

MONITORING OF LONG-TERM PAVEMENT PERFORMANCE SITES IN THE WESTERN CAPE PROVINCE OF SOUTH AFRICA

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ABSTRACT

In 2005, the Department of Transport and Public Works of the Western Cape province in South Africa entered into a contract with the Council for Scientific and Industrial Research (CSIR) in South Africa to start a Long-Term Pavement Performance (LTPP) programme. Two LTPP sites were initially established and monitored. The South Africa National Road Agency Ltd (SANRAL) is developing a new mechanistic-empirical pavement design method referred to as South African Road Design System (SARDS). The SARDS will heavily rely on LTPP data to calibrate asphalt cracking and rutting performance models. In 2011, an expanded programme was approved by the Western Cape government with the primary aim of collecting more LTPP data that could assist in the calibration of rutting and cracking models incorporated in the SARDS. Monitoring of the LTPP sites is based on biannual assessments in May during the end of the dry season and in November at the end of the wet season during the contract periods. This paper presents and discusses the findings of the Western Cape province's LTPP programme since its inception, showing a congregation of field and laboratory data to support the development of the new pavement design method. The methodologies used such as sampling procedures, field and laboratory testing are presented in detailed. Field and laboratory data are compared for four LTPP sites. Finally, recommendations to improve and sustain the Western Cape's LTPP programme are presented.

1. INTRODUCTION

The Department of Transport and Public Works of the Western Cape Government (WCG) in South Africa is funding an LTPP monitoring programme of selected sites around the Western Cape province. The CSIR has been contracted by WCG's Department of Transport and Public Works to conduct the LTPP studies. Two LTPP sites were established and monitored from 2005 to 2011. These sites are located on the N7 (a high volume highway) outside Cape Town and Road MR538 (a low volume road) near Elandsbaai. These sites were specifically linked to Accelerated Pavement Testing (APT) sites. Detailed findings and recommendations of the combined study of LTPP and APT are presented by Wynand et al (2012).

In 2011, the LTPP programme was expanded to include four additional sites on regional roads R46 (one site), MR559 (two sites), and a national highway N1 (one site). In 2013 an additional site was established on regional road M5. Monitoring of the site on N7 continued. Thus, six sites are currently being studied. Three sites are located in Cape Town (N1, N7 and M5), two in Langebaan (MR559- new and rehabilitated roads) and one in Tulbagh

(R46). Currently, the WCG has the most comprehensive LTPP programme in South Africa. The goal of the expanded programme was to include laboratory evaluation of field samples in the overall LTPP programme, essentially to establish a comprehensive database for the experimental sites. The plan to evaluate granular and stabilized base/subbase materials in the laboratory was abandoned in order to channel the available resources to establish the site on M5. Collection of quantitative data on cracking, which had not been part of the programme since its inception in 2005 was also included in the expanded programme. As part of the new programme, an LTPP guideline was developed (Anochie-Boateng and O'Connell, 2013).

The selection of the LTPP sites was based on similar pavement types and environmental areas, as well as areas where detailed traffic count and traffic characteristics affecting performance of the pavement could be obtained. The ultimate intention is to use the LTPP data in the WCG pavement design and pavement management systems, and to develop simple models to represent the behaviour of the asphalt materials in the LTPP sites over time. The objective of this paper is to present the findings of four (out of six) LTPP sites (N7, M5, N1 and MR559) monitored between 2005 and 2014. Both field and laboratory test results are presented and discussed on the four LTPP sites.

2. OBJECTIVE AND BENEFITS

The primary objective of an LTPP programme is to investigate in-service pavements and to provide adequate data, information, and products (e.g. performance models -rutting and cracking) that can describe the pavement life. The WCG LTPP programme seeks to achieve this objective. Some of the benefits of the WCG LTPP programme include:

- Road authorities and their appointed consultants and researchers will have access to the data collected from the LTPP sites;
- Data collected will contribute to the WCG and national road agency database for pavement design;
- Development of a database for archiving road pavement performance data;
- Effective management of assets in terms of the costs of road maintenance and rehabilitation and road user costs;
- Performance records of pavements under different maintenance and climatic conditions; and
- Road deterioration /performance models for basic and advanced pavement design.

3. METHODOLOGY

Methodologies for the establishment and monitoring of LTPP sites as well as establishing comprehensive database were developed previously (Jones and Paige-Green 2003; Anochie-Boateng and O'Connell 2013). The methodologies followed for the WCG LTPP programme include the following aspects:

- Traffic counts;
- Visual assessments;
- Field data collection;
- Sampling and testing of asphalt layer materials;
 - Coring at predominantly distress sites of the road; and
 - Laboratory testing on asphalt cores and extracted binders for modelling purpose.

- Analysis of stiffness, permanent (plastic) deformation, strength, and moisture sensitivity tests results for asphalt layers;
- Evaluation of ageing models for bituminous binder; and
- Development of stiffness and performance models for asphalt materials.

Both long-term structural and functional performance of the LTPP sites are monitored in the field to better understand pavement performance. Apart from the rut and deflection data collected on the sites, in situ density and moisture content data are also collected during each monitoring visit. These visits are carried out approximately every six months to ensure that data is collected at the end of the dry and wet seasons. Logistics do not always allow for precise intervals in these data collection visits, and gaps may thus exist in the data. The structural conditions of the LTPP sites are assessed by means of Falling Weight Deflectometer (FWD) and Dynamic Cone Penetrometer (DCP) tests. The primary objective of these non-destructive testing is to establish whether or not failures of the sites are related to the specific properties of the surfacing and the conditions of the substrata.

In the laboratory, standard test methods are followed to collect data from asphalt cores extracted from the LTPP sites. The laboratory test results are correlated with mix design data, as-built data and performance data and to identify causes of failure and attributes of performance taking into consideration all available data on the LTPP sites.

Traffic counts are performed to distinguish between light, medium, heavy, and very heavy vehicles. The damage caused by the different vehicle types on the pavement is usually expressed in an equivalent of a standard 80 kN axle load (E80). As part of the traffic survey, axle configurations are also identified for all heavy vehicles and the percentage of heavy vehicles are also identified for analysis purposes.

4. FIELD DATA COLLECTION

The CSIR project team in partnership with the Department of Transport and Public Works of the Western Cape province project team conduct detailed field investigation of six sites biannually. Field (monitoring) data is collected on a periodic basis throughout the life of the test section as a means of tracking the structural and functional condition of the pavement sites over time. These activities provide a historical database that helps establish relationships among distress, performance, traffic volume, axle loads, age, maintenance, and other significant variables. Monitoring data collected on the LTPP sites include visual assessment, rut depth measurement, pavement temperature, density and moisture content, and deflection measurements. The visual assessment is done based on the standard visual assessment manual for flexible pavements in South Africa (TMH9 1992).

After completion of the non-destructive testing (deflection), cored samples of the asphalt surfacing are extracted from the LTPP sites to determine the physical and engineering properties including density, stiffness, tensile strength, resistance against permanent deformation, grading and water permeability. The conditions of the binder recovered from the cored samples are also assessed by means of various physio-chemical tests. In this paper, the laboratory and field data collected from four LTPP sites (N1, M5, N7, and MR559) are presented and discussed.

4.1. Pavement temperature data

Pavement temperature was monitored using i-buttons installed under the surfacing (about 20 mm from surface of asphalt layer). Diurnal temperature fluctuations remained clearly

noticeable. A summary of the temperatures measured for the four LTPP sites is provided in Figure 1. It can be seen that the maximum and minimum temperatures for all four sites were approximately 50°C and 10°C, respectively. As expected, the maximum temperatures are recorded during the summer months, whereas the minimum temperatures are recorded during the winter months.

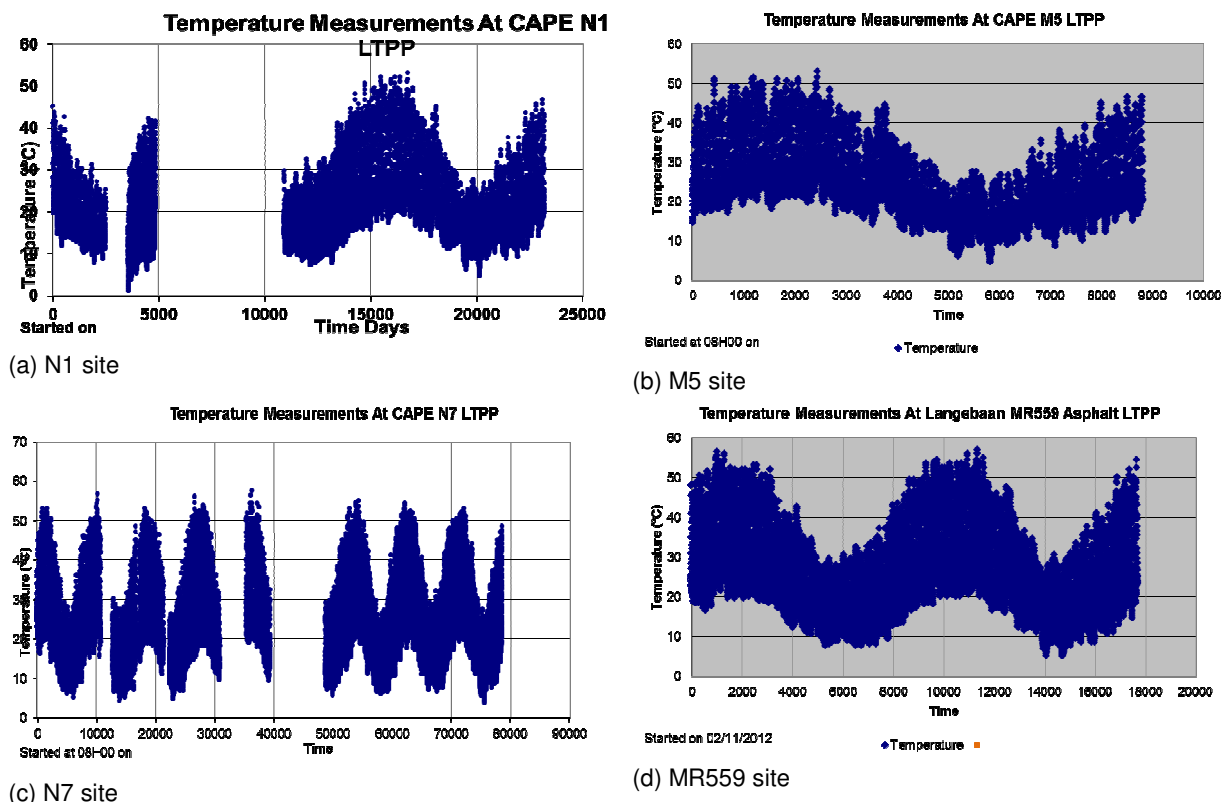


Figure 1- Pavement temperature results for LTPP sites

4.2. Visual inspection

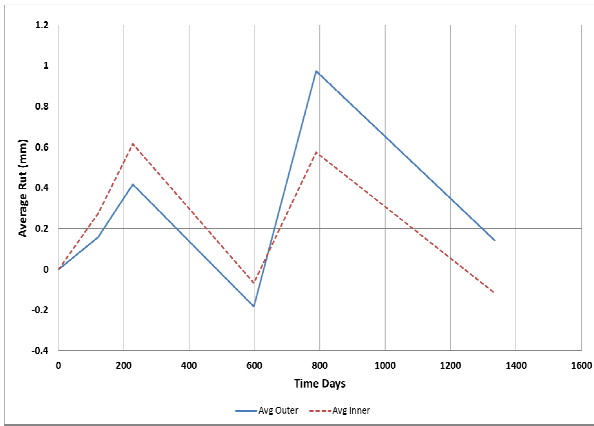
A detailed visual inspection of the four LTPP sites was undertaken to establish the overall condition of the road. All modes of distresses such as bleeding, rutting, cracking, surface disintegration, localised failures, and other obvious pavement related characteristics were recorded in detail, with reference to the location along the outer, between and inner wheel tracks of the sites. The degree and extent of visible distresses were recorded and evaluated in accordance with guidelines as set out in South African Technical Methods for Highways (TMH 9, 1992). Figure 2 shows typical distresses recorded on the four sites. Longitudinal cracking, block cracking, rutting and crocodile cracking were the main distresses observed in all four LTPP sites.



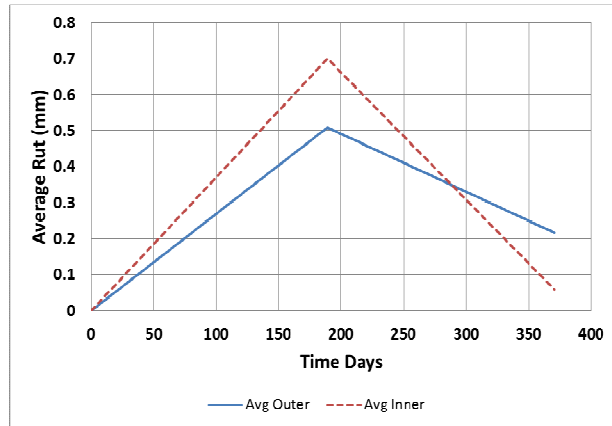
Figure 2 - Various distresses observed on some sites

4.3. Rut depth measurements

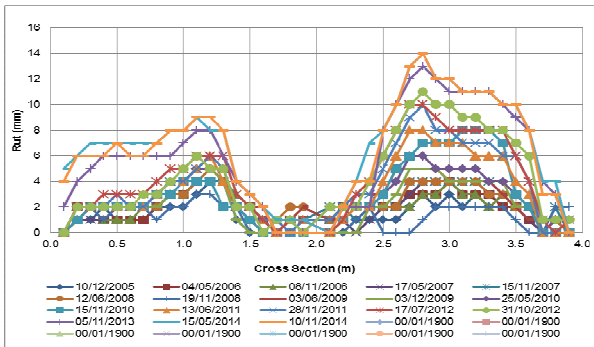
A two-meter long straight edge and a wedge were used to measure rut depths of the four sites (N1, M5, N7, MR559) in accordance with procedures set in TMH 9 (1992). Rut depth is defined as the maximum permanent deformation measured under the two-meter straight edge. The cross sectional profile was measured from the yellow line on the shoulder towards the centre of the pavement. In most cases, the cross sectional profile was measured by placing the straight edge on top of the shoved asphalt so that a measurement of zero (0) mm could be obtained on the shoulder as the yellow line was not visible. Figure 3 shows the maximum rut depths for the outer and inner wheel tracks. Generally, the measurements for the inner wheel tracks were found to be higher than those of the outer wheel tracks as depicted clearly in Figure 4.



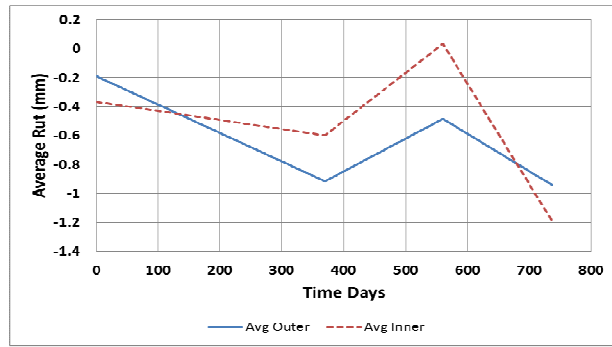
(a) N1 site



(b) M5 site



(c) N7 site



(d) MR559 site

Figure 3 - Rut depths at various sites.

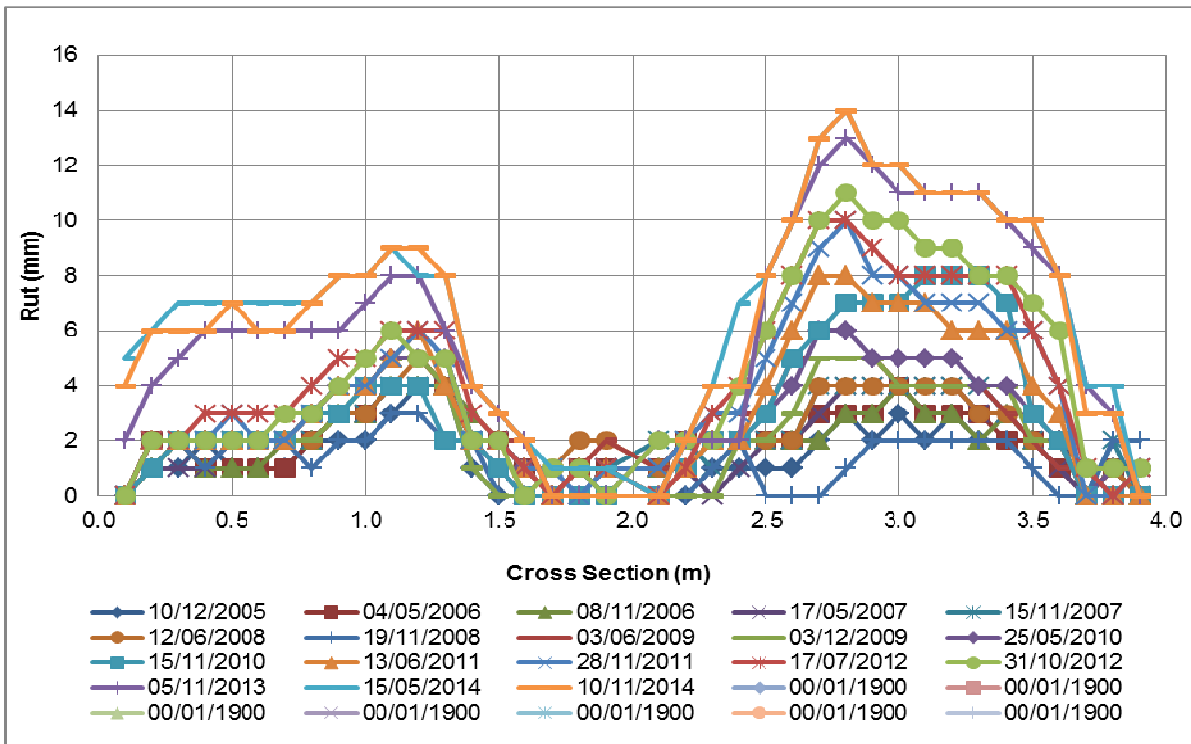


Figure 4 - Rut depths in outer and inner wheel paths

4.4. FWD Measurements

FWD is commonly used to measure deflections, and to evaluate the in situ strength and stiffness properties of the pavement structure. The FWD test was carried out at all four sites. The tests were conducted at intervals of 50 m on these sites. In order to simulate the axle load of 80 kN standard axle, the FWD tests were carried out using an impact load of 40 kN.

Figure 5 shows that deflections have increased over the years on all LTPP sites. Generally, higher deflections were recorded in the period of November to March (hot and dry season) when compared with deflections recorded between May to October (cold and wet season), i.e., an indication that deflection increases with increasing temperature. It is interesting to note that on the N1 site, deflections were lower in the outer wheel track when compared with the inner wheel track, however, this relates to the observed rut measurements (Figure 4). As expected, deflections in both wheel tracks were significantly higher than between wheel tracks (centre lane). No clear trends are however, established at this time, for the deflection on the M5, N7 and MR559 sections.

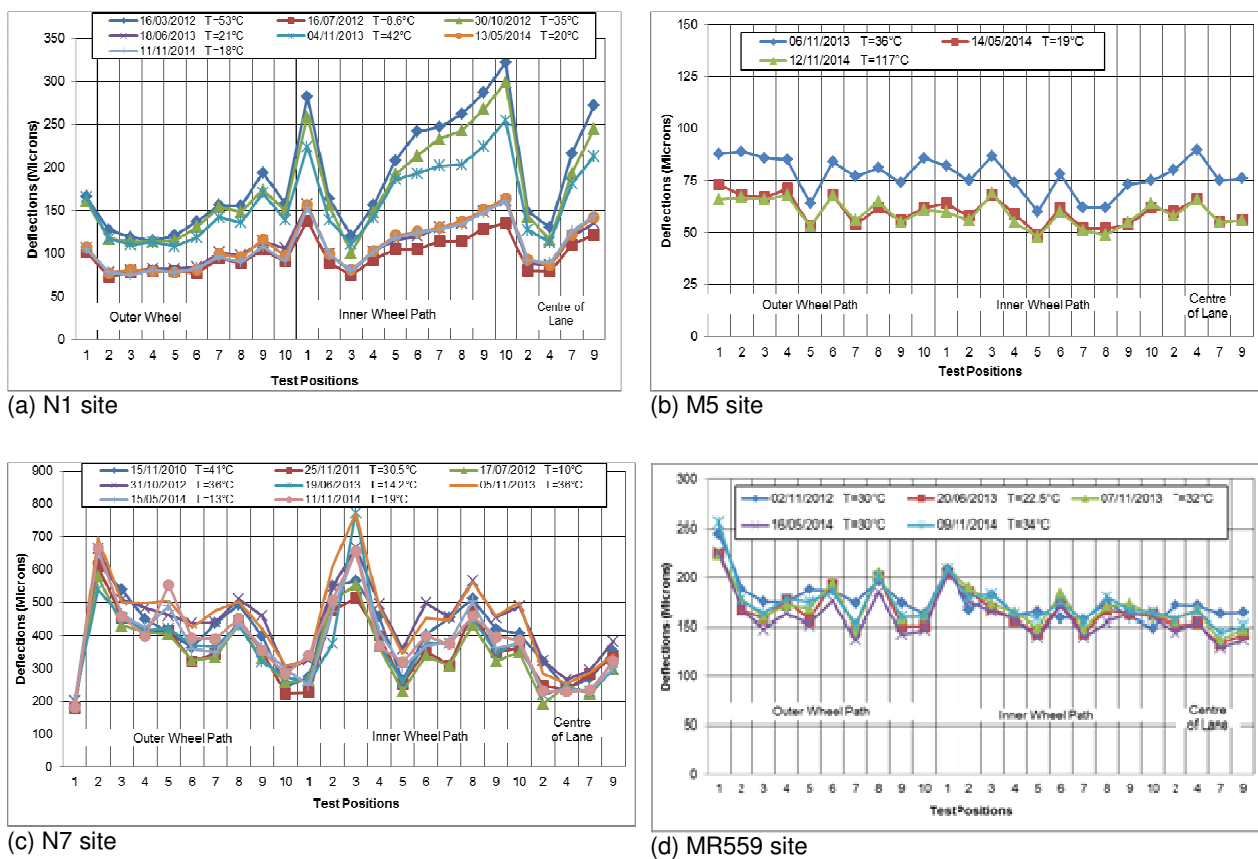


Figure 5 - FWD measurements at different wheel tracks

4.5. Sampling of asphalt cores

Cores have traditionally been used to determine layer thickness, and tested in the laboratory to determine the physical and engineering properties of the component materials. A 100-mm and 150-mm diameter cores were extracted from the four LTPP sites for detailed visual assessment and laboratory evaluation of the binder, aggregates and asphalt mix properties. The samples were extracted in the outer wheel track, between the wheel track and the inner wheel track. Cores were drilled to the bottom of the pavement

surface, reducing the water to a trickle for the last 25 mm of drilling so that the base material will not be contaminated with excess moisture. The core samples were firstly assessed to determine the extent of damage to the asphalt surface layers, including location, width and depth of cracking, porosity, segregation, binder condition, bleeding and other conditions. Note that porosity in this instance is a subjective evaluation of whether or not the layer is porous. It is not scientifically based, and requires confirmation via voids determination. Core samples were taken from the asphalt surfacings at the same positions where the DCP tests were performed.

At every site, a minimum of nine cores were taken (three outer wheel track, three from between wheel tracks, and three from inner wheel track). These cores were used for mechanical and chemical laboratory testing. All cores were sampled in accordance with the guideline developed for the Western Cape's LTPP programme (Anochie-Boateng and O'Connell, 2013). Figure 6 shows typical cores extracted from the four sites.

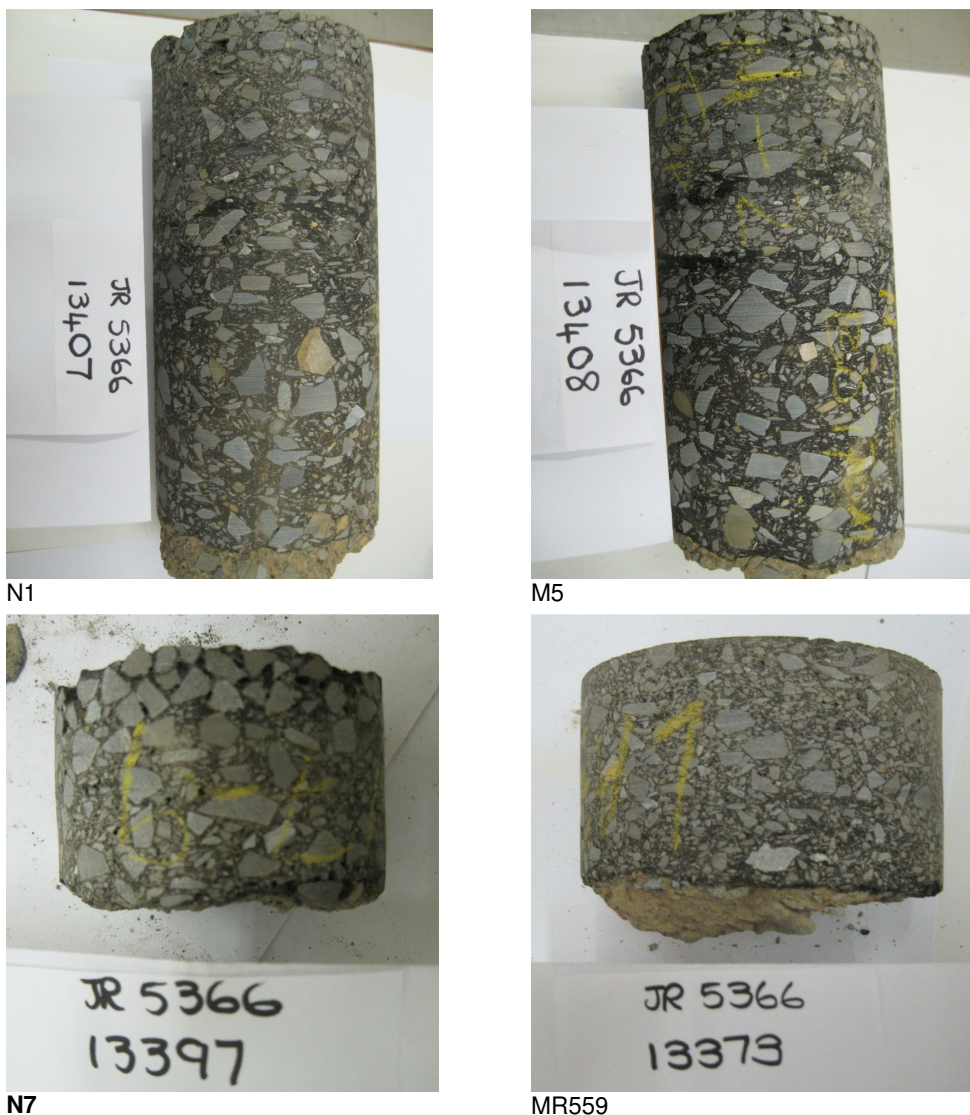


Figure 6 - Photographs of cores from N1, M5, N7 and MR59 sites

5. DISCUSSION OF FIELD RESULTS

In terms of structural assessment, increasing areas of cracking were noted. There are signs of pumping from these cracks. Rut depth generally increased significantly in the inner wheel tracks when compared with the outer wheel tracks. No potholes, patches or edge break were noted. A moisture profile of the outer wheel track shows an increase in moisture over time. Seasonal influences are not clear cut at this stage of monitoring. Density measurements remained relatively constant and consistent over the length of most sites. Densities were marginally higher in the outer wheel tracks compared with the inner tracks and between wheel tracks, again supporting the rut and deflection data observations.

The rut depth and FWD data collected from the four sites indicate that rutting and deflection in the wheel paths is the major concern. Similar trends were observed on the other LTPP sites that are not included in this paper. Cracking was a major problem observed on most sites selected for the programme. There were signs of crack development in the inner wheel and outer wheel tracks, and an increase in surface cracks. However, more signs were observed mainly in the outer wheel track. Cracking was prevalent on the N7 section. Hence, the expanded LTPP programme recommended the inclusions of cracking width and cracking length measurements during the 2014 to 2017 contract period. The slow lane of the dual carriage of the N7 section showed more cracking and pumping when compared with the fast lane. As indicated in Figure 7, increase in crack length on the N7 section within six months appears to be substantial.

Apart from cracking, no significant distress was recorded on the four sites during the assessments period. For example, in Figure 2, the maximum rut depth measured on the N7 section from December 2005 to November 2014 was about 14 mm. This amount of rut depth based on South Africa standards is a warning (note that <10 mm is sound, and >20 mm is severe conditions). No ravelling was noted and the binder condition of most sites was rated as fresh. Indistinct discolouration was evident in the wheel tracks of some sites (e.g. N7), attributed to minor wear (polishing) of the pre-coating on the surfacing chips.

In terms of functional assessment, no deterioration was recorded over the period of the visits. Riding quality has been affected due to the increase of cracking. The skid resistance and surface drainage were all rated as 1 (very good). The sealed shoulders were rated as good and side drainage remained clear of vegetation.

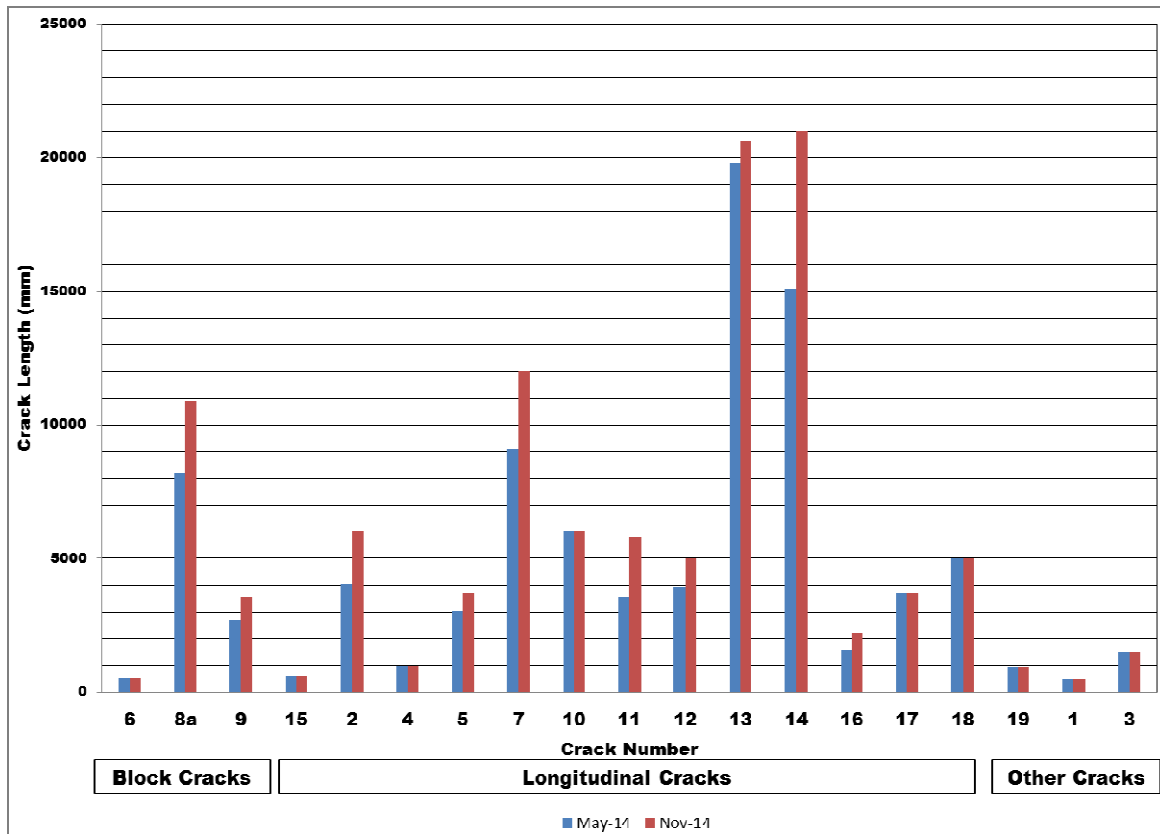


Figure 7 - Crack propagation on N1 section during winter and summer

6. LABORATORY TESTING

6.1. Determination of recovered binder properties

The binder properties were determined for all binder types recovered from asphalt cores extracted from the four sites. Both standard (empirical) and the advanced dynamic shear rheometer (DSR) test procedures were used to determine the rheological properties (i.e., complex modulus and phase angle) of the binder. The complex shear modulus and phase angle of the binder will be used to develop ageing model for the binder. In addition, the complex shear modulus of the binder can be used to model the dynamic modulus of the asphalt cores using predictive equations.

Binder recovered from core #1 from each site was tested with respect to all binder properties. The penetration, softening point and viscosity values are indicators of ageing in the field. Binder content can be used to determine film thickness, which in turn is associated with ageing. Ash content is a quality control measure to determine the extent to which the binder has been recovered without excessive fines. The ash content values correlate well with the relative density (specific gravity), which increases with increasing fines content. A summary of the binder test results for the LTPP sites is presented in Table 1.

Table 1 - Recovered Binder properties for the LTPP sites

	N1	M5	N7	MR559
Binder Content (%)	4.5	4.4	5.2	5.5
Penetration @ 25 °C	34	76	49	44
Softening point (°C)	56.8	49	53.4	55.8
Dynamic viscosity @ 80 °C	59.2	21.7	36.6	29.4
@90 °C	20.7	8.58	13.1	11.2
@100 °C	8.25	3.85	5.34	4.61
Complex modulus (kPa) @ 20 °C	8 260	4 610	9 130	10 100
Complex modulus (kPa) @ 40 °C	330	129	259	328
Specific gravity	1.035	1.048	1.047	1.043
Elastic recovery (%)	-	30	-	-
Ash content (%)	0.409	1.596	1.297	1.794

6.2. Determination of air voids content

Table 2 presents the air voids of the asphalt layer in the wheel tracks and between wheel tracks for the four LTPP sites. The average voids between the wheel tracks are 7.9% compared to average voids in the wheel tracks of 6.3% for M5. This is expected since the cores in the wheel tracks are expected to be more compacted than the cores between the wheel tracks. A similar trend cannot be found for N7 and N1, nor the MR559 in the table. Further investigation into compaction during construction and due to traffic is required in order to provide a valid interpretation of these results. However, the average air voids content obtained for N7, N1 (asphalt surfacing) and M5 are within the acceptable field voids of the sites (design voids + 3%).

Table 2 - Voids content of cores from critical locations

Core number	Core position	N1	M5	N7	MR559
		Voids (%)	Voids (%)	Voids (%)	Voids (%)
Core 1	Left wheel track	5.7	6.0	6.8	7.7
Core 2	Between wheel tracks	5.6	8.1	6.0	7.2
Core 3	Right wheel tracks	NA	6.3	6.5	5.4
Core 4	Left wheel track	5.2	6.6	6.4	6.7
Core 5	Between wheel tracks	6.0	7.6	6.6	6.4
Core 6	right wheel tracks	6.9	6.9	6.0	5.2
Core 7	Left wheel track	6.2	6.3	7.2	6.3
Core 8	Between wheel tracks	7.6	7.9	5.6	5.1
Core 9	right wheel tracks	8.4	5.6	6.2	6.0

6.3. Evaluation of engineering properties of asphalt cores

Three engineering properties (i.e. stiffness, permanent deformation and strength) were evaluated for the cores extracted from the four LTPP section. The stiffness of the asphalt mix is required to determine stresses and strains in a pavement structure under the actual loading conditions, and used to predict rutting and cracking.

In this LTPP programme, stiffness is evaluated by using either dynamic modulus (thick asphalt cores, >100 mm thick) or resilient modulus (thin asphalt cores). Accordingly, dynamic modulus tests (AASHTO TP 79, 2009, with modifications by CSIR, Anochie-Boateng et al. 2010) were conducted on the extracted cores from N1 and M5, whereas resilient modulus tests (BS EN 12697-26:2004) and the indirect tensile strength tests (ASTM D6931, 2012) were conducted on cores extracted from N7 and MR559 sites.

Similarly, depending on the specimen size, both repeated simple shear and repeated axial (triaxial) load permanent deformation tests were conducted on the cores from the LTPP sites. The choice of test to be performed on cores from each LTPP section was based on the thickness of the core. The repeated load simple shear tests were conducted on the more thinner cores (50 mm high), whereas the repeated load triaxial tests were performed on thicker core samples (>100 mm high). Based on this the repeated load simple shear tests (AASHTO T 320, 2007) were conducted on the cores extracted from N7 and MR559 sites, whereas the repeated axial load tests (AASHTO TP 79, 2009, with modifications by CSIR, Anochie-Boateng et al. 2010) were done on cores obtained from N1 and M5 LTPP sites.

A summary of the engineering properties of the asphalt cores evaluated for the four LTPP sites are presented in Table 3. It should be mentioned that the data gathered so far is not enough to present any detailed discussions and to develop any trend or simple models for the asphalt cores tested.

Once all the data has been gathered, interim ageing models will be available for the LTPP asphalt sites. The interim ageing models will display retarded ageing rates due to the protection afforded by the ultra-thin friction course layer to the asphalt layer. Such ageing models will be used in the Witzack and Hirsch predictive models to adjust the predicted dynamic modulus with time. Ultimately, however, the ageing model should predict the onset of cracking and pothole development, whereby it can be incorporated as a tool in planned maintenance.

Table 3 - Engineering properties of asphalt cores

Section	N1	M5	N7	MR559
Pen grade and mix type	AE-2 + 15% RA	50/70 + EVA	Data Unavailable	Data Unavailable
Engineering properties				
ITS (kPa)	-	-	1843	2569
Resilient modulus (MPa) @10Hz, 20°C	-	-	4 623	3 201
Dynamic modulus (MPa) @10Hz, 20°C	4737	9 277	-	-
Flow number (Cycles) @40°C	6800	774	-	-
Plastic shear strain @ 5000 cycles (%)	-	-	3%	6.25%

7. CONCLUSIONS AND RECOMMENDATIONS

Based on the results presented in this paper, the following conclusions and recommendations are made:

- The major deteriorations on the four LTPP sites are surface cracking. Some potential seasonal variation in terms of moisture content and temperature, and its influence on density and deflection, appears to be apparent, although additional monitoring will be required before any firm conclusions can be drawn.
- It is expected that clearer trends will start to emerge from these comparisons. Moisture contents should be closely monitored as this appears to be influencing density, strength and deflection measurements.
- From an economical viewpoint it should be appreciated that the operation of a decent LTPP programme requires dedicated funding over a number of years, while limited data is added to the database each year. The significance of the data only materializes once sufficient data is available to compare realistically with the collected APT data.

- From a practical viewpoint, it is important to ensure that the LTPP sites are located on similar pavement types and environmental areas, and that the traffic on the LTPP site can be monitored in enough detail to use as input into the analysis process and that this traffic resembles the traffic applied to the APT section within a reasonable period.

It is recommended that the scope of the LTPP programme needs to be expanded in order to obtain additional and essential data to help improve the applicability and accuracy of pavement performance models for diverse pavement conditions in South Africa, and that a database of mechanical properties of pavement materials on all LTPP sites be established to enable development of calibrated Highway Development and Management (HDM4) type models. Generally, five years continuous data would give a complete view of the behaviour of the materials for the individual sites.

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REFERENCES

1. AASHTO T 320. 2007. Standard Method of Test for Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures using the Superpave Shear Tester (SST). American Association of State Highway and Transportation Officials, Washington D.C.
2. AASHTO TP 79-09. Standard method of test for determining the dynamic modulus and flow number for hot mix asphalt (HMA) using the asphalt mixture performance tester (AMPT), AASHTO, USA.
3. Anochie-Boateng, J and O'Connell, J (2013). Guideline for Long-Term Pavement Performance (LTPP) Data Evaluation in Western Cape. CSIR, Pretoria.
4. Anochie-Boateng, J., Denneman, E., O'Connell, J., and Ventura, D. 2010. Hot-mix asphalt testing for the South African pavement design method. Proceedings of 29th Southern Africa transportation conference, Pretoria.
5. ASTM D6931-12, Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures, ASTM International, West Conshohocken, PA, 2012, www.astm.org
6. BS EN 12697-26. 2004. Bituminous mixtures – Test Methods for Hot-Mix Asphalt. Part 26: Stiffness.
7. Jones, D. and Paige-Green, P. 2003. A protocol for the establishment and operation of LTPP sites - 1st Draft. Pretoria: CSIR-BE. (Contract Report CR-2003/11).
8. TMH9. 1992. Pavement Management Systems: Standard Visual Assessment Manual for Flexible Pavements. Technical Methods for Highways. South Africa Department of Transport, Pretoria, South Africa.
9. W.J.vdM Steyn, J.K. Anochie-Boateng and C. Fisher, D. Jones and L. Truter. Calibration of Full-Scale Accelerated Pavement Testing Data using Long-Term Pavement Performance Data. 4th International Conference on Accelerated Pavement Testing, Davis, California, USA, September 19-21 2012.