APPENDIX H

Technical Memorandum

Updating Bituminous Stabilized Materials Guidelines: Mix Design Report, Phase II

Task 8: Curing Protocol: Validation

Final Report: Sept 2008

AUTHORS:
KJ Jenkins
PK Moloto

1. FIELD MONITORING AND VALIDATION

The N7 carriage highway towards Malmesbury in Cape Town served as CIPR project for curing investigation.

Soil Lab (Pty) Ltd was designated as the authority to perform site investigations for monitoring of initial field properties and construction quality during the CIPR process. Soil Lab performed tests on the original road prior to the CIPR process. The performed laboratory reports showed high compaction as witnessed by measured field densities of Hornfels and asphalt pavement. Table 3.6 put below outlines a summary of reported results.

Table H.1: Soil Lab density report on N7 highway prior to rehabilitation

Project	**ROADSMART: N7**				**Job No:**	**SK883**	
Layer	**ETB: CRUSHED HORNFELLS & ASPHALT**				**Date:**	**14.02.2007**	
Test No.	**TEST METHOD**						
Stake Value/Off Set		**16670L**	**16650R**	**16560R**	**16540L**	**16500R**	**16400L**
Layer Thickness (mm)		256	258	257	258	256	256
Mod. AASHTO Density (a)	TMH 1 A7	2139	2135	2134	2114	2170	2155
% Optimum Moisture Content	TMH 1 A7	5.5	7	5	7.2	6.5	5.8
Bulk Relative Density (b)	D14 + D15	2597	2565	2556	2524	2553	2651
Field Density (kg/m^3)	TMH 1 A10 (b)	2367	2350	2323	2272	2305	2287
% Field Moisture Content	TMH1 A7	2.3	4	2.2	3.1	3.7	3.3
% Compaction (a)		110.7	110.1	108.9	107.5	106.2	106.1
% Compaction (b)		91.1	91.6	90.9	90	90.3	86.3
% Field Binder Content		1.5	2.3	2.8	2.7	2.9	3.2

Prior to the CIPR process, average original field binder content was in the vicinity of 2.5% from the asphalt section whilst average field moisture content showed 3%. The noticeable high Mod. AASHTO field density values may stem from years of layer compaction under traffic loading.

Test results by Soil Lab suggested N7 CIPR project be treated with emulsified bitumen binder and milling of RAP sections were to involve depths of 250-300 mm. Table 3.7 demonstrates mix design properties. Road rehabilitation properties have also being included.

Table H.2: N7 CIPR project properties

Material Type	Emulsion Content	Res Binder Cont	Cement Content	Milling Depth	Project Length
Crushed Rock Hornfels	3.3%	2.0%	1%	250 mm	6 km

Milling was done using Caterpillar recycling machinery. In terms of CIPR sequence, bitumen emulsion truck hauled caterpillar milling machine in front, supplying bitumen emulsion to the recycler. The steel roller compaction machines followed the milling recycler machine for compaction of rehabilitated material.

Figure 3.13 below shows schematic view of N7 CIPR process.

Figure H.1 Schematic process of N7 CIPR construction project, April 2007

1.1. Crushed Rock Hornfels Material Properties

Aggregate Properties

The crushed stone Hornfels material was recycled from the exciting pavement prior to rehabilitation. To record, 5 tones of 100% RAP crushed rock Hornfels material was transported to Stellenbosch University for laboratory use.

Material was sampled at six isolated locations around the stockpile using sampling techniques for the grading analysis. Particles larger than 19mm were crushed for laboratory grading purposes. Only particles passing through 19mm sieve were considered and grading involved both dry and wet grading tests according to TMH 1 manual.

Figure 3.14 below illustrates crushed rock Hornfels stockpile including dry and wet grading envelopes.

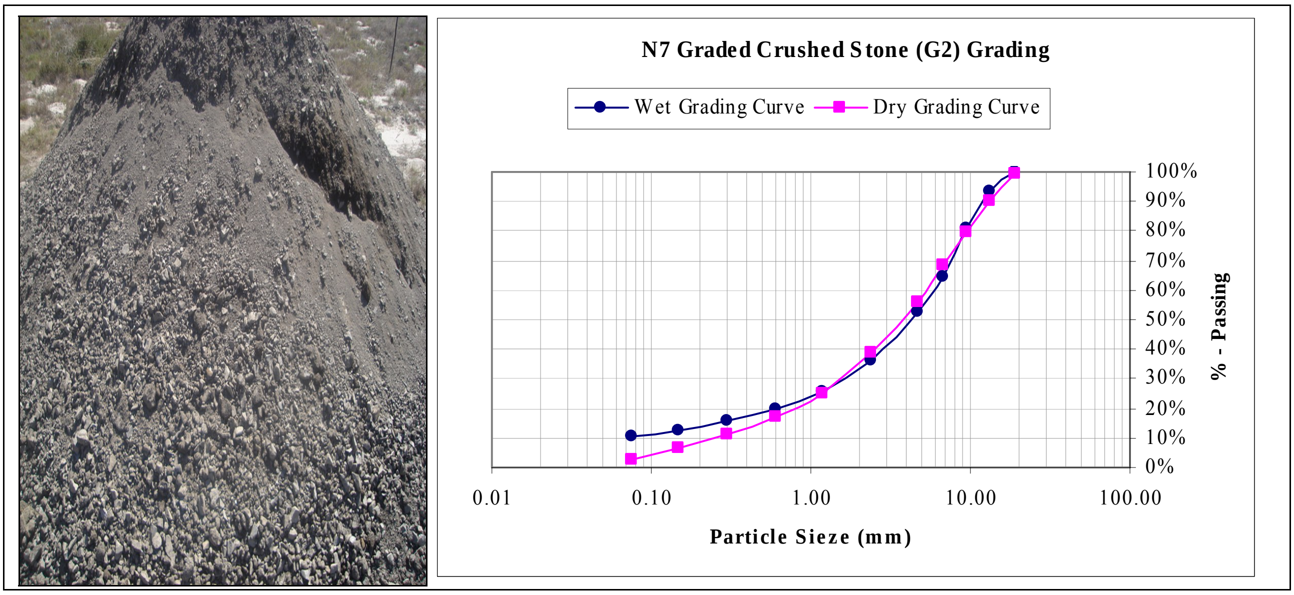

Figure H.2 Stockpile of 100% RAP crushed Hornfels material on N7 highway & lab grading curves

As observed from Figure 3.15, the wet grading curve improved particles passing through 0.075 mm sieve by almost 7%. The wet grading curve satisfies TG2 grading envelopes for particles passing through 0.075 mm sieves. As mentioned in literature review, particularly for foam mixes, the filler content is responsible for the most coating by foam binder in the pugmill mixer.

Furthermore, filler content from the grading envelopes is well above 10% and this should improve foam binder mixing properties. Consequently, controlled laboratory grading will have to be implemented and closely monitored to maintain consistent field grading.

- ***Maximum Dry Density Properties***

Field investigations by Soil Lab from table 3.6 reported average MDD values of 2114-2170 kg/m3 corresponding to average field OMC values of 5-7.2% using standard Modified Aashto compaction. Mould sizes of 150x100 mm were used at Stellenbosch University for analysis of Mod. AASHTO compaction using Proctor compaction shown in figure 3.15 below.

Figure H.3 Standard Proctor compaction machine

Laboratory MDD investigation at Stellenbosch University using standard Mod. Proctor compaction provides the following results shown in figure 3.16:

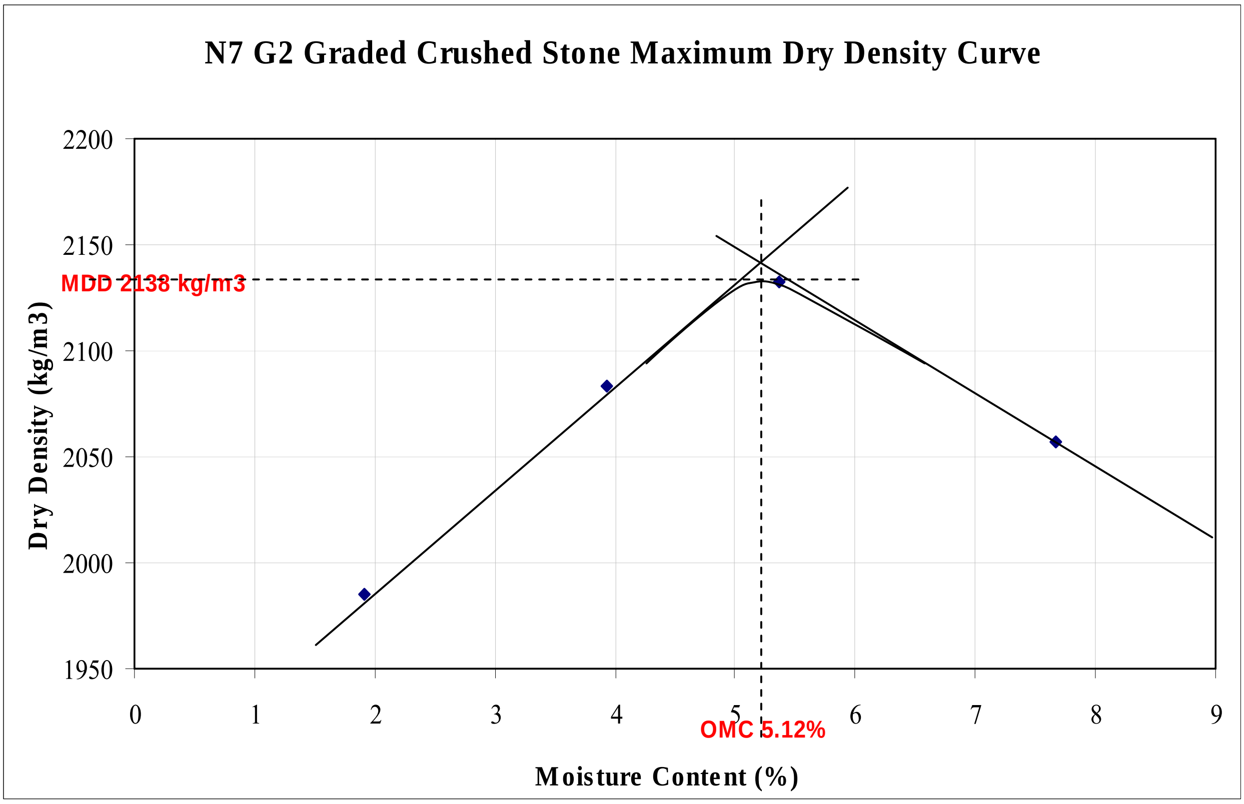

Figure H.4 N7 Graded crushed rock maximum dry density curve

Laboratory analysis showed MDD of 2138 kg/m3 and OMC value of 5.12%. Results produced by Stellenbosch University are in the same order of magnitude as field results by Soil Lab and this further demonstrates close correlation between laboratory and field environments.

Following specimens to be produced at Stellenbosch University, material properties obtained from Figure 3.16 and controlled grading from wet grading curve in Figure 3.14 will be implemented. Moreover, close correlation between laboratory and field conditions will be strictly maintained to yield comparable trends.

1.2. Moisture Sampling and Trends

Moisture sampling took place during construction and service periods. Design specifications on the project required that the recycled layer be exposed to in situ climate with no traffic prior to applying the wearing course layer. Normally, this process varied between 7 to 14 days maximum.

Exposure of CIPR layer to in situ conditions led to monitoring of field moisture during the first 7 days of exposure. Once the recycled layer was compacted, water would be sprayed occasionally over the top surface of recycled layer to aid with the cement hydration process. This technique was applied to stiffen the top surface and to also make the surface smooth for primer application.

Following this process, the layer would then be subject to field conditions, with the aim to achieve 0.5 x %OMC at upper depth section of the recycled layer, a prerequisite before primer can be applied prior to the wearing course layer.

In situ moisture monitoring was achieved with the use of a jack hammer. Holes up to 300 mm deep were drilled with the most average depth being around 230 mm deep. Also, up to 12 points (B1-B6) along the road have been investigated. These points are located at 10m to 20m intervals per group of points over 2 km stretch of rehabilitated road.

During daily in situ moisture monitoring, specific points representing moisture contents at any particular locations served as reference points for future monitoring. This meant that assessment of moisture measurements during future visits would be performed within a localized radius of about 500 mm.

Figure 3.17 below shows how moisture samples were collected during construction phase of road rehabilitation.

Figure H.5 Collection of moisture samples on site during and after construction

Moisture sampling continued well into the service period of up to 7 months. Figure 3.18 illustrates moisture contents expressed as percentage OMC. All field moisture samples were oven dried for moisture analysis.

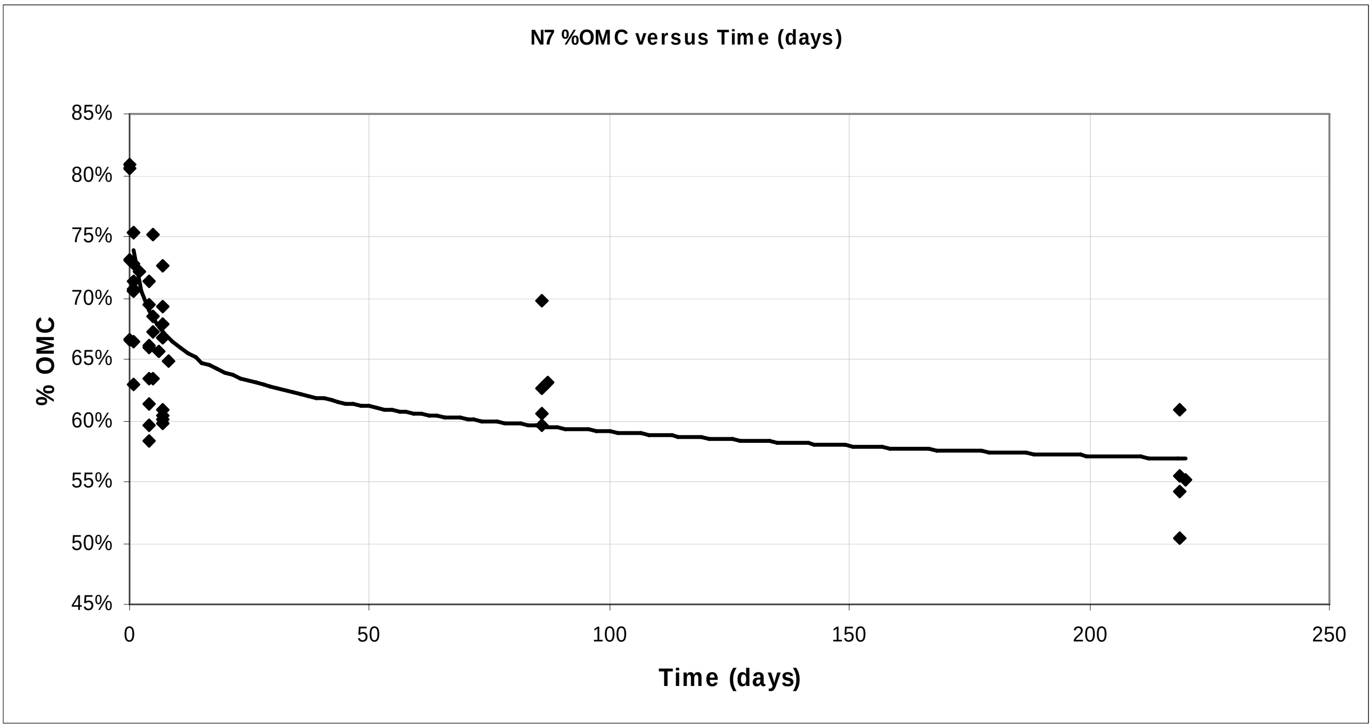

Figure H.6 N7 Graded crushed rock percentage OMC curve over 6 months of curing period

The gradual decrease in moisture content is a result of the curing of the rehabilitated layer. As observed from Figure 3.18, %OMC ranges from 75% during construction to 55 %OMC after 7 months of service period.

Moreover, following the trend line from Figure 3.18, EMC should be reached within 2 to 5 years of field curing (To be clarified by extrapolation into 2 to 5 years in Figure 3.18). Furthermore, most change in field moisture occurs within 6 months to 1 year from the time of construction. As a result, EMC can stabilise anywhere between 50 to 40 % of OMC within a period of 2 to 5 years.

1.3. Field Temperature and Humidity Conditions

In order to gain holistic understanding of field curing mechanisms, it was necessary to monitor temperature and relative humidity conditions in the recycled layer. Obtaining field data on temperature and relative humidity conditions will help guide with formulation of laboratory curing environments conducive to field curing simulation.

Due to drainage channels in pavement structures, it became necessary to capture 2/3 of the height of recycled layer on the shoulder section due to typical higher moistures levels at these locations. Capturing of 1/3 of the height of recycled layer closer to the centerline was considered adequate. Distribution of temperature and relative humidity conditions at these locations were critical to unlocking understanding of field curing mechanisms at different positions within the recycled pavement.

Figure 3.19 shown below illustrates typical positions maintained for button installations in the recycled pavement.

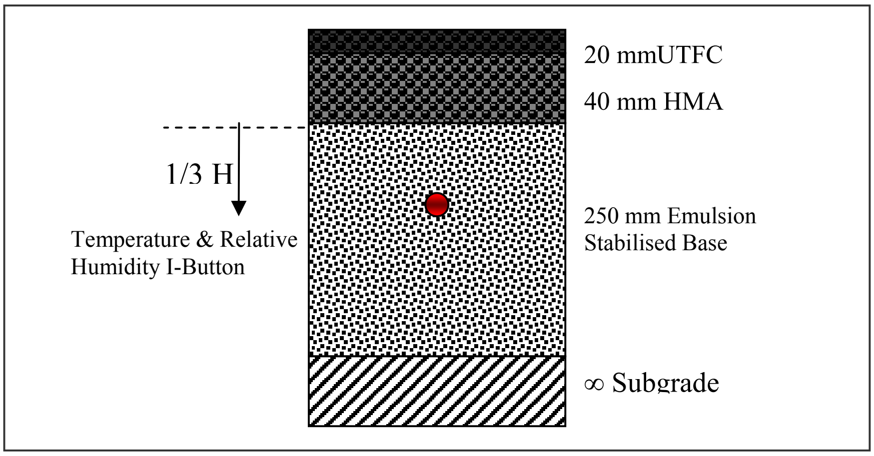

Figure H.7 N7 centreline temperature and relative humidity button location within recycled layer

Locations of temperature and relative humidity buttons were mainly governed by logistic challenges on the road. Due to safety and coordination issues, it was decided that investigation of recycled pavement be performed closer to the N7 weigh bridge centre.

A plan layout of investigated points along the recycled pavement is shown below in Figure 3.20. The designated OL means outer lane (closer to shoulder line) and IL means inner lane (closer to centreline). The red points represent temperature and humidity buttons whilst grey points represent extra investigation locations. In total, both moisture and stiffness analysis were performed on all 12 points during construction and service period of up to 7 months.

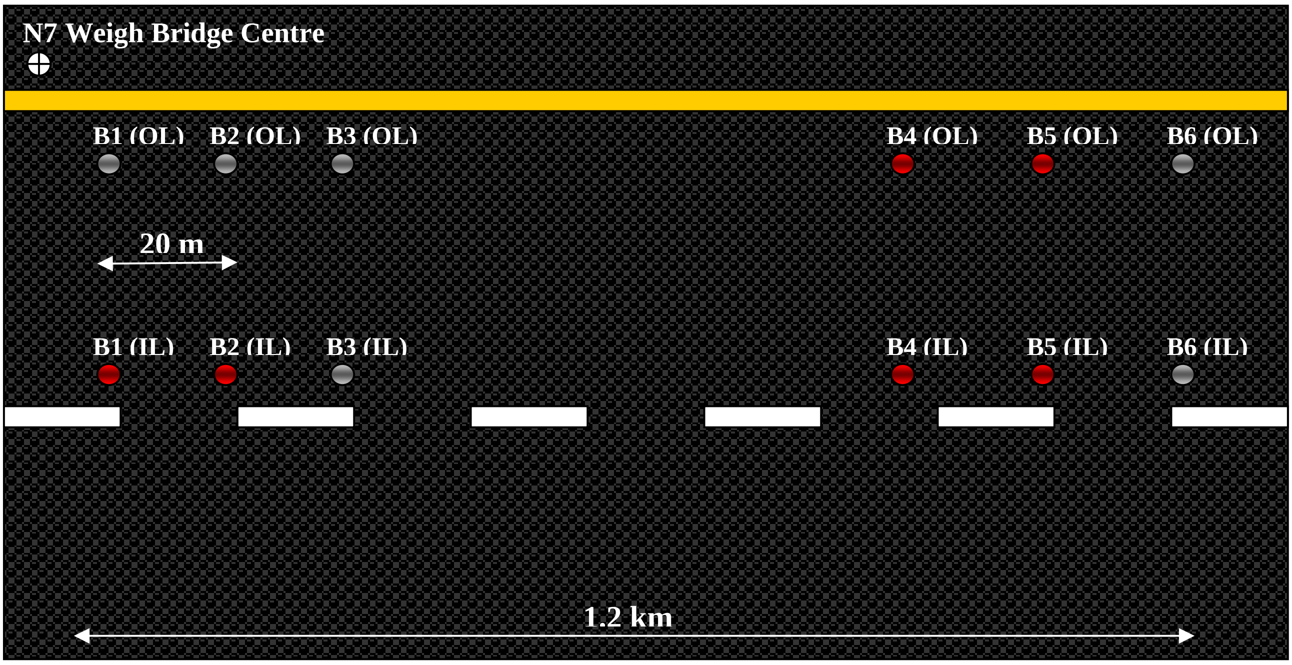

Figure H.8 N7 schematic view of investigated points along the rehabilitated road

Installation of temperature and humidity buttons involved drilling of 10 mm diameter holes into recycled pavement. Buttons were covered with dry soft sand and then later with warm mix asphalt to seal off the holes. After measurements of field data, buttons were extracted using 100 mm diameter coring machine. Figure 3.21 shown below illustrates button installations and extraction processes.

Figure H.9 Installation of i-buttons on N7 highway for temperature & relative humidity measurements

All button installations were performed after construction of UTFC layer to help maintain proper markings on the road surface. Centreline depths were maintained at 85 mm (1/3 H) into the recycled layer. Holes of 85 mm plus 40 mm of HMA and 20 mm of UTFC were drilled. This led to holes of up to 145 mm being drilled at centreline positions. Shoulder line holes were maintained at 230 mm.

Both field temperature and relative humidity centerline data is presented in Figure 3.22. All data represents 5 months of field curing period.

Figure H.10 N7 centreline temperature and relative humidity data

From Figure 3.22, temperature seems to rise as seasons approach summer temperatures. The highest recorded temperature is in the vicinity of 38°C. It is further noted that temperatures of up to 40ºC and perhaps even higher temperatures are reasonably evident in the field. This suggests that it would be realistic may be necessary to cure laboratory samples at these temperatures to accelerate laboratory curing.

As part of the research process, it was desirable to be able to witness relative humidity conditions that showed a decrease in field trends corresponding to decreasing field moisture contents. Results in Figure 3.22 show relative humidity conditions that are well above 100% despite curing of recycled layer. Consequently, field humidity conditions have proven difficult regarding relating field moisture content to humidity conditions and also for the purpose of reconciling observed trends to moisture trends.

A trial test in the laboratory also made it difficult to reconcile humidity conditions to sample's moisture content. Furthermore, the varying trends of field humidity conditions suggest that temperature curing provides a more effective measure for modeling moisture change than controlled humidity conditions. Relative humidity conditions are a real part of the curing environment mechanisms necessary for curing simulation, but are not necessarily effective for accelerated moisture extraction. In-service, high relative humidity conditions are readily achieved in the layer even at relatively low moisture contents.

Consequently, relative humidity as recorded by the buttons is a measure of localized humidity and not a reliable reflection of moisture content. Moisture content indicates with the compositional properties of the mix in terms amount of water by mass, whilst relative humidity in a layer is little more than a reflection of moisture presence.

Consequently, curing at set relative humidity conditions and lower temperatures would prove to be a lengthy process, whilst the combination of relative humidity conditions and higher temperatures would prove ideal for field simulation whilst achieving rapid curing.

1.4. Field Compaction and Stiffness Behaviour

Field compaction is achievable using high energy steel-drum rollers. The working action of steel rollers coupled with high energy vibrations has a significant impact on field stiffness trends. Depending on the surface contact-area, the kneading action of steel rollers influences shallow depth stiffness and article orientation whilst bearing weight of compactor coupled with high amplitude vibrations impacts on deeper sections of the recycled layer.

Figure 3.23 depicts both caterpillar compactor and PSPA device.

Figure H.11 Field compaction using high energy steel rollers and the relative impact on stiffness

Figure 3.24 depicts three measurements made by the PSPA device on centerline position B2 (IL). These measurements were made hours after field compaction by high energy steel rollers. As mentioned before, the kneading action of the rollers seems to impact the first 50 to 80 mm of the recycled layer. The kneading action and additional high frequency vibrations seem to generate the most stiffness at the top third of the recycled layer. There seems to be an interface region within the recycled layer where trends shift back to stiffer regions with increasing depth especially from 150 mm onwards.

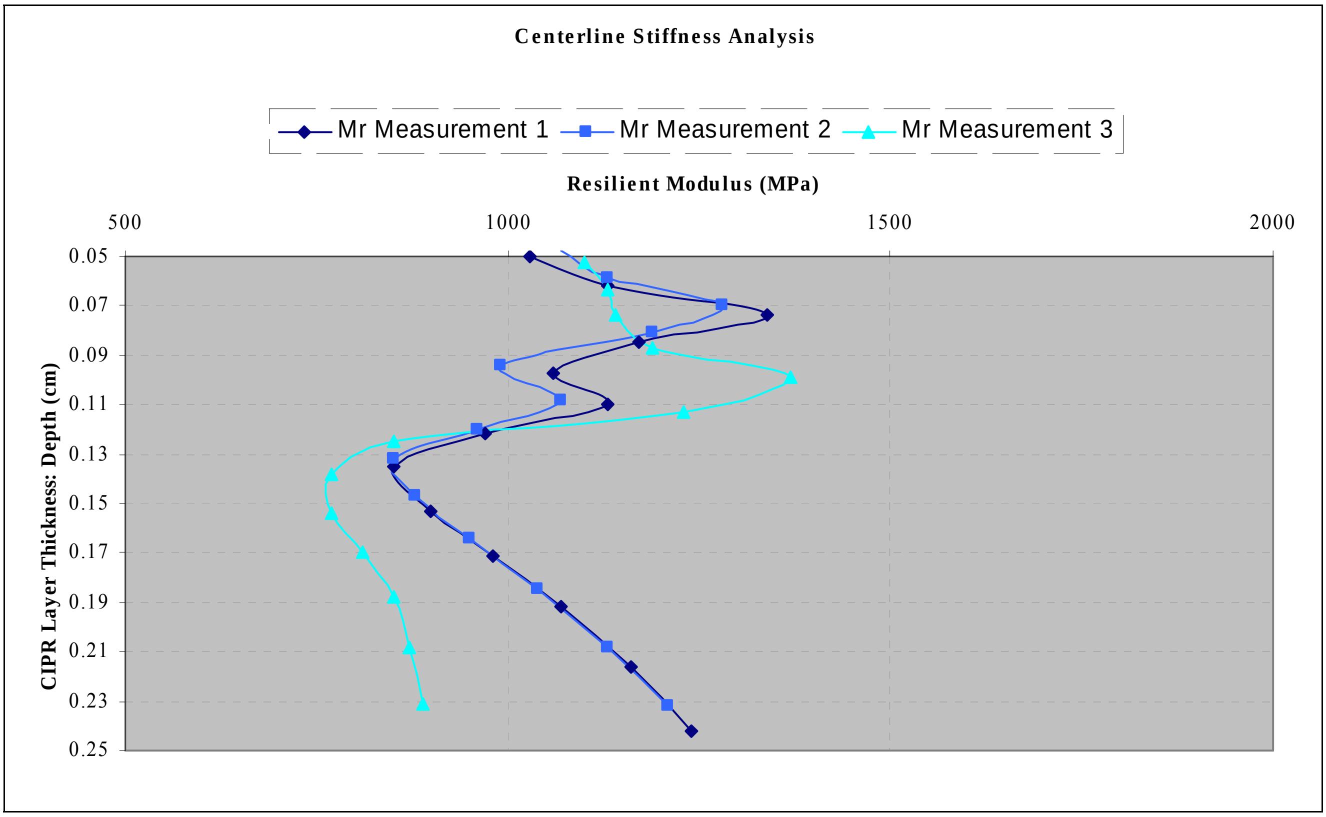

Figure H.12 N7 crushed rock day 0 stiffness behaviour after compaction on centreline position B2 (IL).

Stiffness patterns after compaction also suggest that stiffness is not constant within the recycled layer. The action of steel rollers has profound impact on trends in stiffness. It was considered essential to the understanding of the effects of curing to monitor stiffness patterns with time during construction and the in-service period.

Each stiffness line shown in Figure 3.43 represents a single measurement by the PSPA device. An average value if automatically calculated from the stiffness distribution of each measurement. The measure results have been summaries in table 3.8 shown below.

Table H.3: Summary of centreline PSPA stiffness modulus performance over 6 months of curing

CENTER LINE STIFFNESS: POSITION B2 (IL)								
Coverage of BSM layer	Date	**Longitudinal Direction Mr (MPa)**						
		Top Stiffness: Mr (50 - 240mm Depth)						
		DAY	**Mr 1**	**Mr 2**	**Mr 3**	**Average Mr**	**Std Dev**	**Cov (%)**
Unsurfaced	11-Apr-2007	0	1079	1058	998	1045	42.254	4.04%
	12-Apr-2007	1	995	1295	1175	1155	151.238	13.10%
	14-Apr-2007	3	1285	1330	1503	1373	115.281	8.40%
	16-Apr-2007	5	1367	1617	1562	1515	131.470	8.68%
	18-Apr-2007	7	1632	1591	1566	1596	33.634	2.11%
Surfaced								
	20-Apr-2007	9	1600	1650	1550	1600	50.000	3.13%
	5-Jul-2007	85	1596	2046	2416	2019	410.819	20.35%
	15-Nov-2007	219	3243	2416	3053	2904	432.912	14.91%

All three measurements were made on Day 0 of compacted material at location B2 (IL). The three measurements have been averaged to yield Day 0 stiffness on location B2 (IL) provided the coefficient of variation is less that 20%. Readings with coefficient of variation of more than 20% represent variability of measurements not supportive of localized trends.

The underlined stiffness analysis process continued for the entire field monitoring process. All points shown in Figure 3.20 were monitored during the 7 months of field analysis. Both moisture and stiffness trends were monitored on each occasion as outlined in Table 3.8.

In order to capture field stiffness patterns, it was necessary to sketch all stiffness distribution curves on a single graph for the purpose of correlating field curing to stiffness performance. Curing of the recycled layer involves release of moisture with time. The curing process hardens the recycled material, as witnessed from preliminary tests with tangent modulus performance increasing with a decrease in moisture contents.

Figure 3.25 demonstrates average centerline stiffness behaviour of up to 7 months of field data. All stiffness trends have been plotted against depth of recycled layer.

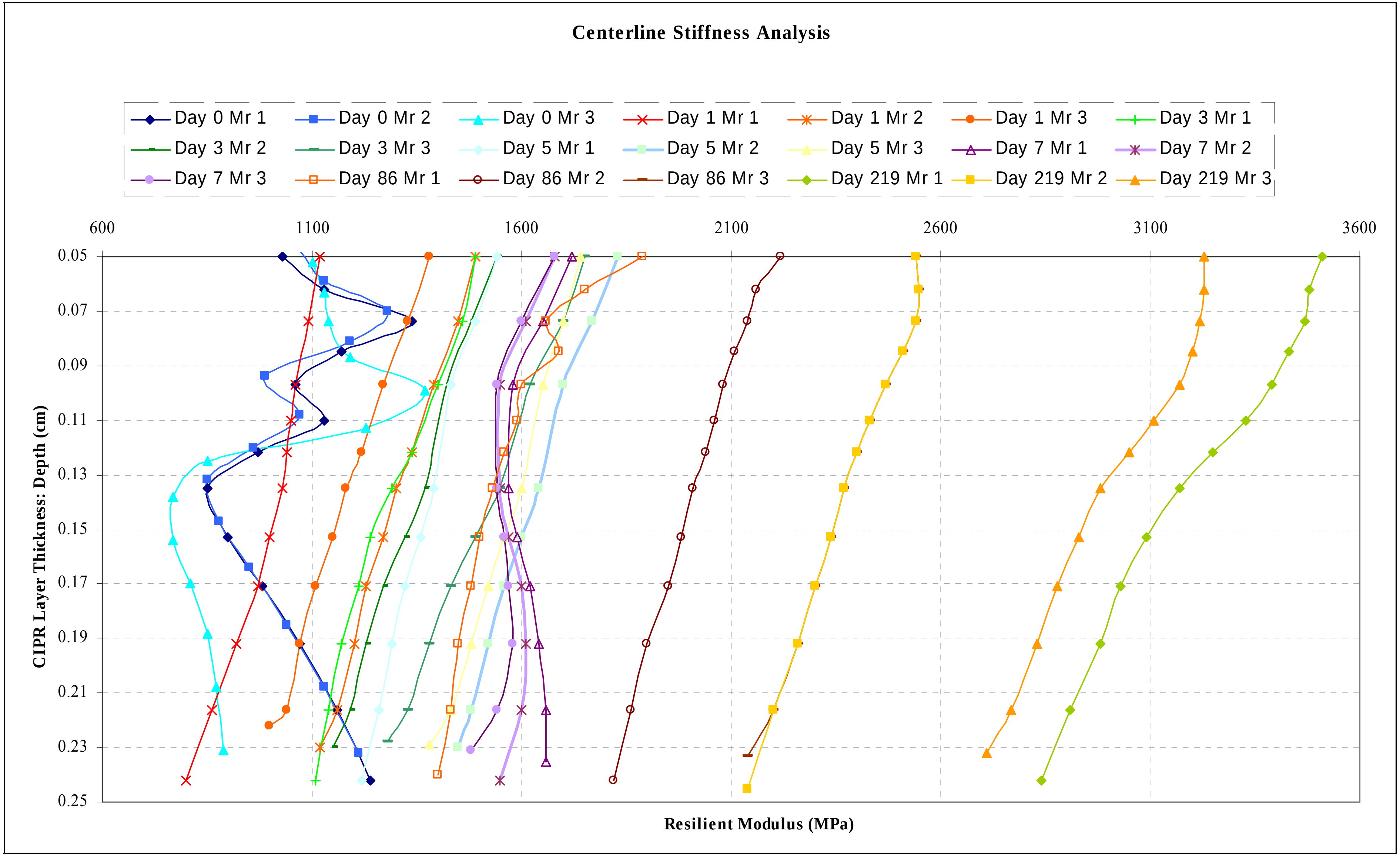

Figure H.13 N7 Graded crushed rock centreline stiffness development during 6 months of field curing after construction

In Figure 3.25, a profound trend in stiffness development with time is noted. The development in stiffness with time is mainly accredited to field curing. The inclusion of cement in layer would also result in layer stiffening.

The variable Day 0 trends evolve into uniform stiffness distributions, over time. The stiffness profiles become more linear in terms of distribution within the depth of the recycled layer. The upper portions of the layer become stiffer than deeper portions. The rapid stiffening at shallow depths is manly attributed to loss of moisture at much faster rate near the surface. Consequently, it takes more time for the bottom section of recycled layer to lose moisture, leading to lower stiffness values as influenced by slightly higher moisture contents at these regions.

Table 3.9 below represents summary of all points along the road during construction and service period. Both % of OMC and corresponding stiffness values have been presented.

In order to generate more sensible results, it was necessary to isolate position B1-B3 as a separate location. Location B4-B6 being further down the road was designated as single section separate from B1-B3 locations. Figure 3.20 illustrates the two main different locations along the recycled road.

Table H.4: Summary of centreline PSPA stiffness modulus performance: All positions (B1-B6)

DAY	%OMC	B1 (MPa)	B2 (MPa)	B3 (MPa)	B1-B3 Avg (MPa)	Std Dev	Cov (%)
0	75%	830	963	900	898	66	7.39%
1	70%	975	980	958	971	11	1.17%
3	64%	938	1050	983	990	57	5.71%
5	69%	1133	1025	1200	1119	88	7.89%
7	63%	1163	1038	1120	1107	64	5.74%
9	67%	1283	1250	1100	1211	98	8.06%
86	63%	1617	1692	2192	1833	313	17.05%
219	55%	2900	3200	2700	2933	252	8.58%

DAY	%OMC	B4 (MPa)	B5 (MPa)	B6 (MPa)	B4-B6 Avg (MPa)	Std Dev	Cov (%)
0	75%	877	622	697	732	131	17.91%
1	70%	1033	850	933	939	92	9.78%
3	64%	983	940	833	919	77	8.40%
5	69%	975	1113	1117	1068	81	7.55%
7	63%	1070	1200	1183	1151	71	6.15%
9	67%	1225	1150	1300	1225	75	6.12%
86	63%	2321	2300	1940	2187	214	9.80%
219	55%	3400	2933	3067	3133	240	7.67%

A summary of all results in Table 3.9 are plotted in Figure 3.26 shown below. PSPA stiffness analysis shows almost identical but slightly higher stiffness values at locations B4-B6 than those at locations B1-B3. Pavement section at locations B4-B6 is on higher vertical slope than locations B1-B3. It may be that terrain at locations B4-B6 is slightly stiffer due to subgrade bedrock properties and other additional factors such as higher temperatures in the recycled layer at time of PSPA stiffness measurements.

Stellenbosch N7 PSPA Data: Emulsion Section

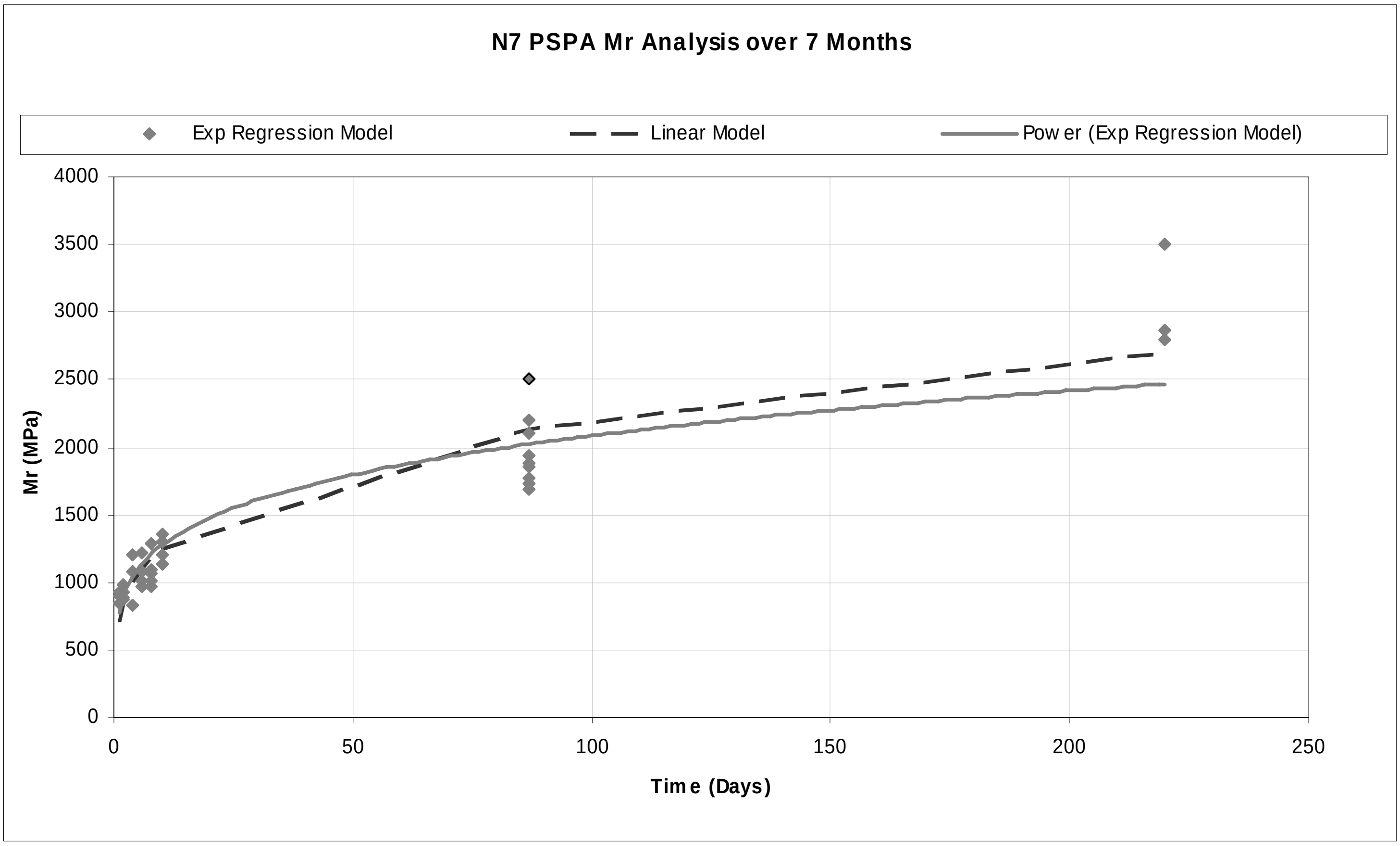

Figure H.14 N7 Graded crushed rock centreline stiffness performance during 7 months of field curing

PSPA measurements (Stellenbosch) revealed that after 7 months of construction, stiffness of emulsion treated ETB layer increased by 3 fold. Because the N7 is a newly constructed road, stiffness growth may well continue into the next five years at least. This is validated by observations made from the 6 year old foam section on N7 showing stiffness growth since 2002 (Data by CSIR).

The most important observation is that field curing has enormous impact on stiffness performance and that laboratory curing will have to replicate field behaviour.

CSIR N7 LTPP PSPA Data: Foam Section

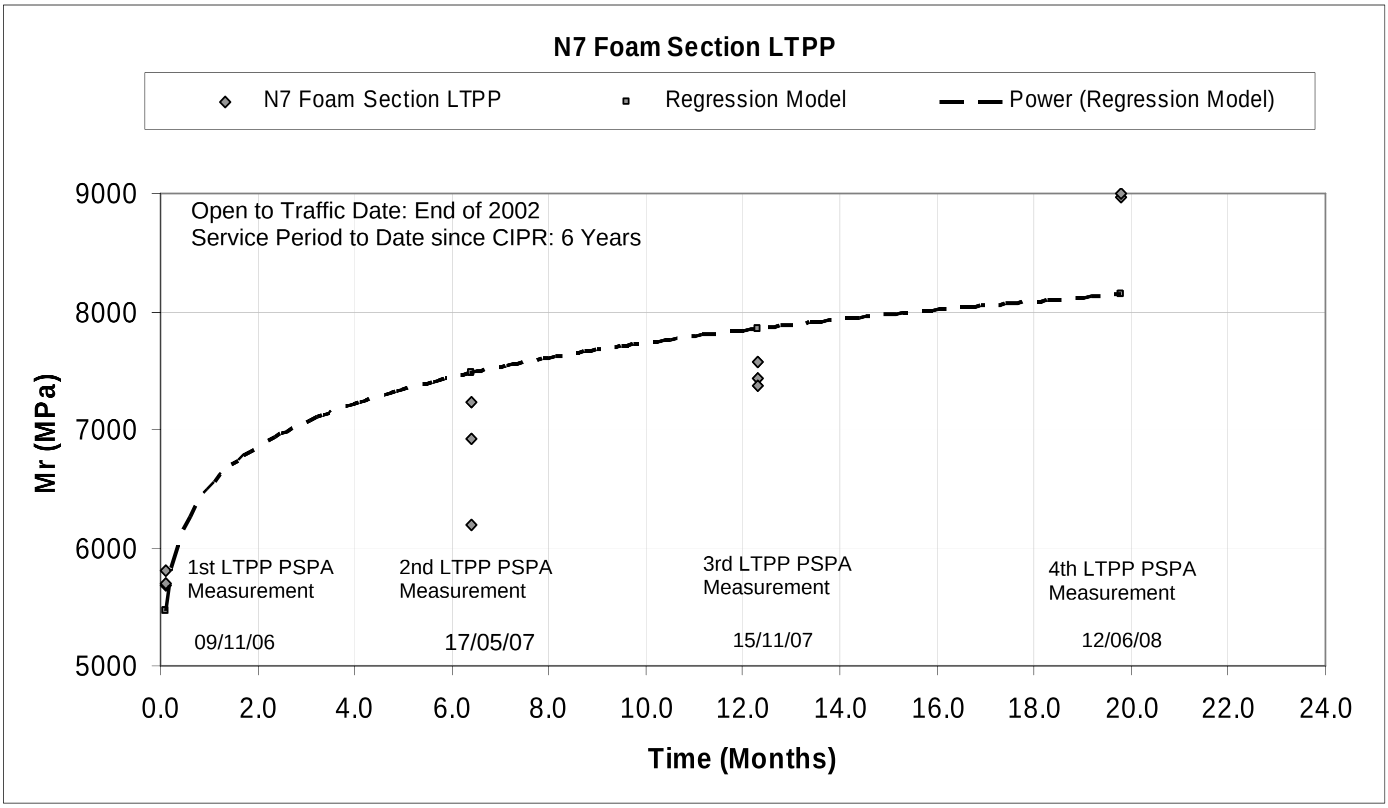

Figure H.15 N7 Foam Section LTPP PSPA Analysis (CISR, 2008)

PSPA measurements (CSIR) revealed that after 4 years of construction, foam treated ETB stiffness increased from 5500 MPa to 8200 MPa for the LTPP period of 2 years. To date, the road has been in service for 6 years.

CSIR data was used as benchmark to fabricate accelerated laboratory curing protocol for foam mixes.

1.5. Discussion of Trends

The following short conclusions have been reached following field stiffness and moisture trends analysis:

- Temperature is a more effective curing variable for extracting moisture from a BSM than setting relative humidity RH conditions. In a confined environment such as a layer, RH is not an accurate variable to control the moisture content within a layer; however, it does provide an indication of localized moisture conditions. In a laboratory, the combination of relative humidity conditions and set curing temperatures is more representative of field conditions than curing at set temperatures with no consideration of humidity conditions.

- Field compaction has both kneading action and impact effects on a BSM layer. The kneading action of steel rollers in conjunction with different frequency settings, initially results in variability in the stiffness of the recycled layer with depth. The stiffness distributions with depth change with time due to curing of recycled layer and traffic loading impact, resulting in more linear relationships.

- Field stiffness values increases with time relative to decrease in moisture contents as influenced by field curing. The decrease in moisture contents appears to be dominated by the temperature in the recycled layer.

- The inclusion of cement seems to increase field stiffness of good quality emulsion BSMs up to three times the original value within 7 months of field curing. Also, hydration process of cement could occur at a faster rate near the surface of recycled layer due to higher surface temperatures, thus resulting in greater stiffening in the top portion of recycled layer.

The outlined findings mentioned above will be further used to correlate field and laboratory trends. The reconciliation of field and laboratory environments is critical to accelerated laboratory curing. Furthermore, comparable trends rather than obtaining similar field and laboratory values will be paramount to reconciling both environments.

2. REFERENCES

Acott, S. M., 1980. The stabilisation of a sand by foamed bitumen – A laboratory and field performance study. Dissertation for Master of Science in Engineering. University of Natal.

Arema committee-1sub committee no. 2-ballast, 1998. Suggested Guidelines for Hot Mix Asphalt (HMA) Underlayment.

Asphalt Academy, 2002. TG 2: The design and use of foamed bitumen treated materials. Pretoria, South Africa, 2002.

Asphalt Institute, 1992. A Basic Asphalt Emulsion Manual. Manual Series No 19, Second Edition. Lexington, USA. Pp 87

Bondietti, M., Murphy, D., Jenkins, K. and Burger, A., 2004. Research on the stabilisation of two different materials using bitumen emulsion and cement. Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04). Sun City, South Africa.

Bowering, R. H. and Martin, C. L., 1976. Foamed Bitumen Production and Application of Mixtures evaluation and Performance of Pavements. Proceedings, Association of Asphalt Paving Technologists Volume 45. New Orleans, Louisiana. Pp 453-477.

Bowering, R. H., 1970. Upgrading Marginal Road Building Materials with Foamed Asphalt. Highway Engineering in Australia. Mobil Oil of Australia, Melbourne South.

Brown, S. F. and Needham, D., 2000. A study of Cement Modified Bitumen Emulsion Mixtures. Proceedings Association of Asphalt Pavement Technologist, Reno, Nevada Vol. 69, Pp 92-121.

Brown, S. F. and Gibb, J. M. Effects of Compaction on Mechanical Properties of Asphalt Mixtures. Proceedings of the 7th Conference on Asphalt Pavements for Southern Africa, 1999.

Houston, M. and Long, F. M., 2004. Correlations between different ITS and UCS test protocols for foamed bitumen treated materials. Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04). Sun City, South Africa.

Hunter, A. E, Airey, G. D, Collop, A. C. Influence of Compaction Method on Asphalt Mixture Internal Structure and Mechanical Properties. 3rd Euroasphalt & Eurobitume Congress, Vienna, 2004.

Jack N. Dybalski, 1981. A comparison of Properties of laboratory prepared Cold Mixes Emulsified and Hot Mixed Asphalt Mixtures. Presented at the 9th Annual Meeting of the Asphalt Emulsion Manufacturers Association March 17-18 1982 Las Vegas, Nevada.

Jenkins, K. J., 2000. Mix Design Considerations for Cold and Half-warm Bituminous Mixes with Emphasis on Foamed Bitumen. PhD Dissertation, University of Stellenbosch, South Africa.

Kekwick, S. V., 2005. Best Practice: Bitumen-Emulsion and Foamed Bitumen Materials Laboratory Processing. South African Transport Convention SATC, Pretoria

Kekwick, S. V., 2004. Accelerated Laboratory Curing of Bitumen-Emulsion and Foamed Treated Specimens: Review of Current Practice. South African Transport Convention SATC, Pretoria

Lancaster, J., McArthur, L. and Warwick, R., 1994. VICROADS Experience with Foamed Bitumen Stabilisation. Proceedings 17th ARRB Conference Part 3. Australia. Pp 193-211

Lee, D. Y., 1981. Treating Marginal Aggregates and Soils with Foamed Asphalt. Association of Asphalt Paving Technologists Volume 50. Pp 211-250

Little, D. N., Button, J. W. and Epps, J. A., 1983. Structural Properties of Laboratory Mixtures Containing Foamed Asphalt and Marginal Aggregates. Transportation Research Record 911. Pp 104-113

Loizos, A and Papavasiliou, V, 2007. Assessment of In-Situ CIPR Performance using the Foam Asphalt Technique. International Conference on Advanced Characterisation of Pavement and Soil Engineering Materials. Athens, Greece.

Long, F. M. and Theyse, H. L., 2004, Mechanistic Empirical Structural Design Models for Foamed and Emulsified Bitumen Treated Materials. Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04). Sun City, South Africa.

Malubila, S. M., 2005. Curing of foamed bitumen mixes. M.Eng thesis University of Stellenbosch, South Africa.

Maccarrone, S., 1994. Cold Asphalt as an Alternative to Hotmix. 9th AAPA International Asphalt Conference. Australia. Pp 19-24

Maccarrone, S., Holleran G., Leonard, D. J. and Hey, S., 1994. Pavement Recycling using Foamed Bitumen. Proceedings 17th ARRb Conference Part 3. Australia. Pp 349-365

Marais, C. P. and Tait, M. I., 1989. Pavements with Bitumen Emulsion Treated Bases: Proposed Material Specifications, Mix Design Criteria and Structural Design Procedures for southern African conditions. CAPSA '89, Swaziland

Parsons R. L, Foster D. H, Cross A. S, 2001. Compaction and Settlement of Existing Embankment. University of Kansas, 2001.

Poirier, J. E., Clarac, A., Ballie, M., and Thouret, D., 2004. Cold Mixes for Base and Wearing Courses. A survey of long term performance over eight years of use. Eurobitume and Euroasphalt Congress, Vienna, Paper 233.

Potii, J. J., Lesueur, D. and Eckmann, B., 2002. Towards a rational mix design method for cold bituminous mixes. The Optel contribution. European Roads Review Special Issue, RGRA 2.

Roberts, F. L., Engelbrecht, J. C. and Kennedy, T. W., 1984. Evaluation of Recycled Mixtures using Foamed Bitumen. Transportation Research Record 968. Pp 78-85.

Ruckel, P. J., Acott, S. M. and Bowering, R. H., 1983. Foamed-Asphalt Paving Mixtures: Preparation of Design Mixes and Treatment of Test Specimens. Transportation Research Record 911. Pp 88-95.

Saleh, M. F., 2004. New Zealand Experience with Foamed Bitumen Stabilisation. Annual TRB Meeting, Washington USA.

Serfass, J. P., Poirier, J. E., Henrat, J. P. and Carbonneau, X., 2003. Influence of Curing on Cold Mix Mechanical Performance. Performance Testing and Evaluation of Bituminous Materials PTEBM’03, 6th International Rilem Symposium, Zurich, Switzerland

Shuler T. S, Huber G. A. Effect of Aggregate Size and Other Factors on Refusal Density of Asphalt Concrete by Vibratory Compaction. Effects of Aggregates and Mineral Fillers on Asphalt Mixture Performance, ASTM STP 1147, American Society for Testing and Materials, Philadelphia, 1992.

Wirtgen, 2004. Wirtgen Cold Recycling Manual. Wirtgen Publication, Windhagen Germany.

Van Wijk, A.. and Wood, L. E., 1983. Use of Foamed Asphalt in Recycling of an Asphalt Pavement. Transportation Research Record 911. Pp96-103