PROBLEMS EXPERIENCED WITH THE CONSTRUCTION OF CEMENT AND LIME STABILIZED LAYERS AND WORKING SOLUTIONS FOR THESE PROBLEMS

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ABSTRACT

Stabilized layers are used extensively in South-Africa in the construction of roads. The layers are usually stabilized with hydrated road lime, cement, slag, fly-ash, bitumen emulsion, foamed asphalt or a combination of several of these agents. In recent times, major problems were experienced with chemical stabilization in the Southern African Region, particularly when CEM I 42,5 cement was used. The standard laboratory design procedure worked in the laboratory but did not perform in the field. This was left contractually to the so called experienced Contractors to identify the cause of the problem and to present the Client/Consultant with working solutions. The paper deals with the cause of these problems, showing that they are generally material and not construction related, and how working solutions were found to overcome these problems. The main reason why these problems were generally not identified before during the design phase was because testing techniques presently used in soils laboratories do not simulate the conditions on site during and after construction. Furthermore, most of these tests only deal with the short term reactions, whilst in many cases these detrimental reactions continue well past the construction phase. This paper discusses the new testing protocol to identify the type of reaction that is taking place in the stabilized material and the experience gained.

KEYWORDS

CEMENT / LIME/ RECYCLING/ STABILIZATION/ RAPID CURING/ TEMPERATURE

1. INTRODUCTION

Normally in South Africa Specifications the Contractor is allowed six (6) to eight (8) hours to complete the construction of such a stabilized layer. However, very often the setting reactions of the specified cement (very often CEM I 42.5 MPa (OPC)) were so rapid that the Contractor could not compact the stabilized layer to the specified density in the allocated time. The reason why this is not picked during the design phase is because the present laboratory test sequence does not simulate the time and temperature constraints with which the Contractor has to deal with on site. The Contractors were accused of using poor construction techniques and workmanship and then contractually held responsible to make good the completed stabilized layer work. If the temperature of the CEM I 42,5 cement stabilized material rises above 35 º C, rapid or flash setting of the cement takes place that severely shortens the working time. The design engineer should therefore simulate the expected temperature conditions and other site construction constraints (i.e. compacting the mixed sample after say 0.5, 2 and 4 hours after mixing in of the cement and water, and placing the mix in plastic bags in the sun) to determine the effect of site constraints has on the proposed design. Furthermore, the Mod AASHTO compaction test does not simulate site compaction conditions as the sample is compacted in five relatively thin layers, which very often destroys the cement bonds. The laboratory compaction should preferably be done on a vibratory compaction table and the sample compacted (using the site grading) in a single layer giving a compacted sample of about 100 to 90 mm thick at the required density. All this is incorporated in the new testing protocol.

Ways to reduce the negative effects of rapid setting such as choosing a lower strength and slower setting cement (i.e. CEM II B-L 32.5 MPa) and other techniques that will be discussed in the paper.

2. CEMENT STABILIZATION AT NEW NELSPRUIT AIRPORT (ACCESS ROAD)

Transportek was contacted by the Contractor who explained that he could not get density with the weathered granite material used for the stabilized subbase, whereas when used in an unstabilized format in the selected subgrade 100 % mod AASHTO density was easily achieved. This material contained muscovite and some pozzolanic material and the effect of this is such that the material that was compacted to the required density would loose its density in the 4 hours that followed after compaction using CEM I 42,5 (OPC)

Three sets of samples were prepared:

- one set adding 7.3 % water only (i.e. no stabilizing agent),
- one set adding a slower setting cement (i.e. CEM II 32,5 B-V Builtcrete) at 8.3 % water, and
- one set using a lime/slag combination also containing 8.3 % water.

The samples were all prepared together where after a number of samples were sealed in plastic bags and placed in the sun to simulate site conditions. The air temperature measured in the shade was 32 ℃. The temperature in the samples after a few hours in the sun were closer to 40℃ due to hydration of the cement (see Photographs). It was noticed that the samples treated with Builtcrete had stiffened substantially inside their plastic bags after a short while in the sun while the samples treated with the lime/slag combination or untreated material had not stiffened. This indicates that a rapid setting reaction is taking place in the material treated with the Builtcrete. The samples were then compacted on both the vibratory compaction table and the standard Mod. AASHTO test and the densities were then calculated.

Photograph 1: temperature inside Builtcrete sample just before compaction

Photograph 2: Temperature inside lime/slag sample just before compaction
The temperatures were very similar for both stabilized materials.

Photograph 3: Four hour lime/slag treated material just before compaction. Notice the loose texture.

Photograph 4: Four hour Builtcrete treated material just before compaction. Notice more lumpy appearance.

Photograph 5: Extruding the 4 hour Builtcrete sample after compaction on the vibratory compaction table.

Photograph 6: Measuring height of four hour Builtcrete sample compacted on vibratory table. Notice height reading of 108.55 mm. Sample size was calculated to be approximately 100 mm high when compacted to 100% Mod.AASHTO

The lime and lime/slagment as well as CEM II B-L 32,5 (Wallcrete) was used previously in the same area by the authors to overcome the muscovite and pozzolan problem successfully on other roads in the same area. The granite in that case had PI's as high as 6, so stabilising with lime or lime / slagment was feasible. The results also showed that higher vibration densities could be achieved using lime or lime /slagment.

Table 1: Vibration Mod. 7 days field conditions (Ideal curing on the road).

Samples		Un-stabilized		Stabilized 1,5%Lime+ 1,5%Slagment		Stabilized 2%Cement CEMII 32,5 B-V	
		0,5h	4h	0,5h	4h	0,5h	4h
MDD	10/10/01	2037	2055	2010	2052	2035	1855
Moulded %MC	10/10/01	7,2	7,5	8,7	8,2	7,8	8,2
Cured %MC	17/10 am	--	--	5,3	4,6	5,1	3,1
Soaked %MC	17/10 pm	--	--	8,4	7,4	7,9	8,9
KN	17/10/01	--	--	51,9	30,5	72,0	14,6
MPa	17/10/01	--	--	2,845	1,672	3,947	0,800
% Compaction		100,0	100,9	100,0	102,0	100,0	91,2

Table 2: Normal Mod AASHTO with rapid oven curing.

Sample	Un-stabilized		Stabilized 1,5%Lime+1,5%Slagment			Stabilized 2%Cement CEMII32,5 B-V		
	0,0h	4h	0,5h	2h	4h	0,5h	2h	4h
MDD	2063	2064	2073	2058	2047	2062	1987	1973
Moulded %MC	7,4	7,4	7,5	8,5	8,3	8,2	7,9	8,4
Cured %MC	--	--	2,1	3,3	3,0	6,8	6,4	6,8
Soaked %MC	--	--	7,3	7,4	7,9	8,5	9,5	9,8
K N	--	--	29,0	49,5	49,0	57,0	36,0	38,0
MPa	--	--	1,590	2,714	2,686	3,125	1,974	2,083
% Compaction	100,0	100,0	100,0	99,0	98,7	100,0	96,4	95,7

3. LABORATORY INVESTIGATION INTO THE FOURWAYS COMPACTION PROBLEM

The material was firstly oven-dried in the laboratory before testing. All +37.5 mm material was removed from the sample before the smaller samples were sized down through riffling. In the microscopic evaluation of the weathered granite Dr Paige-Green noted the presence of both biotite and muscovite in this material.

Six samples each were prepared for compaction with the vibratory compaction table and the modified AASHTO compaction procedure respectively. Four samples of each set were treated with 3 per cent the slow curing cement as used on site. All the samples were given the same amount of moisture content namely 7.7%. All the samples were prepared at the same time, stored in plastic bags and compacted on the following time scale:

- 0h00   one untreated and one treated sample of each batch

- 2h00 one treated sample of each batch
- 4h00 one treated sample of each batch
- 5h00 one untreated and one treated sample of each batch

The dry density of each of these samples was determined. During the time delay the samples were placed in the sun to simulate site conditions as close as possible. Temperature measurements were taken on top of these samples. These showed that although the air temperature was about 28 ℃ the temperature on the ground actually rose to nearly 40 ℃ (see Photographs 2 to 4).

Table 3: Laboratory compaction results

Time	Sample	Cement	Vibratory	mod	Vibratory	mod
			kg/m^3	kg/m^3	%mod	%mod
0h00	1	Y	2125.44	2079.66	102.82	100.6
0h00	2	N	2150.38	2071.22	104.03	100.2
2h00	3	Y	1984.7	2017.06	96.01	97.58
4h00	4	Y	1961.8	2002.16	94.9	96.86
5h00	5	Y	1901.01	1830.92	91.96	88.57
5h00	6	N	2170.95	2063.12	105.02	99.8
			mod=	2067.17		

The MDD (mod. AASHTO) was taken as the average of the two densities of the untreated samples (i.e. No 2 and 6).

The client was advised to lower the specificied density requirement so as not to destroy the cementituous bonds that formed during the flash setting of the cement.

Photograph 7: Modified AASHTO samples exposed to site conditions before compaction

Photograph 8: Vibratory table samples exposed to site conditions before compaction

Photograph 9: Temperature measurement on top of samples showing temperature

4. CONCLUSION

The laboratory compaction results clearly indicate that the rapid curing of the cement is definitely the reason why the material cannot be compacted to the optimal density. This is confirmed by the compaction results of both the vibratory table and the modified AASHTO compaction test. The vibratory table results also compare well with what has been achieved on site during construction. The results also confirm that it was possible to achieve the specified compaction level of 95% mod. AASHTO with the cement-stabilized subbase, which was constructed from the same material. The high soil temperature accelerates the curing of the cement.

The new cement specifications shown in Table 4 clearly shows the effect that the new specifications have on early cement strengths. The class 32,5 cement is typical the type of cement that was used previously for road stabilisation works.

Table 4: Compressive strength requirements of SABS ENV 197-1 (Addis, 1997).

Strength Class	Compressive strength [MPa]			
	Early strength [MPa]		Standard strength [MPa]	
	2 days	7days	28days	
32,5	--	≥16	≥32,5	≤52,5
32,5R	≥10	--	≥32,5	≤52,5
42,5	≥10	--	≥42,5	≤62,5
42,5R	≥20	--	≥42,5	≤62,5
52,5	≥20	--	≥52,5	--
52,5R	≥30	--	≥52,5	--

Note: Strengths were determined in accordance with SABS EN196-1:1994 (Addis, 1997), using a Water / Cement ratio of 0,5.

Fulton (Fulton, 1976) has shown that the pure compounds of tri-calcium silicate (C_3S), di-calcium silicate (C_2S), tri-calcium aluminate (C_3A) and tetra-calcium aluminoferri (C_4AF) when independently hydrated, react at different rates at normal curing temperatures (22 to 25℃). This is shown in Table 5.

Table 5: Measured reaction times for the different cementing reactions to take place (Fulton, 1976).

Rate of hydration in Days	C_3S percentage reacted	C_2S percentage reacted	C_3A percentage reacted	C_4AF percentage reacted	Laboratory Testing notes
1	35	4	80	90	
7	40	5	85	91	Damp cure
14	46	6	87	92	
28	50	12	91	93	
56	54	28	92	94	Oven cure
90	58	35	94	95	
180	63	50	96	96	
360	70	68	97	97	

Note: The normally curing is taken to be 7 days at 22 to 25℃. In practice it was found necessary to prolong this to 14 and 21 days to be comparable to rapid oven curing results for some types of material.

The estimated rate of hydration reactions at 55℃ r oad temperature (4 hour day at 55℃) is shown in Table 6. Figure 5 in TRH13 (COLTO, 1986) was interfaced with Table 5 to produce Table 6.

Table 6: Equivalent reaction times at 55 ℃ and 25 ℃ for cementing reactions (TRH 13 COLTO, 1986).

Rapid rate of hydration in days at 55℃	C_3S percentage reacted	C_2S percentage reacted	C_3A percentage reacted	C_4AF percentage reacted	True rate of hydration in days at 25℃
1 day [4h]*	35	4	80	90	1 day
2 days [8h]	46	6	87	92	14 days
3 days [12h]	50	12	91	93	28 days
4 days [16h]	54	28	92	94	56 days
5 days [20h]	58	35	94	95	90 days
6 days [24h]	62	42	95	95	112 days
7 days [28h]	63	50	96	96	180 days
8 days [32h]	70	68	97	97	360 days

Note:The aluminate reactions appeared to be relatively rapid, and were almost complete within one day [4 hours at 55 ℃]*. The biggest changes occurred in the di- and tri- calcium silicates. These reactions produced calcium hydroxides as a by-product. The very high pH value on site confirms that these reactions had occurred (Semmelink et al, 2001).

This effect can be seen in Table 7. The main contributing factor is most probably high C_3A content currently found in South African cements (Fulton, 1976).

The effect of a pozzolan friendly cement was demonstrated, with ash from Sasol with known pozzolanic properties that was used to make ash bricks (Table 7). The destructive cement crystal growth can clearly been seen in the 21 day test results. These reactions were observed at normal ambient laboratory temperatures (Botha, 1999). The rate of the reaction can be demonstrated with the results of a compaction investigation in Table 2.

Table 7: Strength of ash bricks with different cements (5 per cent cement content).

Sample Number	F1		F2	
Type of cement CEM I 42,5(OPC)	Lafarge MPa	PPC MPa	Lafarge MPa	PPC MPa
1 Day	2,05	2,77	0,89	2,93
3 Days	3,87	4,57	2,41	5,48
7 Days	5,63	6,42	3,82	7,71
21 Days	5,51	7,64	3,56	8,07

This knowledge was recently applied on a project were similar conditions prevailed with granites with similar XRD's. In this case it was found that the reactions could be controlled by lime stabilizing the layer first and then 24 hours later cement stabilizing the material. The movement under the roller could be controlled and the required density specification was lowered to 97% Mod AASHTO. This solved all the field construction problems. The laboratory findings also showed that SS60 Anionic Emulsion stabilization gave even better results (Botha, 2004).

5 CONCLUSIONS AND RECOMMENDATIONS

These two case studies clearly show the need to incorporate site conditions and construction constraints in the design phase. The new testing protocol demonstrated goes a long way in taking cognizance of site constraints and conditions.

The following test protocol is recommended:

- Do X-Ray Diffractions (XRDs) to determine the clay minerals present in the raw material before you stabilize the material;
- Perform reactivity tests with different stabilizing to determine the activity of these minerals;
- Make correct choice of stabilizing agent to be used. This is crucial to successfully stabilize materials.
- If necessary accept lower density requirement rather than destroying the stabilized upper layer by over-rolling as in the second case study;
- Find out what stabilizing agent worked the best in the past in the area that you are now working in.
- Build up a case history record of which stabilizers worked the best with that particular material.

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