Some material and construction aspects regarding in situ recycling of road pavements in South Africa

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ABSTRACT. *In situ recycling as a pavement rehabilitation option in South Africa is becoming increasingly important. Use has been made of both bitumen (emulsion and foamed) and traditional chemical stabilizers (lime, cement, lime/slagment, etc). Very little detailed information regarding the effect of the in situ processing on the original material properties or the consistency of mixing and effectiveness of deep compaction has been reported. A project in which the shoulder and base of a national road were milled, mixed and replaced as a subbase with the addition of 2.5 per cent cement has recently been investigated. Testing of the material prior to and after recycling was carried out and the densities achieved after compaction were measured. This paper summarises the findings and conclusions from this project and highlights aspects that need better control during the in situ recycling operations.*

KEY WORDS: *Recycling, cement, rehabilitation, material characteristics*

1. Introduction

Many asphalt roads within the ageing South African network are approaching the end of their design lives and urgently require rehabilitation. Faced with limited funds, an increasing scarcity of good road building materials and pressures to work under heavy traffic conditions, alternative and more cost effective construction methods must be considered.

Recycling damaged road layers allows rapid rehabilitation of the road, but can introduce potential problems. The reworked material is often a combination of different layer materials, and as such the properties may vary considerably if not mixed thoroughly. This can affect the moisture content required for successful compaction of the material, as well as strength uniformity. There is also concern regarding the thickness of layer that can be compacted to the required density with conventional compaction plant.

Some tests were carried out during a recent national road rehabilitation contract involving recycling of the existing surfacing and base course layer in the province of KwaZulu-Natal, South Africa.

The section comprised a 60.2 km portion of the two-lane N2 national main road near Hluhluwe built more than 25 years before. Light reseals were applied from time to time, but its condition continued to deteriorate with cracking and deformation over extended sections. In 1998, the remaining serviceable life was estimated to be between 2 and 6 years. Corrective measures to repair and improve the strength of the road were urgently required, and a 22-month contract was awarded in August 1999 to rehabilitate the road.

This paper describes the results of a limited investigation to evaluate various aspects regarding variability of the materials being recycled and the related construction variability.

2. Scope of the work

The contract included milling the existing road surface, base course and shoulder material to a depth of 200mm, mixing and stabilizing it with 2.5 per cent cement, and then recompacting to form a new 200mm C3 quality subbase layer [COM 86]. The road was then finished with an imported G1 crushed stone base and Cape Seal surfacing (combination of single and slurry seal).

The existing road consisted of a slurry seal and up to 3 subsequent surface treatments over 200 mm of crushed river gravel and sand (G2). This was supported by 150 mm of C3 stabilized material over 300 mm of G9 soil (CBR 3 to 7 per cent). The road was not originally constructed with sealed shoulders: these were added later with stabilized sand base and subbase (G6 to G8) between km 14.05 and 38.0 and a stabilized weathered basalt base (G5) and weathered basalt subbase (G5 to G6) between km 38.0 and 74.25.

The recycling therefore resulted in a blend of about 60 per cent of existing unstabilized carriageway material and about 40 per cent stabilized shoulder material (probably in an equivalent granular state [COM 86] after about 20 years in service). The new subbase therefore consisted of a variety of materials.

2.1 Work sequence

To accommodate traffic, one half of the two-lane road was closed over a length of about 5 kilometres to facilitate reconstruction of the road layers. Signalised control allocated equal time between the opposing traffic movements with average wait times of about ten minutes per direction. Up to four such sections were operational over the 60.2 kilometre length simultaneously.

The half width, comprising a 3.7 metre carriageway lane and 2.4 metre shoulder was milled to a depth of 200mm using a mobile recycling machine, water was added to enable the layer to be compacted at 2 per cent below the optimum moisture content, and the material was then mixed in three 2.5 m wide passes with the recycler.

The road shoulder was milled on the first pass. The loosened material was then removed and windrowed evenly across the intact carriageway lane with a grader, and the exposed shoulder layer beneath rolled. This was done to achieve a better blend, as the shoulder material was more finely graded than the carriageway material.

Bagged cement was opened and manually placed on the windrow to increase the labour component of the contract. Then it was lightly bladed to spread it evenly over the carriageway. The cement, spread shoulder material, and 200 mm existing surfacing and base course material beneath were then milled and mixed in two passes. As the width of mixing was about 3.7 metres, there was a generous overlap on the final pass.

The milled material was then bladed back across the full 6.1 metre width of the carriageway lane and shoulder, and compacted using two 18 tonne smooth steel vibrating drum rollers [WIR 98]. The layer was finished to the required tolerances to form the new 200 mm stabilized subbase layer. Production rates were between 1.2 and 1.8 km per day for the 6.1 metre width processed, i.e. 1500 to 2200 m^3 per day.

2.2 Plant used

The milling and mixing was done using a Wirtgen WR2500 mobile recycling machine. Water was supplied to the Wirtgen via a water tanker linked in tandem. A CAT 140H grader was used to spread the material and blade to tolerance. Two single smooth steel drum 18T HAMM 2520 self-propelled vibrating rollers were used to compact the layer.

2.3 Quality control

Contract acceptance testing of the recycled layer was done using an onsite laboratory. Testing of the compacted density, Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) tests was carried out. No difficulties were experienced in attaining the specified standards, with only small, localised areas having to be reworked as a result of not meeting the standards. All density testing was carried out using nuclear test devices, for which the moisture determination was calibrated on a regular basis. Previous work [PAI 92] has shown that, despite this, significant discrepancies can be obtained in the moisture determination, particularly for deep layers. These result in serious errors during calculation of the dry density from the field wet density and the nuclear moisture content. This would be exacerbated by the presence of hydrocarbons in the recycled bitumen within the layer. The use of conventional gravimetric moisture contents when stabilizing with cement is, however, impracticable as the results only become available after the final compaction time for the layer has elapsed. Drying of the material using a microwave oven is a possible alternative, but the size of the samples that can be successfully dried in a microwave oven is often too small to be representative, particularly for coarse gravel.

The routine quality control testing [SAI 98] did not attempt to check any possible density gradients through the layer, or confirm the physical uniformity of the mixed material along the length of the road. Additional tests were therefore required to ascertain the density gradient and mix consistency. These were carried out at the site laboratory on an ad hoc basis.

3. Additional testing

For the purposes of this investigation, the first section of road between distance km 14.1 and 30.85 was selected as it was originally constructed under one contract, although the shoulders were only added at a later date.

Testing was conducted over two shorter lengths, the first being the northbound half of the road between km 25.64 and 29.46 that was recycled in 4 sections over 4 days during October 2000. The second section was the southbound half of the road between km 14.1 and 17.06, which was constructed in 5 lengths over the same number of days during November 2000. Results from specific tests were also obtained from various other short sections.

Carriageway and shoulder grading and grading modulus[1] results from the existing base course material were extracted from the consultant's rehabilitation design investigation report for comparative purposes.

Tests were taken on both the upper and lower 100 mm portions of the recycled layer and included, density and moisture content, UCS and ITS strengths, and material grading and grading modulus (GM). The GM is a useful parameter for comparing different materials, as the entire grading curve can be represented by a single value.

The test results are summarised in the Appendix (Section 8).

4. Analysis

4.1 Material characteristics/homogeneity

The primary material characteristics evaluated were the particle size distribution (grading) and the strength of the materials (UCS and ITS). Normally, the Atterberg limits would be evaluated but it was assumed that the cement would neutralise any plasticity, as normally happens. The objective of the investigation was to determine the consistency of vertical mixing of the material, the homogeneity of the processed material and the degree of compliance with the required strength specifications.

The average gradings of the existing shoulder and carriageway materials prior to recycling (based on the results in the Appendix) as well as the combined average of the shoulder and carriageway materials are shown in Figure 1. The specified grading envelopes for G3 and G4 materials [COM 86] indicate that all of the materials contain excessive fines, as a result of sand being a major component. Some residual cementation appears to be present in the carriageway material but in the shoulder material it seems to be minimal. The samples for these gradings did not include any of the previous bituminous surfacing, which was removed prior to sampling.

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[1] Grading Modulus (GM) = (P2+P425+P075)/100 where P2, P425 and P075 are the percentages retained on the 2.0, 0.425 and 0.075 mm sieves, respectively.

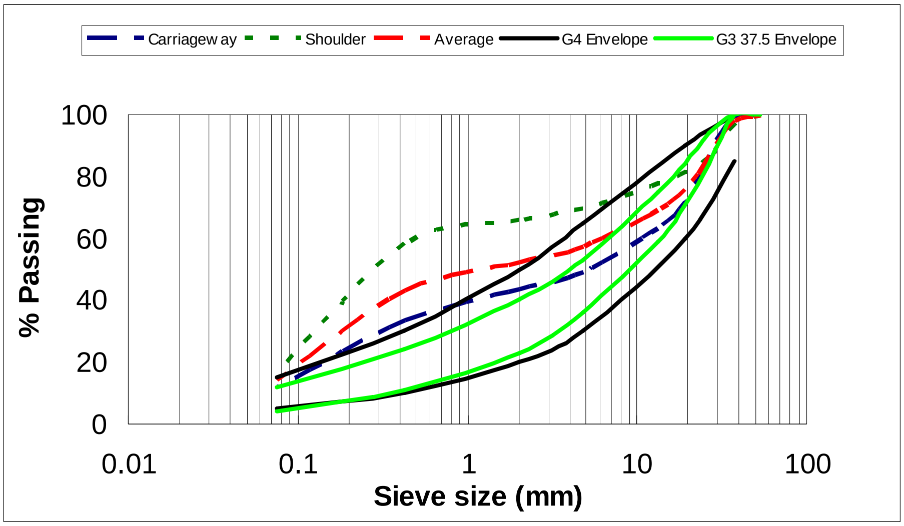

Figure 1. *Particle size distributions of existing road material relative to unbound material standards [SAI 98]*

Figure 2 shows the envelope of 62 grading analyses carried out on material removed from the road after milling (including particles of milled bituminous surfacing) as well as the averages for the shoulder, carriageway and combined materials. The envelope shows a wide spread with excessive fines but essentially no oversize, indicating the effectiveness of the milling operation. The materials are, however, generally gap graded with very little material in the 0.5 to 5.0 mm range, similar to the original material.

Examination of the results where individual grading analyses were carried out on the upper and lower 100 mm of the layer showed little significant differences between the two fractions (Figure 3). Six of the points lie on (or very close to) the line of equality; four lie below it and three above it. This is indicative of good vertical mixing, and is contrary to the general assumption that segregation is common with coarser material accumulating at the bottom of the layer [COL 01]. Apart from the coarsest material (GM = 2.41), the majority of the coarser (higher GM) of the materials from any individual layer in the data shown, in fact occur in the upper 100 mm of the layer. This anomaly may of course be a result of the relatively small proportion of aggregate larger than 30 mm in the material.

Analyses of the grading modulus using the cumulative sum technique [MOW 00] were carried out to identify trends in the particle size distribution. Distinct changes in the slope of the "cumulative sum" line indicate boundaries between homogeneous or uniform sections. The plot shown in Figure 4 is a composite plot of 43 results obtained between km 14.2 and km 31.8 including sections with no data (portions of the line with no data points) and should be assessed as such.

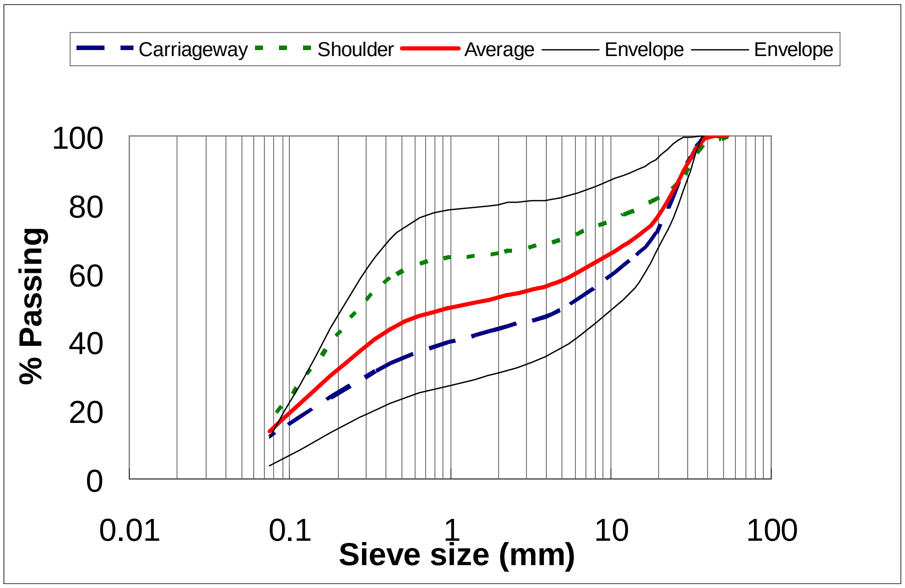

Figure 2: Particle size distributions of milled material

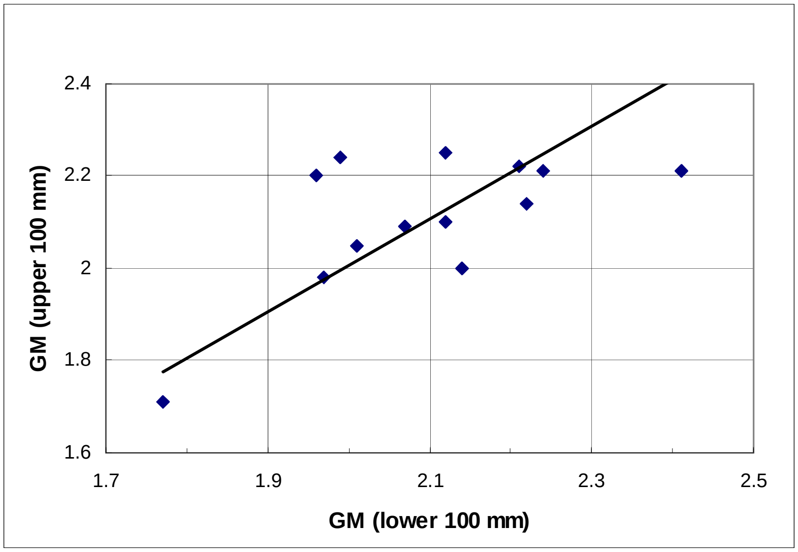

Figure 3: *Comparison of Grading Moduli in upper and lower 100 mm of recycled layer (solid line is line of equality)*

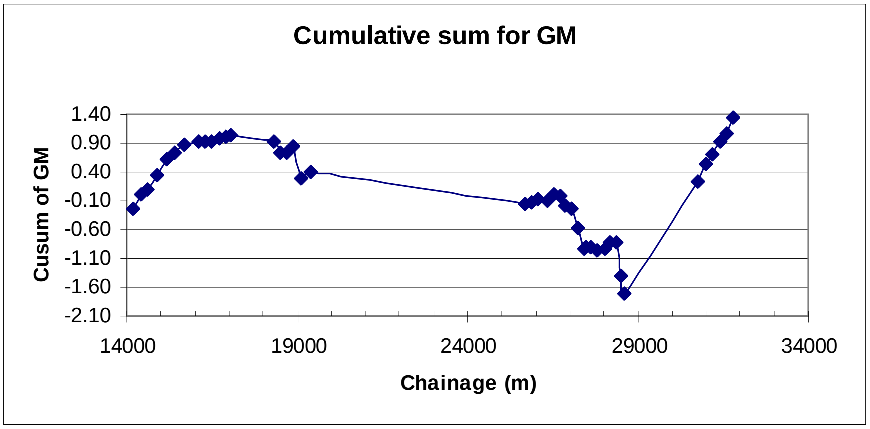

Figure 4: *Cumulative sum plot of grading modulus of milled material*

It is clear from Figure 4 that the material was relatively homogeneous between km 14.2 and 17.08, variable between km 18.3 and 19.4, and between km 25.7 and 28.6 and then extremely uniform between km 30.7 and 31.8. The homogenous sections can generally be related to daily construction lots but significant variations occur, eg, between km 18.3 and 19.4, which was constructed in a single shift. No reason for this can be inferred from the data available.

Samples were collected from site and compacted in the laboratory for standard Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) testing. The cumulative sums were plotted similarly to that for the grading modulus to determine homogeneity (Figures 5 and 6). The plots for both UCS and ITS are very similar, indicating that the variations in results are directly related to the materials and not the test techniques. The trends in fact correspond reasonably with the grading modulus cumulative sum plot, particularly between km 24 and 34. The changes in strength can thus probably be related to changes in the particle size distribution. Figure 7 shows the actual grading modulus, UCS and ITS results plotted against chainage.

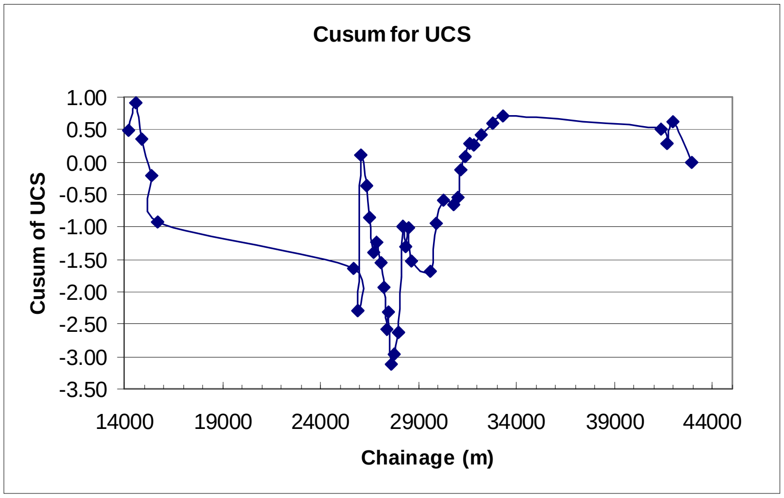

Figure 5: *Cumulative sum plot of Unconfined Compressive Strength (UCS)*

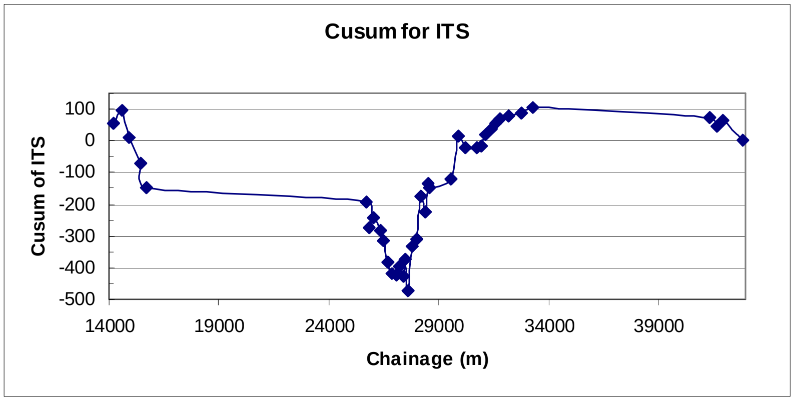

Figure 6: *Cumulative sum plot of Indirect Tensile Strength (ITS)*

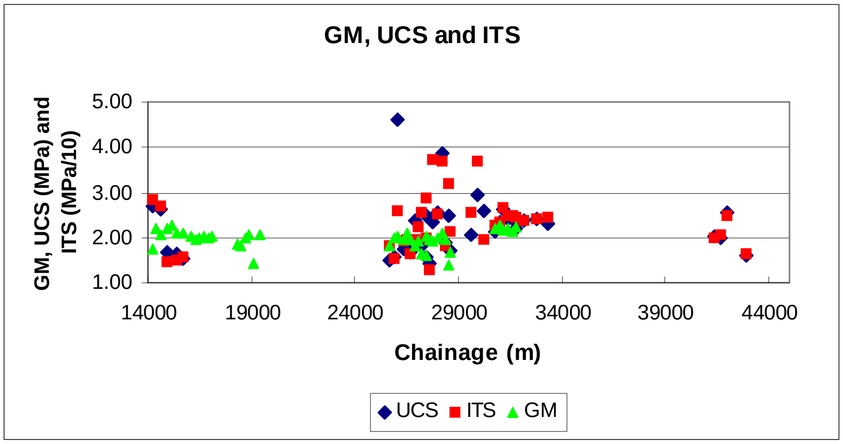

Figure 7: *Plot of UCS, ITS and grading modulus against chainage*

It is clear from the results that a wide range of material strengths has been obtained. In general the materials meet the specified strength requirements (both UCS of 1500 kPa and ITS of 200 kPa) although a number of the UCS and many of he ITS results are below the specified requirement. As the laboratory strengths are produced under significantly better control than the field results, in terms of compaction, mixing and curing, it can be assumed that the field strengths will on average be less than the laboratory strengths. On this basis, construction traffic on areas with low strengths, eg, around km 15, could result in premature damage to the structure. In the case under study, the recycled layer is subbase and the layer would not normally be opened to traffic for some time. It should, however, be noted that the laboratory strength result is obtained after 7 days of controlled curing, a process that is poorly reproduced in the field.

Recent work [PAI 04] has shown that high construction temperatures can accelerate the setting time of the cements currently available in South Africa considerably. The sections between km 25 and 29 were built during October and those between km 14 and 17 during November, a generally hotter month. This relationship was found not to be significant, however. It would appear that the difference is more likely to be related to improvements and streamlining of the construction procedure with time.

4.2 Compaction and density/depth variations

An attempt was made to determine the degree of compaction obtained and whether any density gradient occurred. It should be noted that relatively heavy compaction plant was utilised and the layer was only a nominal 200 mm thick, 50 mm more than a typical layer and 100 mm less than some of the layers that have been constructed using in situ recycling.

The first observation was that an average compaction in excess of 95 per cent Mod AASHTO (the specified minimum) was obtained with median values of 95.9 and 96.9 per cent for the two sections investigated. Closer examination indicates that the 44th and 17th percentiles of compaction, respectively, are 95 per cent indicating that up to 44 and 17 per cent respectively of the test results obtained do not comply with the specified requirement. It is not known whether additional rolling was applied, but it is unlikely given the limited compaction time specified (8 hours) for cement-stabilized materials [SAI 98]. In fact, working times of less than about 3 hours seem to be more appropriate for local cements during the summer months [AUS 98; VIC 00; PAI 04].

The high degree of non-compliance in the results from the second section could be attributed to the wide range in compaction moisture contents. Both data sets show definite trends that the drier the material was during compaction, the higher the degree of compaction (Figure 8). This is anomalous with conventional theory and is probably indicative of the problems associated with moisture content determination using nuclear methods [PAI 92]. Evaluation of the field moisture content (FMC) at compaction indicates that this was on average two per cent below optimum, which was the target value. This reduced moisture content is used to minimise shrinkage cracking [SAI 98].

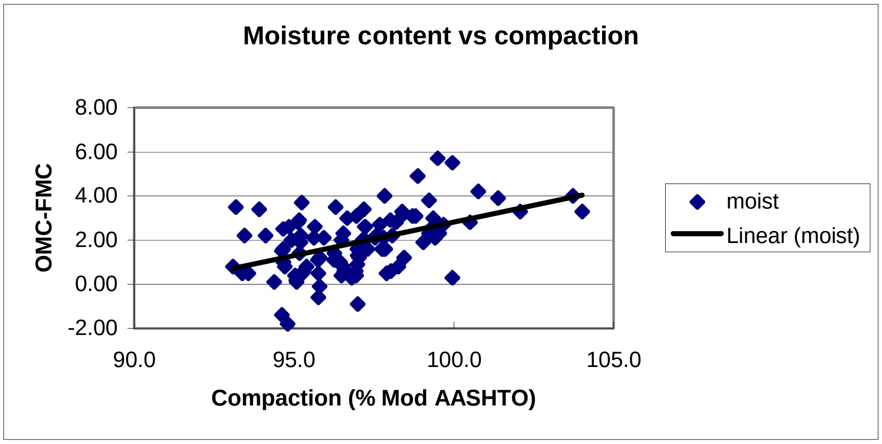

Figure 8: *Plot of trend between moisture content and compaction*

A comparison of the degree of compaction in the top 100 mm of the layer with that achieved in the lower 100 mm of the layer was carried out. It was clear that there was a marginal but probably insignificant difference (Figure 9).

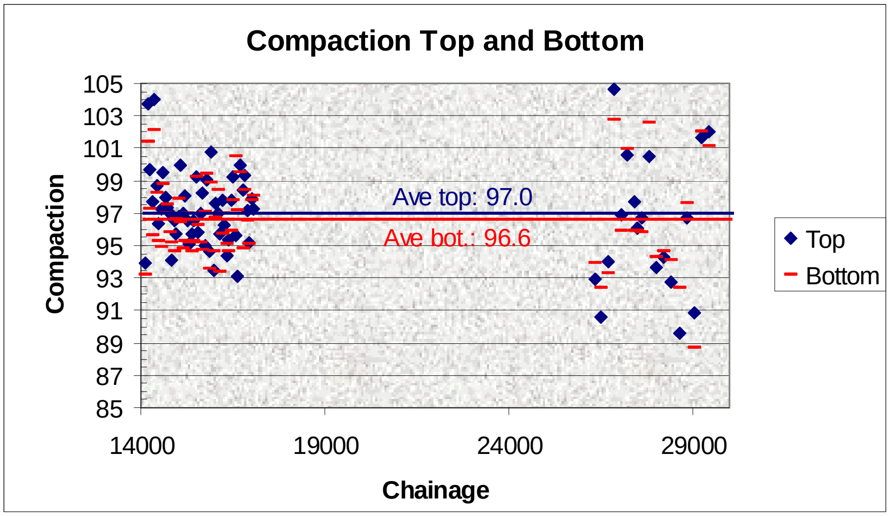

Figure 9: *Plot of compaction in top and bottom half of layer*

An evaluation of the potential for the material to be compacted to a high density was carried out using the COMPACT software [COM 97]. Based on the particle size distribution a predicted maximum density of 2184 kg/m^3 and optimum moisture content of 7.4 per cent was determined. These agree closely with those determined in practice. It is theoretically possible to compact the material to 82.4 per cent of apparent solid density, ie, a maximum in situ density of 2184 kg/m^3 or 98.5 per cent of Mod AASHTO maximum dry density. The data in Figure 10 show a number of values exceeding this. This is indicative of considerable variability in the material grading or poor testing of the compaction.

Based on these results, it appears that for a 200 mm layer, conventional compaction plant, albeit heavier than the minimum suggested [WIR 98], is sufficient to achieve homogeneous density through the layer. Further investigation would be necessary to ensure uniform compaction through layers thicker than 200 mm, although layers up to 300 mm are regularly constructed in one pass. It should, however, be noted that proof rolling should initially be carried out and a “method specification” based on the outcome of this, followed. This should be adjusted as the material properties vary. Conventional quality control testing should, however, still be used.

5. Conclusions

An investigation into the properties and homogeneity of recycled material has been carried out on a full-scale contract. The investigation showed that the process of cement stabilization using in situ recycling that was followed resulted in a successful project.

Despite the variation in material properties and the necessity to blend two different types of material, a homogeneous layer was generally achieved. The test results show that vertical mixing of the material was uniform with no marked segregation of coarser material. The project also indicated that conventional heavy equipment is adequate for the compaction of layers up to 200 mm thick.

An area that possibly needs more attention is the accurate and repeatable measurement of compaction within the time frame allowed for working of the cement stabilized layers. This will allow areas with insufficient compaction to be improved within the expected working time and prior to development of the excessive cementing bonds that will be broken down with additional rolling.

The use of proof rolling and a method specification for compaction is suggested.

6. Acknowledgements

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8. Appendix

Summarised properties of materials before recycling

Property	Number of samples	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
Shoulder						
P26.5*	21	60	100	86.3	10.6	0.12
P13.2	21	37	100	78.1	18.6	0.24
P4.75	21	22	99	69.7	24.0	0.34
P2.0	21	16	97	66.2	26.1	0.39
P0.425	21	10	94	58.6	27.2	0.46
P0.075	21	5	47	16.7	11.1	0.66
GM	21	0.62	2.66	1.59	0.61	0.38
Plasticity Index (%)	21	NP	12	-	-	-
Linear shrinkage (%)	21	0	6.2	1.9	2.4	1.26
MDD** (kg/m3)	21	1760	2195	1957	126.6	0.06
OMC **(%)	21	5.2	13.5	9.2	2.5	0.27
Carriageway						
P26.5*	13	77	100	88	7.0	0.08
P13.2	13	43	100	63.6	13.6	0.21
P4.75	13	31	98	49.5	15.9	0.32
P2.0	13	27	97	44	17.1	0.39
P0.425	13	21	90	33.9	17.6	0.52
P0.075	13	9	31	12.2	5.7	0.47
GM	13	0.82	2.42	2.10	0.4	0.19
Plasticity Index (%)	13	NP	7	-	-	-
Linear shrinkage (%)	13	0	3.4	1.5	1.1	0.73
MDD (kg/m3)	13	1850	2354	2250	146.4	0.07
OMC (%)	13	4.7	12.1	6.6	2.4	0.36

* P26.5, P13.2, etc are the percentages passing the 26.5, 13.2 etc mm sieve.
** MDD and OMC are maximum dry density (Mod AASHTO effort) and Optimum Moisture Content at 100% Mod AASHTO.
NP = Non-Plastic

Summarised properties of milled and recycled materials

Property	Number of samples	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
P26.5*	62	80	99	90.7	4.6	0.05
P13.2	62	54	89	71.2	7.1	0.1
P4.75	62	38	82	56.6	9.8	0.17
P2.0	62	31	80	50.6	9.9	0.17
P0.425	62	22	70	39.5	10.1	0.26
P0.075	62	4	12	7.3	1.7	0.23
GM	62	1.4	2.41	2.03	0.205	0.1
UCSx (MPa)	39	1.41	4.62	2.22	0.64	0.29
ITSx (kPa)	39	128	373	230	60.2	0.26
MDD**(kg/m3)	8	2167	2216	2187	16.6	0.01
OMC** (%)	8	7.0	9.4	7.9	0.92	0.11
FDD+(kg/m3)	100	2022	2254	2120	44.8	0.02
FMC+ (%)	100	3.0	9.0	5.9	1.29	0.22
Compaction (%)	100	93	104	97	2.15	0.02
FMC/OMC	100	0.39	1.25	0.76	0.17	0.22

* P26.5, P13.2, etc are the percentages passing the 26.5, 13.2 etc mm sieve.

x UCS and ITS are unconfined compressive and indirect tensile strengths

** MDD and OMC are maximum dry density (Mod AASHTO effort) and Optimum Moisture Content at 100% Mod AASHTO.

\+ Field Dry Density (FDD) and Field Moisture Content (FMC).