Draft Protocol Guideline 1: Application of the MMLS3 for evaluating permanent deformation and moisture damage of asphalt *December 19, 2008 (First Draft Version 3 Rev1)*

Towards Development of an International Standard Test Protocol

DPG1 – Method for evaluation of permanent deformation and susceptibility to moisture damage of bituminous road paving mixtures using the *Model Mobile Load Simulator (MMLS3)*

This Protocol guideline is based on an earlier draft proposal by Dr Anton Hartmann from Africon, for use by SRT. It was presented at the CAPSA 2004 conference (Kruger et al, 2004). The latest draft was prepared as a task by a team at the request of the RPF in November 2007. At the RPF meeting in October, 2008 it was resolved that the Protocol should now be used. Copies of this Protocol may be distributed freely to Users provided the source of the information is duly recognized.

Feedback on applications and subsequent performance will be used to consider adjustments and revisions that should be made to the Protocol. **It should therefore not to be regarded as a *Standard Test Method.***
Comments should be returned to:

SANRAL Chair
Stellenbosch University
Stellenbosch
7600
emails:alett@sun.ac.za or jmyburgh@sun.ac.za

Preface

This draft of *DPG1 - Method for evaluation of permanent deformation and susceptibility to moisture damage of bituminous road paving mixtures using the Model Mobile Load Simulator (MMLS3),* was formulated as a best practice Protocol guideline for use by practitioners in the asphalt industry. The Protocol encapsulates a wide range of reasearch and applications relating to the MMLS testing system. Some details are contained in the list of references in the document. Users are advised to utulise referenced companion tools and equipment where and when appropriate.

In accordance with a resolution of the *Road Pavement Forum (RPF)* of October 2008, the Protocol should now be used by practitioners. Feedback on applications and subsequent performance, where available, should be sent to a database under the auspices of the *SANRAL* Chair for subsequent review and consideration. Adjustments and revisions to the Protocol should be made whenever appropriate but, no later than October 2011. Overviews of the feedback and revisions will be presented to RPF meetings on agreed occasions.

As one of tests being used by South African road authorities, the draft DPG1 will also be submitted for inclusion in the *South African Pavement Engineering Manual (SAPEM)* via the section on *Laboratory Management* and *Quality Management*.

Acknowledgements:

The Task Team responsible for compiling the Protocol comprised the following:

Dennis Rossmann - *SANRAL*
Derek Pretorius - *Arcus Gibb*
Erik Denneman - *CSIR*
Elzbieta Sadzik – ESJ Pavement Consulting Engineers (formerly GPDTPW)
Pieter Molenaar - *SSI*
Eben de Vos - *ITT*
Representatives from *SRT* and *Roadlab* commercial testing laboratories
Interested persons by co-option
Corresponding international members:
  Steve Emery Consultant - Australia
  MMLS3 International users
Fred Hugo - Chair and Coordinator

December 15, 2008

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. SCOPE

With this procedure the permanent deformation performance and susceptibility to moisture damage of bituminous road pavement mixtures, is evaluated using simulated traffic loading with the 1/3 scale Model Mobile Load Simulator (MMLS) under controlled environmental conditions. The method is applicable to asphalt surfacings and asphalt road base mixtures containing penetration grade bitumen's and modified binders. Bituminous mixtures with emulsion and foamed bitumen as binder have also been evaluated with the MMLS, but these have not been considered in this Protocol.

The test results should always be considered in the context of construction characteristics as well as actual traffic and environmental conditions to which the material is subjected during its lifecycle.

2. DEFINITIONS

*Total rut de*pth is the deformation of an asphalt layer (pavement, slab, core or compacted specimen) due to stresses and strains resulting from the axle loads and tire pressures applied by MMLS trafficking. It is measured as the vertical distance between the maximum and minimum surface elevation of a cross section profile or the sum of the down rut and associated upward heaving as indicated in Figure 1.

Heaving is the vertical distance between the maximum surface elevation and the original surface profile prior to starting the formal test trafficking.

Down rut depth is vertical distance between the minimum surface elevation and the original surface profile prior to starting the formal test trafficking.

Layer thickness is thickness of the asphalt layer(s) affected by being subjected to trafficking.

Deformation is the distance that the asphalt material has deformed in any specified direction.

Shoving is the movement of the material resulting from a shear force stemming from the trafficking by the load wheels.

Trafficking is the application of sequential wheel loads to the asphalt surface by the MMLS at a fixed selected speed or frequency.

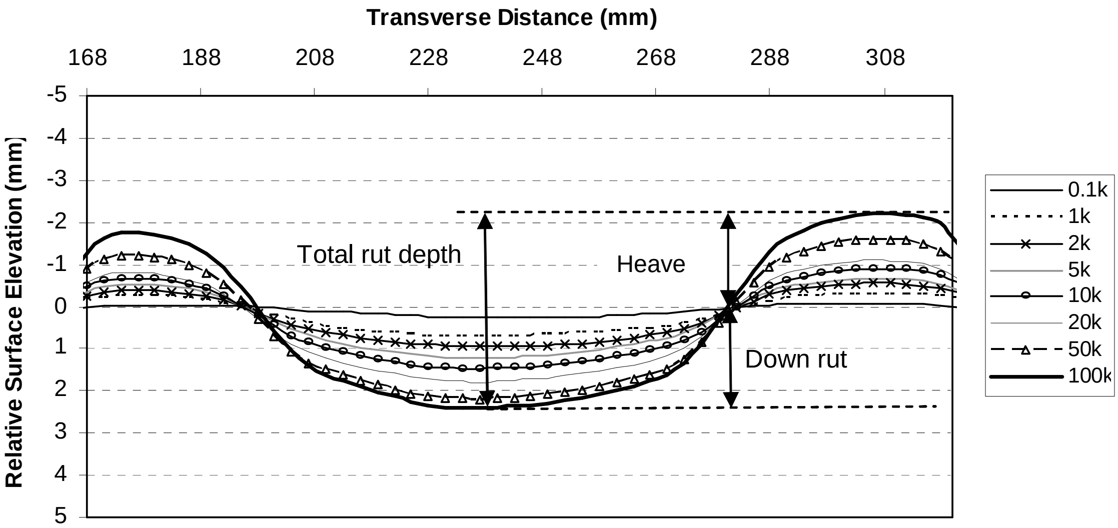

Figure 1: Typical output of profilometer readings*

*Users should pay particular attention to the establishment of the reference profile. Details are set out below under item 3.

3. SUMMARY OF TEST METHODS

Testing can be performed in a laboratory and in the field. Tests in the laboratory can be done in a test bed on cores and compacted specimens or on constructed slabs. In the field, tests can be done on insitu constructed pavements. Specimens for the test bed shall be machined as specified prior to being installed to fit snugly in position. Prior to starting the test, the specimens or test section shall be conditioned to reach the predetermined, specified test temperature gradient. Thereafter one hundred MMLS load applications shall be applied to ensure proper seating of the specimens. Pre-trafficked cross section profiles shall be then measured to serve as a reference before test trafficking is started. Trafficking shall be applied to the specimens or the test pavement while maintaining the carefully controlled test temperature. Trafficking for seating is not required for field tests.

At predetermined intervals the trafficking shall be stopped and cross-section profiles measured. A final profile shall be measured when trafficking is terminated. When wet trafficking is prescribed, water shall be filled into the test bed to a level of 1 mm ± 0,5 mm above the highest specimen surface. The water shall be re-circulated during the test. For wet trafficking in the field the water shall be sprayed across the test pavement during trafficking. A dam shall be made around the test section to re-circulate the water using the same equipment as in the laboratory. The temperature of the water shall be maintained at the selected test level (MLS Test Systems 2002).

The depth of the downward rut and condition of the surface shall be reported. With wet trafficking the degree of stripping shall be reported according to visual evaluation of the percentage of stripped aggregate. In addition 100 mm cores shall be extracted from the centre of the test specimens or test pavement for evaluation of structural damage due to the impact of the water during trafficking. Thereafter the test specimens shall be removed and the test bed cleaned.

4. APPARATUS

The apparatus shall consist of:

- A MMLS3 machine with its control unit set to apply the pre-selected wheel load per axle at a pre-selected tyre pressure and number of cycles per hour (MLS Test Systems 2003).
- An environmental chamber (if required) and a hot air blower and control unit able to heat and maintain the slab/specimen temperature at the pre-selected level within ± 2°C.
- Profilometer with mounting plates, screws, computer and data acquisition equipment able to measure the cross-sectional profile at a intervals of at least one reading every 3 mm to an accuracy of ± 0,1 mm.
- Five Type K thermocouples with data logging equipment able to record temperatures on an hourly basis to ± 1,5°C accuracy .

5. TEST TEMPERATURE

The test temperature shall be as prescribed or determined according to the value determined on the basis of the seven hottest sequential days in a period of one year for the past thirty years (or known record if less) at the site where the mix is to be constructed. Several research reports about procedures and/or related issues have been published (Williamson and Marais, 1975), (Deacon et al, 1994), (Huber, Gerald A., 1994), (Everitt et al, 1999), (Martin-Epps, et al, 2002), (Epps, A.L., et al, 2003), (Burger, 2004), (Denneman, 2007). The latter reference is particularly useful for South African conditions. The specimen temperature should be monitored and recorded on an hourly basis. Whenever the specimen temperature at a depth of 17 mm or 25 mm from the trafficked surface differs by more than 2°C from the prescribed set level (depending on the thickness of the asphalt layer). Trafficking shall be stopped and only continued when the correct temperature is reached. The extent of the stoppage shall be recorded for possible subsequent diagnostic reviews. A depth of 17 mm shall be used for a layer of 50 mm or less. Otherwise a depth of 25 mm shall be used.

6. LATERAL WANDER

When test are conducted on slabs in the laboratory or in the field lateral wander can be applied according to a prescribed rate and pattern. *No lateral wander can be applied in the test bed. Hence this has to be taken into account when adjudicating the rutting performance under trafficking.*

7. SPECIMEN GEOMETRY

The cylindrical specimens shall have a diameter between 149 mm and 150 mm and shall be either cored from an in-situ pavement or prepared in the laboratory. The specimen thickness may be between 30 mm and 90 mm (± 2 mm). Specimens shall be machined by sawing and trimming with a planing blade to a tolerance of ± 0,5 mm with two parallel edges of the specimen, 112 mm apart and perpendicular to the direction of trafficking as shown in. Specimens shall then placed snugly with straight sides square against each other as shown in Figure 3. Thereafter they shall be tightened with the clamps and screws in the test bed.

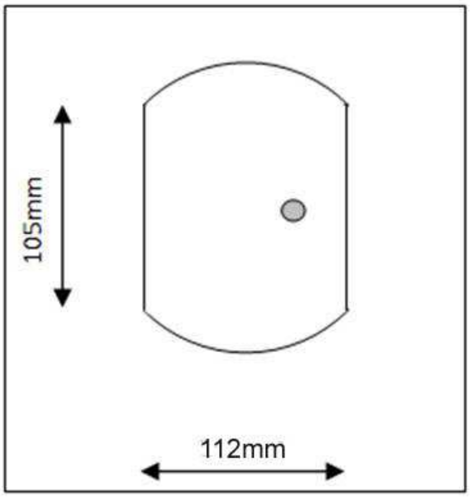

Figure 2: Test specimen dimensions (mm)

8. SPECIMEN PREPARATION

8.1. SAMPLING AND MIXING

Compacted specimens in the test bed can either be prepared from raw materials or plant mix. To prepare the minimum of nine specimens for testing a total amount of ± 50kg mix is required. Refer to TMH 1 (1986) Method C2 and TMH 5 (1981) Method MB7 for the prescribed procedure to sample, heat and mix the material. If preferred or there is a need to use fewer specimens, dummy specimens from earlier tests or specially prepared material, can be used at either end of the test bed to fill the outer spaces.

8.2. COMPACTION

Cylindrical specimens prepared in the laboratory shall be compacted with a gyratory compactor. Refer to ASTM Method D 3387-83 for the prescribed compaction procedure. Alternatively, specimens may be compacted by hammer and mould as per Manual 13, 1987 LAMBS.

8.3. FIELD CORING

In general, nine cores shall be extracted for one wheel tracking test. If preferred seven specimens may be cored for each test, with dummy cores at either end in the test bed. The coring operation requires a diamond coated asphalt core drill with a constant water supply to prevent excessive heating of the cutting face during the machining operation. Each core machined from an in service pavement shall be marked to indicate the direction of traffic flow. Cores should be trimmed to remove all unwanted lower road layers*. It should be noted that the final diameter should not exceed 150 mm.*

8.4. CONDITIONING/CURING

Asphalt compacted in the laboratory should be conditioned for 4 hrs at 135 °C in a force draft oven and then brought back to the required compaction temperature prior to manufacturing the test specimens or test slab.

8.5. THICKNESS AND SURFACE REGULARITY

Surface undulations or distortions across the surface shall not exceed 2 mm. This should be established by placing a steel rule across a diameter of the face to be trafficked. Specimen with a distortion of more than the specified level shall be rejected. Repeat measurements across three directions at 45° shall be made. To ensure that the samples conform to the surface regularity requirements, the bottom ends can be machined trimmed using an asphalt table saw with constant water supply and suitable clamping jig. To ensure that specimens do not lose their shape during the clamping and machining operation the specimens can be cooled down to 5℃ prior to handling and machining.

Thickness of the test specimen shall be measured at four points at 90° intervals. The average of these four measurements shall be used as the thickness of the specimen.

8.6. STORAGE OF SAMPLES

Specimens extracted from a pavement shall be protected from excessive vibration or jarring of containers during transportation to the laboratory. Packaging in bubble wrap is advisable. Specimens should be stored with the test surface horizontal at a temperature of not more than 20℃. If storage is intended for more than four days the temperature shall not exceed 5℃. The actual storage time in days, should be recorded on the test sheet for possible subsequent diagnostic reviews. Specimens should also not be stacked on top of each other or on other objects.

9. LAYOUT OF TEST SPECIMENS IN THE TEST BED

9.1. PLACING AND CLAMPING OF THE SPECIMENS

Prior to placing the specimens in the test bed, the inside walls and floor should be thinly coated with emulsified silicone rubber to prevent slippage of the asphalt along the slick surfaces. The specimens should be orientated on the mounting table so that the wheel-tracking path aligns with the direction of the road traffic flow (if this known) and the test surface is in contact with the table as indicated in Figure 3. For expediency the specimens can be placed in the test bed on the bottom surface initially prior to coating the silicone rubber. Thereafter spacer plates can be stacked on the specimen surface to reach a level of ± 2 mm from the top surface of the mould. When the surface is within tolerance from the specified level, the plates and underlying specimens can be removed and inverted with the specimens on top of the packing plates.

Lock the x-axis clamp, indicated in Figure 3, first using the torque wrench and ensure that the specimens are in full contact with one another and the underlying test bedplate without deforming the specimens.

Clamp the specimen snug tight in the y-axis using the semi-circular clamps. Take care not to over tighten the clamp and damage the specimens.

9.2. INSTALLING THE THERMOCOUPLES

1. Drill 4 mm holes to the required depth for placing the thermocouples between specimens 2/3, 5/6 and 7/8 at the joints between the respective specimens. Two thermocouples at either end should preferably be positioned in the upper third of the specimen at a depth of -17 mm for cores 40 – 50 mm and -25 mm for thicker cores. Three thermocouples should be placed at the 5/6 position as follows: one at quarter depth as specified for the two end thermocouples, one at the middle and one at three quarter depth. The control thermocouple for the heater unit is placed between specimen 4/ 5 at a depth of -25 mm. A thermocouple may also be placed on the surface or at other depths if considered necessary.
2. The thermocouples are installed as close as possible to the middle of the trafficking path of the wheels as follows:
   - Bend the end of the wire 90 degrees so that the perpendicular section is long enough to penetrate to the middle of the specimens.
   - Dip the end of the thermocouple in silicon sealer and push it into the hole. Care should be taken to use an *Aluminium* based silicon since conventional silicon can damage the asphalt.
   - Use duck tape or silicon to maintain the thermo couples in position.
   - Lead the wire at a right angle away from the centre so that it does not cross the path of the profilometer or is caught and pinched anywhere.

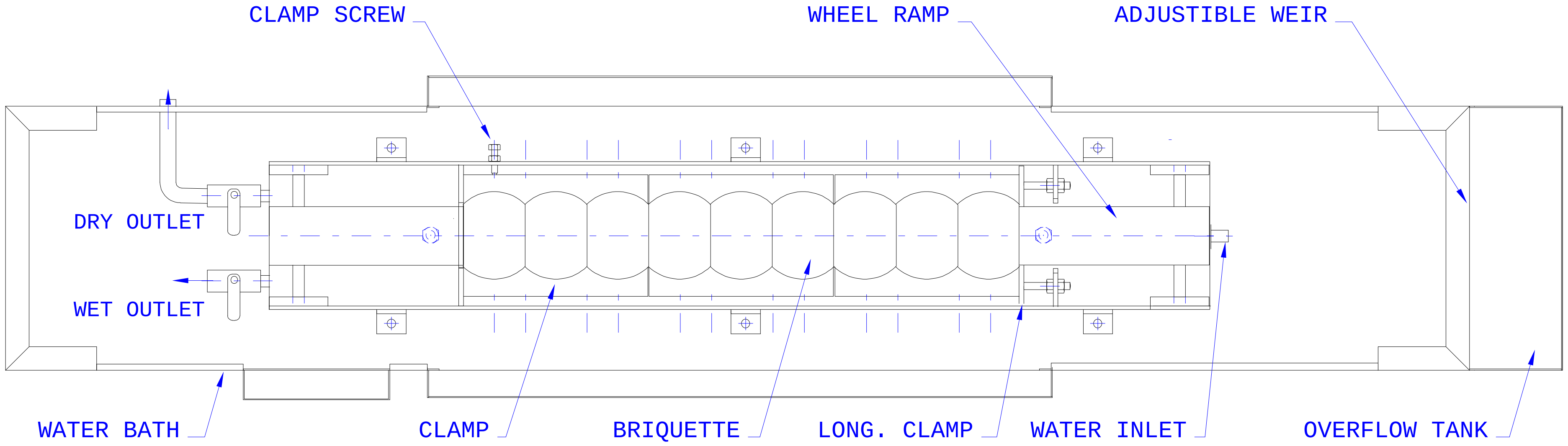

Figure 3: Partial plan view of test bed, showing prepared briquettes and clamps

10. PRE-HEATING THE PAVEMENT TEST SECTION

Pre heat the pavement test section to the prescribed temperature (± 2℃) at the upper thermocouples (17 mm or 25 mm) depth. Take care to not overheat the asphalt surface (> 75°C), which may change its properties.

11. TAKING PROFILOMETER ZERO-READINGS

A cross–section profile should be measured across the centre of the inner 7 specimens (i.e. specimen no. 2, 3, 4, 5, 6, 7, 8). Refer to the profilometer manual for procedures to take readings. The zero-readings are used to normalise all subsequent profile measurements. In the test bed the seating should be done prior to taking the zero-readings

12. RUNNING THE TEST

Set the blower to the required temperature and run it until the correct specimen temperature is reached. Run the MMLS3 for the specified number of load applications and take surface profiles across the centre of each test specimen after completion of each of the required number of load applications. Temperature readings should be recorded continually with readings taken and logged at the prescribed intervals. After each measurement of surface profiles, the test should only be resumed after the test specimens have regained their prescribed temperature. Steps should be taken to minimize temperature loss during data collection intervals.

Ensure that all tyres are still fully inflated before resuming trafficking and remove any binder deposit on the curved end plate of the machine. Also ensure that the entry and exit transition plates are flush with the specimen surfaces. Adjust, should it be necessary. After taking the readings, ensure that the machine is stable with the blower nozzles in position. The test typically progresses with increments up to the pre-selected total number of load applications as indicated in Table 1 or according to the selected speed. The standard number of load cycles is one hundred thousand (100 000). However, for specific purposes the load applications may be increased or decreased. It has been found that the rutting performance generally follows a power function relative to trafficking. Extrapolation of fewer load applications may provide results of sufficient accuracy for specific situations. Likewise, the load applications may have to be increased beyond 100k applications to explore critical conditions. In similar vein, the number of applications for wet tests may be adapted to suite the site conditions (see notes in Appendices).

TABLE 1: TYPICAL TEST INCREMENTS		
Axle Increment	**Estimate time lapse @ 7200 appl/h**	**Total axles**
2 500	21 min	2 500
2 500	21 min	5 000
5 000	42 min	10 000
10 000	1 hr 23 min	20 000
30 000	4 hr 10 min	50 000
50 000	7 hr	100 000

After completion of the last trafficking, remove the machine and take the final profilometer readings. This should be done preferably while the specimens are still hot. The surface should also be inspected and the condition reported.

13. RESULTS

Vertical deformation measurements should be processed with a spreadsheet program (*MasterRutProcessingSpreadsheet.xls*) (Muller, FPJ, 2008). The consolidation program (*Consol.exe)*(Muller, FPJ, 2008) shall be used to consolidate the data for all measured profiles into one file, before importing the data into the spreadsheet. Results from the profilometer are reported in a graph format displaying the Relative Surface Elevations (mm) versus the Transverse Distance (mm) as typically shown in Figure 1. Data for the central 7 specimens are averaged and, the Down Rut, Heave and Total Rut Depth determined as indicated in Figure 1, and reported as shown in Table 2. The Down Rut Depth (mm) may also be graphically displayed versus the MMLS Axle Repetitions as shown in Figure 4. Heave can also be displayed in a similar manner.

TABLE 2: STANDARD RESULTS SUMMARY			
Total axles	**Down rut (mm)**	**Heave (Left) (mm)**	**Heave (Right) (mm)**
2 500			
5 000			
10 000			
20 000			
50 000			
100 000			

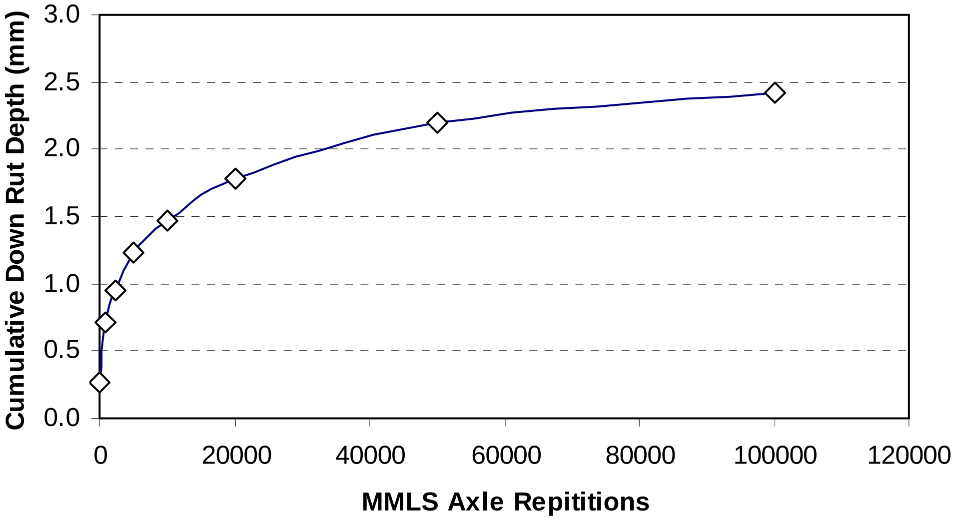

Figure 4: Typical example of accumulation of deformation with increasing load cycles

14. PROCESSING OF DATA AND EVALUATION OF FINDINGS

The results can be evaluated in two ways with due regard to the guidelines set out in the appendices:

14.1 Empirical evaluation (refer to Appendices A and B)

For this evaluation the basis is the selection of an appropriate maximum limit of the downward rutting after trafficking with application of pre-selected conditioning. Factors such as topography of the pavement, the climatic zone of pavement location and the trafficking during the life cycle of the pavement are considered. The influence of layer thickness is considered on the basis of the difference in stress level of the MMLS tyre and the full-scale tyre on the respective layers. The comparative results from MMLS and full-scale APT's with truck trafficking and traffic simulators is utilised as point of departure. The extent of heave also reflects the shear stability of the asphalt mix under trafficking. Empirical norms have however not yet been established, but guidelines will be developed in due course as data is collected and reported.

14.2 Pseudo-Mechanistic (refer to Appendices A, B and C)

For this evaluation, the pavement structure is analysed theoretically in terms of stresses under full-scale and one third scale loading. Material characteristics are required with due regard to the prevailing life-cycle conditions. Trafficking levels and environmental conditions during the life cycle are estimated and considered. The comparative results from MMLS and full-scale APT's with truck trafficking and traffic simulators is also utilised as point of departure. Performance under 100k (or 200k) trafficking is *interpolated or extrapolated* to expected design life cycle traffic volumes and considered in terms of acceptable performance levels.

15. CLOSURE REMARKS

The draft Protocol was compiled and proposed on the basis of an extensive number of applications based on the initial comparative tests reported by Martin Epps et al (2002), Smit et al (2003). More recently a study was conducted in South Africa on the R80 and it is still underway (Hugo and De Vos 2008a; 2008b). The users of the Protocol should do so with due regard to consideration of sound engineering judgement and experience. As performance data is gather a sound reference base is expected to develop for subsequent review and where necessary revision on the basis of long-term observation and monitoring of performance.:

16. REFERENCES

ASTM D 3387-83 (1995) *Standard test method for compaction and shear properties of bituminous mixtures by means of U.S. Corps of Engineers Gyratory Testing Machine (GTM)*. Annual Book of ASTM Standards, ASTM, Philadelphia, USA, Vol. 04.03, pp. 305-315.

BS 598: Part 110 (1996) *Sampling and examination of bituminous mixtures for roads and other paved areas; Part 110. Method of test for the determination of the wheel-tracking rate*. BSI, London, England.

Burger, M (2004) Experimental Convection Heat Transfer Coefficient on a Horizontal Surface Exposed to the Natural Environment, Department of Mechanical Engineering, University of Stellenbosch, Master Thesis

Deacon J, Coplantz J, Tayebali A, & Monismith C, (1994), Temperature Consideration in Asphalt Aggregate Mixture Analysis and Design*, Transp. Research Record* 1454.

Denneman, E, (2007), The Application of Locally Developed Pavement Temperature Prediction Algorithms in Performance Grade (PG) Binder Selection, Proceedings of the 26th South African Transportation Conference (SATC), Pretoria. http://researchspace.csir.co.za/dspace/bitstream/10204/1032/1/Denneman1_2007.pdf

Epps, A.L., Hugo, F., Walubita, L.F. and Bangera, N. (2003). *Comparing Pavement Response and Rutting Performance for Full-Scale and One-Third Scale Accelerated Pavement Testing,* Journal of Transportation Engineering, Vol. 129, No. 4, pp. 451-461.

Everitt, PR, Dunbar, R, Swart, G. and Rossman, D, (1999), Current Pavement Temperature Monitoring in South Africa and its applicability to Superpave and FWD requirements, CD-ROM Proceedings of the 7th Conference on Asphalt Pavements in Southern Africa (CAPSA), Victoria Falls, Zimbabwe.

Gerber, J (2008) Development of the Criteria for a Reliable Rut Relationship between Field and Laboratory MMLS3 Testing, Project report Faculty of Engineering, US.

Huber, Gerald A., (1994), Weather Database for the SUPERPAVE TM Mix Design System; Report SHRP-A-648A Rev Feb 1994--Supersedes SHRP-A-648, SUPERPAVE TM Strategic Highway Research Program, National Academy of Sciences, Washington, DC, http://gulliver.trb.org/publications/shrp/SHRP-A-648A.pdf.

Hugo, F, De Vos, ER (2008a), Evaluation of HMA Rutting Performance Under MMLS3 Trafficking in the Laboratory and in the Field on a trial section on the R80, First Report prepared for Gauteng Government Department of Public Works and Transportation, May

Hugo, F, De Vos, ER (2008b), Evaluation of HMA Rutting Performance Under MMLS3 Trafficking in the Laboratory and in the Field on a trial section on the R80, Second Report prepared for Gauteng Government Department of Public Works and Transportation, September

Hugo, F., De Witt, R., Helmich, A., (2004), *Application of theMMLS3 as APT tool for evaluating asphalt performance in Namibia,* CD Rom Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04) 12 – 16 September 2004 ISBN Number: 1-920-01718-6 Sun City, South Africa Produced by: Document Transformation Technologies cc

Hugo, F., (2004), MMLS3 Testing and Application Protocols, presented and discussed at the Third Annual Users Group Meeting of MMLS3, Louisiana, USA.

Kim S-M., Hugo, F., Roesset J.M. and White T.D. (1995). Dimensional Analysis of the Mobile Load Simulator on Pavements. Report 2914-3F, Center for Transportation Research, The University of Texas at Austin, May.

Kim S-M., Hugo F. and Roesset J.M. (1998). *Small-Scale Accelerated Pavement Testing,* Journal of Transportation Engineering, ASCE, Vol. 124, No.2, Mar/Apr 1998, pp. 117-122.

Kruger, J, Hartman AM, Loots H, (2004) Towards Developing a Test Protocol for Field Permanent Deformation Performance Evaluation Using The MMLS3 CD-Rom of Proceedings CAPSA 2004

Manual 13, (1997), LAMBS – The design and use of large aggregate mixes for bases, SABITA

Martin Epps, A., Ahmed, T., Little, D.C., Hugo, F., Poolman, P. and Mikhail, M. (2002). Performance prediction with the MMLS3 at WesTrack. CD-Rom of Proceedings of the Ninth International Conference on Asphalt Pavements Copenhagen, 17 – 22 August.

MLS Test Systems, (2002), MMLS Wet Pavement Heater Preliminary Users Manual, MLS Test Systems, June.

MLS Test Systems (2003) *MMLS3 Operators Manual*. MLS Test Systems cc, Stellenbosch, South Africa.

Molenaar, P., Hugo, F., Beukes, J., Catin, G., (2004), Rehabilitation of RWY 03L-21R at Johannesburg International Airport: selection of asphalt mixes using MMLS3 testing. CD-Rom of Proceedings and presentation at 8th Conference on Asphalt Pavements for Southern Africa.

Muller, FPJM, (2008), *MasterRutProcessingSpreadsheet.xls*. Software for processing MMLS data

Muller, FPJM, (2008), *Consol.exe* Software for processing MMLS data

Raab, C., Partl, M.N., Jenkins, K., Hugo, F.: (2005), Determination of Rutting and Water Susceptibility of Selected Pavement Materials using MMLS3. 7th International Conference on the Bearing Capacity of Roads, Railways and Airfields, BCRA'05, Trondheim, 27.-29. June

Smit, André. de Fortier., Hugo, Fred. Rand, Dale Powell, Buzz, (2003), Model Mobile Load Simulator Testing at National Centre for Asphalt Technology Test Track, Transportation Research Record 1832, Journal of the Transportation Research Board, Washington, D. C. USA, October.

Smit, A. de F., Hugo, F and Yeldirim, Y, (2004b), *A Discussion of MMLS3 Performance Testing of Laboratory Prepared HMA Slabs and Briquettes Compared with Hamburg and APA Wheel Tracking Tests,* CD-ROM Proceedings Second International APT Conference, Seattle, USA.

Smit, A. de F, Van de Ven, MFC, Fletcher, E, (1997), Towards the use of semi-circular bending test as a performance related specification tests. Proceedings, SATC Conference on Transport Infrastructure II, volume 3A, Paper no 6. Johannesburg

Smit, A. de F., Hugo, F., Poolman, P., Powell, R. B., Bacchi, C., (2004a), Distress of hot mix asphalt on the NCAT test track due to accelerated wet trafficking, CD-Rom of Proceedings and presentation at the Second International APT Conference, Minneapolis, USA.

Taute, Arthur, Pretorius, Derick, Marais, Herman, and Grobler, Joe (2007), Hot Mix Asphalt Quality Control, CD Proceedings of Capsa 07, Botswana.

TMH 1 (1986) *Standard method of testing road construction materials*. Technical Methods for Highways, Committee of State Road Authorities, South Africa.

TMH 5 (1981) *Sampling methods for road construction materials*. Technical Methods for Highways, Committee of State Road Authorities, South Africa.

Walubita, L.F., Hugo, F., Martin Martin Epps, A. L. (2002), Indirect tensile fatigue performance of asphalt after MMLS trafficking under different environmental conditions, Journal of the SA Institution of Civil Engineering, Johannesburg, South Africa, Vol. 44, Number 3.

White, T.D., J. Hua, and K. Galal, (1999), “Analysis of Accelerated Pavement Tests” (CD-ROM), Proceedings of the First International Conference on Accelerated Pavement Testing, Reno, Nev., Oct. 18–20,

Williamson, RH and Marais, CP, (1975), Pavement Temperatures in Southern Africa, Die Siviele Ingenieur in Suid-Afrika

APPENDIX A: IMPACT FACTORS AFFECTING RUTTING PERFORMANCE

The following factors need to be considered when evaluating rutting performance under MMLS trafficking whether this done empirically or analytically. In the former case the factors are generally taken into account in an overall manner where as they are considered more discreetly with analytical evaluation and performance prediction:

A. Environmental impact
    i. Temperature
    ii. Rainfall
    iii. Aging
B. Traffic volume and related axle loads
C. Traffic speed
D. Layer thickness and pavement structure
E. Specimen preparation and test mode

The influence of the respective factors is discussed below. This is followed by a proposed tabular summary of the draft proposals suggested for use in determining the extent of rutting allowable under specific circumstances.

A. ENVIRONMENTAL IMPACT

Temperature is a test parameter that has to be selected since it affects the rutting performance of the asphalt directly. It is dependent on a number of factors such as geographic region and elevation amongst others. Procedures have been developed to assist with selection of appropriate critical temperature(s) for testing based on prescribed analytical procedures. Users are referred to the following references:

- Williamson and Marais, (1975)
- Deacon et al, (1994)
- Huber (1994)
- Everitt et al (1999)
- Martin-Epps et al (2002)
- Denneman (2007)

The test temperature of the deep(er) asphalt layers should take the thermal gradient in the asphalt with depth into account when testing asphalt used below the wearing course. The prediction algorithm for pavement temperature at depth in South Africa developed by Viljoen and reported by Denneman (2007), is useful for this. It also contains a table of information on the temperature at a depth of 20 mm for eleven sites in South Africa. It should be noted that some practitioners opt to keep 50°C as the minimum test temperature. The temperature of the water on the underside of the test bed should be set to establish and maintain the specified thermal gradient.

The temperature during the initial phase of rutting is of critical importance since it controls the extent of the initial rut depth. This in turn controls the limit reached during the secondary phase. The latter is of course dependent on the rutting rate which is also a function of trafficking temperature. (see Figure A1 below (Gerber, 2008) and also notes under item E below). The net effect of these two phases of trafficking ultimately determines the rutting performance subject to the other factors that are discussed in more detail below.

There is evidence that wet trafficking can increase the rutting of asphalt. It can also damage the structure of the asphalt. Rainfall patterns need to be considered with respect to frequency, duration and intensity relative to trafficking. This provides the basis for selection of the nature of the wet trafficking that should be used. Decisions relate to the extent of wet trafficking and the selection of a trafficking temperature. This is discussed in more detail under item E below.

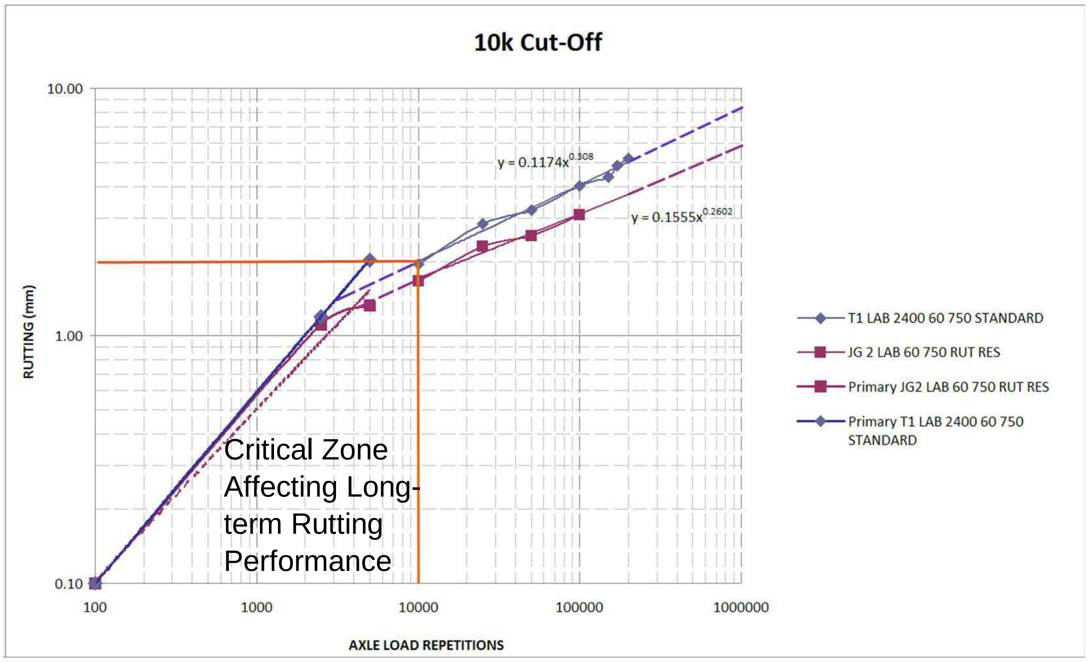

Figure A1: Comparative Performance of Two Mixes Differing in Terms of Critical Zone Effects on Secondary Rutting after 10k Load Applications (after Gerber, 2008)

Aging is a factor that is time and region dependent and it can have a profound effect on the performance of an asphalt layer in terms of rutting. Examples exist that vividly demonstrate this. Early trafficking is therefore a factor that affects performance. In the same vein, traffic during the latter part of the life cycle would have less effect. Material characteristics that provide insight into the extent of aging are unfortunately not always readily available. In general aging is accounted for by reducing the *expected rutting as finally estimated from the MMLS rutting performance* by 30%. This is based on the progressive increased stiffness over time due to aging. Of course, if the asphalt that is being tested is already aged due to the passage of time, the rate of rutting relative to trafficking will be less throughout the test. Heavy trafficking shortly after paving would require specific consideration such as special attention to the use of high resistant mixes or if feasible even diverting the traffic briefly during the vulnerable period. Serious distress occurred at Westrack on one section during the first 60 000 load applications! (Martin Epps et al, 2002).

To account for this rationally, it is important to record the age of the asphalt at the time of testing. It is proposed that the status should be categorized and recorded in terms of the following timeframes for possible subsequent diagnostic reviews.
:

- Within one day after construction
- One to seven days after construction
- One month after construction
- Six months or longer after construction

Preconditioning of specimens or test sections prior to testing (if applicable) should be reported.

B. TRAFFIC VOLUME AND RELATED AXLE LOADS

Traffic volume and related axle loads need to be selected to reflect the respective statistics pertaining to critical temperature phases. This is generally when the asphalt is above 40C. Furthermore, the early life traffic i.e during the first 30 days should be considered carefully since it impacts on the critical primary rutting phase. Critical trafficking is generally taken as prevalent only during a portion of the day in the life cycle of the pavement.

The extent of critical trafficking volume is also affected by lateral wander of the traffic. This reduces the number of load applications at a specific location in the transverse profile. It also affects the way in which the asphalt is moulded transversely. Although the distribution is random, the resulting deformation profile is normally of a Gaussian format. With extremely vulnerable mixes it can however manifest in uneven sharp vertical displacements across the profile. Lateral wander is discussed in more detail under item E below.

C. TRAFFIC SPEED

The speed of trafficking has to be selected to reflect the application of the asphalt layer(s) whether it is for highways or airports. Further distinction has to be made to account for factors such as average speed, gradients, truck traffic volume, traffic flow rate and stop-start conditions. The following categories are recommended for the respective conditions:

- flat (level) free flowing traffic,
- rolling gradients and free flowing traffic with high truck volumes,
- slow channelised traffic on steep inclines and highway intersections;
- free flowing airport runways and taxiways with high contact stresses,
- airport aprons, stop-start taxiways and runway thresholds (~150m).

The maximum equivalent MMLS speed of 7200 load applications per hour are considered as relating to free flowing highway speed in excess of 27kph. Slower speeds are used progressively to simulate the other more strenuous situations. Ultimately it is reduced to 1800 load applications per hour that is considered to simulate complex and high stress conditions such as intersections, airport aprons, stop-start taxiways and runway thresholds. Other factors relating to test mode are discussed under item E below.

D. LAYER THICKNESS AND PAVEMENT STRUCTURE

Layer thickness relates to the comparative stresses between MMLS and full-scale trafficking tyres. The thinner the layer, the closer the comparative relationship is. The result is that the rutting under MMLS trafficking relative to full-scale trafficking generally has to be proportionately increased as the layer thickness is increased.

In similar vein, the thinner the asphalt layer, the more the total surface rut of the structure may be influenced by underlying layers which are often non-asphalt. Hence it is important to measure the rutting directly related to the asphalt. For this a pin is anchored under the asphalt layer to enable the rutting in the asphalt to be determined separately from settlement underneath (Hugo et al, 2004). This may limit the allowable rut depth in the asphalt.

Figure 6: Pins used for monitoring settlement/deformation below the asphalt layer.

Tyre pressure plays an important role in the performance of the asphalt material especially when fresh. Comparative measurement with the SIM device has identified tyre pressures that cause similar contact stresses on the asphalt surface. A tyre pressure of 800kPa is considered as appropriate under a high percentage of very heavy truck traffic. This may cause excessive wear on the tyres. Therefore a slightly lower value of 750 or 700 should be used when the heavy percentage is not too high. The wheel load also has to be considered since it affects the footprint. With the high tyre pressure a load of 2,9kN is used. When the lower values are used the load is reduced to 2,7kN per axle. The resulting performance with the respective pressures and loads is then used for life cycle performance prediction.

Layer thickness for testing with the MMLS should not exceed 150 mm due to the limited depth of the stress profile related to the tyre size. In similar vein, the nominal maximum aggregate (NMAS) size should be less than 50% of the layer thickness of the asphalt.

E. SPECIMEN PREPARATION AND TEST MODE

The method of specimen preparation and test mode influences the performance of asphalt layers in terms of rutting and damage under wet trafficking.

Trafficking in the test bed and in the field: Recent studies have shed further light on the relationship between performance results resulting from testing cores in the test bed and the parent material in the field (with similar preparation of the mix). Previously it was reported that the field rutting results are slightly more than results from lab test beds (Molenaar et al, 2004). It has now been found that the results are closer to par provided the conditioning of the asphalt prior to and during testing is the same (Gerber, 2008). This is possibly as a result of the bottom heating of the test bed using the water heating system. It may however be dependent on the layer thickness, which in turn influences the stress distribution in the layer. In similar vein, the lab compacted specimens (other than roller compaction) rut less than cores. The relationship was reported by Molenaar et al,(2004) as 1.2:1 (Surface mixes) and 1.55:1 for base course mixes.

Construction quality: Factors relating to construction affect rutting performance. The following should be borne in mind:

- poor or excessive compaction whether variable or not
- segregation would affect rutting and the impact of water during trafficking
- variation in mix composition in terms of aggregate and binder
- variation in the nature and quality of the binder

Specimen geometry: Note that cores from a “standard” 150 mm diameter coring barrel are often unsatisfactory because they are either less than 149 mm diameter or more than 150 mm Particular care should therefore be taken when extracting specimens for MMLS3 testing. The core diameter should be checked on site before sending to the laboratory.

Number of core specimens: Consider extracting twelve cores, to allow one to tested for volumetrics and availability of spares in case of damage during shipping.

Storage of samples: Samples are often shipped internationally by courier. If the asphalt is cooled (below 100 deg C), it is not classed as *"dangerous goods"*.

Lateral wander and wet trafficking: Generally, lateral wander has been considered less damaging than channelised trafficking (White et al,1999). Their research was done on thick asphalt layers and supported by theoretical FEM analyses. To simulate the effect of lateral wander, the APT trafficking can be distributed transversely. This is normally done by moving the wheel progressively transversely across a selected width during the trafficking to simulate a Gaussian distribution. With extremely vulnerable mixes this would not simulate the situation during the initial phase of testing depending upon the moulding of the asphalt under shear. Generally this is not attempted with normal APT.

Recently it was also found that the lateral wander on asphalt with a thickness of 40 mm under high temperature caused significantly more damage to the asphalt in terms of rutting than channelized trafficking. This still has to be studied in more detail (Hugo and de Vos, 2008b). Until this has been done, it may be more conservative to consider doing tests on thin asphalt layers under critical trafficking conditions with lateral wander.

As mentioned under item A above, wet trafficking can increase the extent of asphalt rutting. In similar vein, the structural integrity can be affected even more so with lateral trafficking wander. However, it is important to select the period of wet trafficking with due regard to the specific climatic situation. In dry areas it may be unnecessary to test in the wet mode. Where the rain only occurs during a part of the year in showers of short duration, the testing mode could be varied to have alternate dry and wet cycles for trafficking.

Wet trafficking tests can either be conducted in the test bed in the laboratory or in the field. In the latter case a dam is constructed around the tests section and water is circulated via a closed-loop pipe system. In both cases the same pump and water heating system is used. The water is allowed to flow over the asphalt at a depth of approximately one mm during trafficking. Lateral wander is of course not feasible in the test bed and in specific cases it may warrant field tests with the MMLS to gauge the impact of the lateral wander.

The trafficking temperature is primarily determined by the temperature of the water. This in turn is selected in relation to the environment as discussed above. The wet tests at NCAT (Smit et al 2004a) (Smit et al 2004b) and in Texas (Walubita et al 2002) were done with the water temperature at 50°C. The tests reported by Raab et al (2005) on Swiss mixes were done at 40°C. A test at ambient temperature (25°C) has also been reported. Clearly 50°C would yield conservative results while 25°C would be least conservative but possibly more representative of long duration of the rain spells. The final evaluation relates to loss of stiffness or fatigue life of the trafficked asphalt versus untrafficked asphalt.

Effect of initial untrafficked structure, composition and condition on rutting: As discussed earlier, rutting generally comprises two phases that should be considered when evaluating life cycle performance namely the primary and secondary phases. The primary phase is indicative of the effect of voids and early tenderness of the mix. The effect can be very serious since it affects the time at which a critical rut depth may be reached. It may also affect the rutting rate with the same effect. It is important to capture the potential risk by determining the voids in the mix before and after trafficking.

In order to normalise comparisons and take account of the pavement condition after initial trafficking, untrafficked MMLS test specimens should be compacted to five percent voids in the mix (+/- 0,3%). Permeability tests could also be done to identify whether the mix is likely to be subject to water infiltration during trafficking (Refer notes in Appendix B). The rutting rate generally stabilises after 10 000, load applications unless trafficking conditions alter or are changed.

Comparison of performance can therefore be made by considering the extrapolated (or interpolated) performance after a selected trafficking pattern or by comparing rutting rates under similar conditions with due regard to the primary consolidation phase on a log-normal basis.

CLOSING REMARKS

The foregoing discussion forms the basis of the methodologies used to evaluate the performance of the asphalt under MMLS trafficking. The empirical methodology has in fact been simplified to capture the impact of the various scenarios in terms of *a limiting rut depth after 100k mmls load applications*. This provides benchmarks for establishing acceptable asphalt construction for specified operational conditions during the life cycle of the asphalt layer. Tables in Appendix B contain proposed guidelines for determining test specifications and performance benchmarks. In Appendix C reference is made to the Quantitative analytical mechanistic methodology for evaluating performance.

APPENDIX B: PROPOSED GUIDELINES FOR DETERMINING TEST SPECIFICATIONS AND PERFORMANCE BENCHMARKS

The empirical evaluation of rutting performance is based on comparative studies between MMLS trafficking and full-scale APT. Case studies date back to 1999 with tests in Texas, Nevada, Alabama and very recently South Africa.

The principle assumption is that the performance can be gauged from the actual life cycle performance under conventional trafficking of full-scale test pavements or full-scale controlled simulated conventional trafficking. The factors discussed in Appendix A serve to adjudicate whether conditions were similar and or taken into account in evaluating the relative performance under the different modes of trafficking.

The evaluation follows a logical process for considering the respective situations. The essence of the system was captured in a meeting of the MMLS3 users in Baton Rouge (Hugo, F, 2004). A considerable number of evaluations have been done based on these guidelines.

On the basis of this, guidelines were established for deciding whether performance under MMLS trafficking yielded acceptable levels of performance of pavements that were investigated. The guidelines have been utilised in South Africa in a wide variety of regions and trafficking conditions. Long-term performance has been monitored by surveillance and reports have confirmed successful applications. In cases where there was still doubt, long-term monitoring procedures were established under applicable guarantees. A case in point is a contract in the eastern Cape at Ugie.

To ensure that all factors are indeed available for consideration, it is imperative that pavement engineers carefully select the test parameters that are to be used for evaluating quality of asphalt mixes. This applies whether for design or construction evaluation. Clients, consultants, contractors and testing laboratories should bear this in mind. To assist in this process tables have been developed for capturing essential information when requesting or considering MMLS testing. These are set out in this Appendix. MMLS users can also find noteworthy recommendations on best practice relating to testing of Hot Mix Asphalt (HMA), in a paper by Taute et al (2007) on quality control of HMA.

The empirically established Protocols for adjudicating MMLS test results and related rutting performance levels of asphalt layers are set out in the table(s) below. These are more comprehensive than the draft Protocol established in Baton Rouge.

It should be noted that the Protocols have been compiled by taking account of speed of trafficking, layer thickness, contact stress and stress distribution within the asphalt. In the case of the 40 mm layer the rutting limits were slightly relaxed to take account of the potential for greater vulnerability of the asphalt to aging.

Users of the Protocol should note that the guidelines already take account of the mode of trafficking with respect to channelization and lateral wander when tests are conducted on slabs, whether in the field or in the laboratory. In these instances no further adjustments should be made to the performance findings. Otherwise compensation will be duplicated. However, when trafficking asphalt on specimens in the test bed, adjustments would still have to be made to account for lateral wander.

INTERIM PROTOCOL FOR EVALUATING MOISTURE DAMAGE

The comparative results from MMLS3 and full-scale trafficking at the test track of the National Center for Asphalt Technology (NCAT) (Smit et al 2004a, Smit et al 2004b) and WesTrack were used as benchmarks for establishing criteria for acceptable rutting performance under wet trafficking. The results of tests in Texas (Walubita et al 2002) were used as guidelines for establishing criteria for evaluating moisture susceptibility or damage to asphalt pavements using wet trafficking after 100 000 applications at 50°C heated wet MMLS3 axles:

These are as follows:
- SCB residual tensile strength of hot mix asphalt (Smit et al1997) 80%
- SASW residual stiffness** (Lee et al, 1997) 80% and
- SCB fatigue ratio 50% for hot mix asphalt

Composite pavements require special consideration to evaluate entrapment of water

Permeability measurements can be utilized to evaluate the ease of access of water into asphalt and possible affects on performance. The Texas Department of Transportation (TxDOT) are now using a very simple permeability device that is documented at the following site:

ftp://ftp.dot.state.tx.us/pub/txdot-info/cst/TMS/200-F_series/pdfs/bit246.pdf

It can be used to measure the falling head permeability of mats and cores and could be useful as supplementary tool for wet testing. In similar vein, test results with the *Marvil* permeability device that is used in South Africa were compared to results with the NCAT Field Permeability Device (Taute et al, 2007) relative to voids, layer thickness and aggregate size.

<table>
<tr><th colspan="7">Instructions for Specimen Preparation and Trafficking</th></tr>
<tr><th colspan="7">Compaction Preparation</th></tr>
<tr><td colspan="5">Lab</td><td colspan="2">Lab</td></tr>
<tr><td>H</td><td>G</td><td>R</td><td>R</td><td>R</td><td>R</td><td>R</td></tr>
<tr><td>Hammer</td><td>Gyratory</td><td>Roller</td><td colspan="2">Roller</td><td colspan="2">Roller</td></tr>
<tr><td colspan="2">Cylindrical mould</td><td>Slab</td><td colspan="2">Slab</td><td colspan="2">Slab</td></tr>
<tr><th colspan="7">Voids in Mix (target - unless standard 5 percent)</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="7">Trafficking</th></tr>
<tr><td colspan="4">Channelized</td><td>Wander</td><td>Channelized</td><td>Wander</td></tr>
</table>

Instructions for Specimen Preparation and Trafficking (cont)

Test Conditioning					Temp C		Temp C
Moisture				Dry		Wet	
o Surface		Inundate/Spray					
o Internal*							
By inundating		Y	N				
Other e.g.by means of suction – report details		Y	N				
Test Temperature							
Artificial Heating		Y	N				
o Surface							
o Minus 17 mm	o Minus 25 mm						
o Minus 34 mm	o Minus 50 mm						

Instructions for Specimen Preparation and Trafficking (cont)

<table>
<tr><td colspan="4">***Trafficking Wheel Load***</td><td>kN</td><td colspan="6">2,7</td><td colspan="6">2,9</td></tr>
<tr><td colspan="4">***Tyre Pressure @ 25°C using Standard Diamond Tread Tyre [Approximately Equivalent Contact Stress @ 25°C]***</td><td>kN/m^2</td><td colspan="3">700</td><td colspan="3">750</td><td colspan="3">800</td><td colspan="3">Other</td></tr>
<tr><td colspan="4">***Tyre Tread (***Std Diamond) / Other</td><td>Diamond</td><td colspan="6">Y</td><td colspan="6">N</td></tr>
<tr><td colspan="4">***Axle Load Applications /h***</td><td rowspan="2"></td><td colspan="6" rowspan="2"></td><td colspan="6" rowspan="2"></td></tr>
<tr><td>***1800***</td><td>***2400***</td><td>***3600***</td><td>***7200***</td></tr>
<tr><td rowspan="4">***Airport aprons, taxiways & runway thresholds***</td><td rowspan="4">***Steep highway gradients/ Intersections***</td><td rowspan="4">***Rolling gradients & >>Trucks/ Fast free flowing airport runways and taxiways***</td><td rowspan="4">***Free flowing highway speed***</td><td rowspan="4">Select</td><td colspan="4">1800</td><td colspan="4">1800</td><td colspan="4">1800</td></tr>
<tr><td colspan="4">2400</td><td colspan="4">2400</td><td colspan="4">2400</td></tr>
<tr><td colspan="4">3600</td><td colspan="4">3600</td><td colspan="4">3600</td></tr>
<tr><td colspan="4">7200</td><td colspan="4">7200</td><td colspan="4">7200</td></tr>
<tr><td colspan="17">***Boundary Conditions***</td></tr>
<tr><td colspan="4">▪ Compacted HMA+ Tack coat (Slab - Field/Lab)</td><td></td><td colspan="6">Y</td><td colspan="6">N</td></tr>
<tr><td colspan="4">▪ Metal mould+emulsion interface (Test bed in Lab)</td><td></td><td colspan="6">Y</td><td colspan="6">N</td></tr>
</table>

The fore mentioned guidelines to the *Empirical Protocols* should be carefully considered when selecting test specifications, performance benchmarks and interpreting the findings.

Proposed Empirical Protocols for Acceptable Rutting Performance HMA >90 mm							
Lab						Field	
	Max Rutting under Trafficking to 100k axles (mm)						
	H	G	R	R	R	R	R
Free flowing highway speed	2,5	2,5	3	3	3,2	3	3,2
***Rolling gradients* >> trucks**	2,5	2,5	3	3	3,2	3	3,2
Fast free flowing airport runways & taxiways	2,1	2,1	2,5	2,5	2,7	2,5	2,7
Steep Gradients / Intersections	2,1	2,1	2,5	2,5	2,7	2,5	2,7
Airport aprons / *stop-start* taxiways	1,8	1,8	1,8	1,8	2,0	1,8	2,0
Trafficking Mode	C	C	C	C	W	C	W

Proposed Empirical Protocols for Acceptable Rutting Performance
HMA >75 mm

Lab						Field	
Max Rutting under Trafficking to 100k axles (mm)							
	H	G	R	R	R	R	R
Free flowing highway speed	2,2	2,2	2,6	2,6	2,8	2,6	2,8
Rolling gradients **>> trucks**	2,1	2,1	2,5	2,5	2,7	2,5	2,7
Fast free flowing airport runways & taxiways	1,9	1,9	2,3	2,3	2,5	2,3	2,5
Steep Gradients / Intersections	1,9	1,9	2,3	2,3	2,5	2,3	2,5
Airport aprons / ***stop-start*** **taxiways**	1,5	1,5	1,8	1,8	2	1,8	2
Trafficking Mode	C	C	C	C	W	C	W

Proposed Empirical Protocols for Acceptable Rutting Performance
HMA 60 mm

	Lab					Field	
	Max Rutting under Trafficking to 100k axles (mm)						
	H	G	R	R	R	R	R
Free flowing highway speed	2	2	2,4	2,4	2,6	2,5	2,4
***Rolling gradients* >> trucks**	2	2	2,4	2,4	2,6	2,5	2,4
Fast free flowing airport runways & taxiways	1,6	1,6	2	2	2,2	2	2,2
Steep Gradients / Intersections	1,6	1,6	2	2	2,2	2	2,2
Airport aprons / *stop-start* taxiways	1,5	1,5	1,8	1,8	2	1,8	2
Trafficking Mode	C	C	C	C	W	C	W

Proposed Empirical Protocols for Acceptable Rutting Performance
HMA 40 mm

Lab						Field	
Max Rutting under Trafficking to 100k axles (mm)							
	H	G	R	R	R	R	R
Free flowing highway speed	2,5	2,5	2,5	2,5	2,7	2,5	2,7
***Rolling gradients* >> trucks**	2,3	2,3	2,3	2,3	2,5	2,3	2,5
Steep Gradients / Intersections	2	2	2,1	2,1	2,3	2,1	2,3
Trafficking Mode	C	C	C	C	W	C	W

APPENDIX C: QUANTITATIVE ANALYTICAL EVALUATION OF RUTTING PERFORMANCE

The quantitative analytical evaluation of rutting performance is also based on comparative studies between MMLS trafficking and full-scale APT. The same Case studies as those used for the empirical evaluation were considered. Comprehensive procedures have been reported by Martin Epps et al (2002) and Smit et al (2003).

Research relating to dimensional analysis pertaining to the MMLS3 work on scaled pavements has been reported by Kim et al (1995) and Kim et al (1998). The latter paper concludes that even when full similitude is not satisfied it is possible to obtain valid results that can be extrapolated to predict prototype performance if one were interested primarily in the behavior of the asphalt layer.

The studies served as benchmarks for the interpretation of the results of rutting performance under MMLS3 trafficking. The relationship between truck trafficking and MMLS3 trafficking was investigated. It was shown that it is reasonable to relate the rutting performance of the respective trafficking systems on a one-to-one basis, provided effective trafficking volume, vertical stress due to load, load frequency, tyre pressure and temperature is taken into account. It was also shown that the rutting results after the application of 100,000 MMLS3 axles gives a good indication of the ultimate rutting performance of the pavement when the results are extrapolated to a number of critical load applications that are anticipated during the life cycle of the pavement. It should be appreciated that applications where the risk of failure is required to be very low, the test should be extended by applying 200,000 or more load applications. This will reduce the margin of error in the final prediction of rutting. Likewise, testing of pavements where larger margins of error are acceptable for the class of application, the number of load applications can be reduced to as little as 50000. An abridged extract from the paper by Martin Epps et al (2002) on the quantitative analytical evaluation is presented below to serve as a guideline for practitioners. A paper by Epps et al, (2003) provides additional supporting information on the topic.

> ### *8.4.2 A Critical Review of the Quantitative Analysis of MMLS3 and Truck Rutting Performance at WesTrack*
>
> *In reviewing the methodology to determine PRrutting and subsequent values obtained in the initial analysis, several additional factors that affect rutting performance were identified. The quantitative analysis was revised to take these factors into account.*
>
> *There was evidence that permanent deformation had occurred throughout the HMA layer and not only in the upper 75 mm. To account for this, the HMA was divided into a number of discrete sublayers, each with its own characteristics in terms of G* and E, and the stress analysis was performed over the entire HMA layer depth. In addition, 0,9 mm of the surface rut in Section 01 was assumed due to deformation in the base course and taken into account in calculating the FRR (Field Rut Ratio)*
>
> *Special attention was given to the stiffness of the HMA sublayers*

since this property affects the stress distribution as well as permanent deformation of the HMA layer. Since no values of G were measured for the lower 75 mm HMA sublayer, corresponding stiffness* values were therefore estimated by proportionately decreasing the stiffness values of the upper HMA sublayer based on respective IDT (Indirect Tensile Strength) values measured for both sublayers.*

For the stress analyses, two procedures were used to determine elastic layer stiffnesses. First they were determined by converting G values to E values. Subsequent research indicated that this approach was invalid at high temperatures Therefore, four-point bending test (FPBT) results measured for the lower 75 mm HMA sublayer were used to estimate elastic stiffness values by proportionately increasing the stiffness values of the lower HMA sublayer based on respective IDT strength values measured for both sublayers. The stiffness values for the respective pavement sections and HMA sublayers were then calculated by making corrections for aging, frequency, and temperature using the procedure from the initial analysis. Both sets of stiffness values gave similar PRrutting results, with revised values shown, based on the revised G*-based stiffnesses. The stiffnesses of the base and the subgrade were selected to reflect the response of the pavements and the effective stresses under the two loading conditions. While different values were used in the revised analysis, the effect of these differences on the calculated stresses was small.*

In the revised analysis, a range of contact stresses was investigated, but the revised PR rutting Final values are based on a 850 kPa contact stress (at trafficking temperature).

To account for the influence of the various factors considered, the calculation of the TRR was revised. The contribution towards rut formation by the different discrete HMA sublayers was accounted for in terms of individual Stress Potentials (SP) and related temperature-frequency correction (TFC) factors. This was different as compared to the procedure previously followed in the initial analysis where a single TFC value was used. Rutting Potential Ratios (RPR) determined from SP and TFC values, Comparative Load Rut Ratios (CompLRR) that account for differences in lateral wander between the two loading conditions, and the TRR (theoretical rut ratios) found by multiplying these two ratios were then calculated for each HMA sublayer.

The revised RD data were used in the revised analytical procedure to determine revised PRrutting values. Considering the limited data, it is remarkable that the PRRutting results are so close to unity. The only major discrepancy was in Section 37, where there was MMLS3 set up problems related to milled truck wheelpaths. The revised PRrutting results indicate that the hypothesis required in the quantitative performance prediction methodology (TRR=FRR) appears to hold for four independent pavement sections, provided steps are taken to factor in differences in the respective loading and environmental conditions.

**Stiffness (elastic modulus) of asphalt can be measured by analysing the velocity of seismic waves in materials. The procedure is invaluable for evaluating the material integrity that may be jeopardised by micro-fracturing. This is achieved by conducting a spectral analysis of surface waves (SASW) using* the PSPA (Smit et al,2003).