testing should be extended to longer curing periods and supplemented by other methods such as ICL and methylene blue adsorption.
- In the case of basic rocks the highest rather than the lowest lime requirement indicated by the various methods should be employed.
- A limit for the maximum plasticity index of road lime should be considered.

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