

# Calibration of Full-Scale Accelerated Pavement Testing Data using Long-Term Pavement Performance Data

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**ABSTRACT:** Accelerated Pavement Testing (APT) has always been conducted with the objective of improving the understanding of real pavements under real traffic and environmental conditions. While APT provides an accelerated view of some of the major structural behavior to be expected from tested pavements, and while various environmental conditions can typically be simulated during APT, it is important to link the results obtained to real world pavement behavior to enable outputs from APT to be calibrated for use in general pavement design and analysis. One way of conducting this type of calibration is to conduct long-term pavement performance (LTPP) evaluations on similar pavements to those tested under accelerated conditions and to relate this information to the APT data to calibrate the them for general use (inclusive of normal traffic and environmental conditions). This paper evaluates six years of APT and LTPP data from two road sections in South Africa. The results of the APT tests are compared to the LTPP data and the pavement behavior models obtained from the APT calibrated to real-world outputs. Various concepts required to conduct these calibrations are discussed and the general procedure is reported. It is recommended that more LTPP sections be assessed in conjunction with APT, which should result in more realistic application of the APT data in that the effects of more real-time environmental and traffic applications will be incorporated into calibrated models.

## 1 INTRODUCTION

Accelerated Pavement Testing (APT) is the controlled application of a wheel loading, at or above the appropriate legal load limit, to a prototype or actual, layered, structural pavement system to determine pavement response and performance under a controlled, accelerated, accumulation of damage in a compressed time period (Metcalf, 1996). Long-term pavement performance (LTPP) focuses on evaluation of the in-service performance of pavements, incorporating normal traffic loads and typical environmental conditions affecting the pavement in a normal way. The calibration of APT data with LTPP data to allow for a realistic incorporation of normal traffic and environmental loading effects has been a topic of interest for APT practitioners for many years. It has been highlighted in two NCHRP synthesis documents (Metcalf, 1996; Hugo and Epps Martin, 2004) as one of the objectives of a comprehensive APT program, enabling the transposition of APT data to real-world applications. It should be appreciated that LTPP data resembles real life (real pavement, real traffic and real environment) while APT data are collected to understand behavior and to develop performance models in an accelerated pe-

riod, and therefore the APT data should be adapted to the LTPP data.

Although the general aims and objectives of the combination of APT and LTPP data have been recognized for many years, the practical and economic aspects of such a combination of data have typically been the major hindrance in achieving this aim. From a practical viewpoint, it is important to ensure that the LTPP sections and the APT sections are located on the same pavement types and in the same environmental areas, and that the traffic on the LTPP section can be monitored in sufficient detail to use as input into the analysis process. This traffic should also resemble the traffic applied to the APT section within a reasonable period. From an economic viewpoint it should be appreciated that the operation of a quality LTPP program requires dedicated funding over a number of years, even though limited data are added to the database each year. The significance of the data only materializes once sufficient data are available to compare realistically with the collected APT data.

This paper focuses on one application of a combination of the data from an APT and LTPP program in South Africa. There are currently two such programs running in South Africa, one for the Provincial Administration of the Western Cape (PAWC) on

which this paper focuses, and one for the Gauteng Provincial Administration. The paper starts with background on the development of the LTPP guidelines used in the program, as well as some thoughts regarding the effective implementation of these guidelines into a provincial roads department environment. This is followed by a short methodology followed in developing this paper, and background information of the two pavements on which the APT and LTPP data were collected. The surface rut and elastic deflection data of the two pavements are compared and discussed, and conclusions and recommendations developed based on the data are provided.

## 2 PROJECT BACKGROUND

In 2003, when the South African initiative to relate APT to LTPP was started, very few formal comparative experiments had been undertaken anywhere in the world, although numerous ad hoc studies had been carried out in a number of countries. The primary reason given for this is usually the absence of sustained long-term funding.

Although committed funding had not been guaranteed for the South African Heavy Vehicle Simulator (HVS) APT/LTPP study program, the need for a protocol to standardize the methodology used for establishing and monitoring LTPP sections in conjunction with APT sections was identified, with a view to initiating such a study. The protocol, written in the form of a guideline was finalized in 2004 (Jones and Paige-Green, 2003) and a paper presented on it at the 2<sup>nd</sup> International Conference on Accelerated Pavement Testing (Jones et al., 2004). The protocol covers management responsibilities, section location and establishment, instrumentation, and data collection and reporting criteria. The protocol was developed for mobile facilities, but most aspects are also applicable to fixed facilities and test tracks.

In 2004, funding to conduct LTPP studies adjacent to two recently completed APT studies was provided by the Gauteng Department of Transport and Public Works to “test” the protocol. The first experiment included two sections where recycled materials (clinker ash) were used as base material with a thin chip seal surfacing. The second experiment was part of a full-depth reclamation with foamed bitumen study. Annual monitoring of these two sections continues today and interim reports have been published (Jones et al., 2007).

Additional funding was provided by the Department of Transport and Public Works (DTPW) of the Provincial Administration of the Western Cape (PAWC) in 2005 for an additional two studies to assess the performance of two pavements also rehabilitated using full-depth reclamation with foamed bitumen (Steyn et al. 2007, Anochie-Boateng and

Fisher, 2010) after HVS tests were completed on a number of test sections on the two roads. The two sections, one on a National Highway (N7, equivalent to an Interstate highway in the United States) and one on a low-volume road (M538) were selected because of the differences in traffic loading, climate, and materials used. The studies on these two roads are the focus of the discussion in this paper.

Both long-term structural and functional performance of the two sections are being monitored, with the primary objective of providing appropriate, adequate data, information, and products (e.g., rutting and cracking performance models) to better understand pavement performance. The ultimate intention is to use LTPP data in the PAWC pavement design and pavement management systems. Based on the data collected to date, PAWC is currently extending the LTPP program by adding further pavement sections into the existing LTPP program.

## 3 PAPER METHODOLOGY

The methodology followed focused on a realistic calibration of the APT data using the available LTPP data. The overall objective is that the pavement performance models that were based on the original APT data be updated/calibrated through comparison with the data collected over a longer period using the LTPP process.

The two pavement sections used in the paper consist of a relatively high volume highway (N7) and a low-volume road (M538). The APT tests were conducted at load levels of both 40 kN and 80 kN, and allowance is firstly made for the calculation of equivalent traffic load repetitions for both the APT data and the LTPP data (based on traffic counts). No detailed environmental data were collected on the sections under investigation, although the seasonal changes are expected to be directly linked to the two main seasons (dry summer and wet winter) experienced in the Western Cape.

Once allowance was made for calculation of equivalent traffic loads, the actual data were compared graphically. At this stage of the process the calibration effort started, which essentially consisted of changes in the damage factor of the load equivalence equation, to allow the measured APT data to resemble the LTPP data as closely as possible. As pavement properties are variable, all data were shown as the average, as well as  $\pm 1$  standard deviation of the average data. The outcome of the calibration process was an improved load equivalence damage factor for application to all the data collected during APT tests on the specific pavement type and region (environmental effects). The rut and deflection data were treated separately in this calculation.

Apart from the rut and deflection data collected on the sites, in situ density and moisture content data were also collected during each monitoring visit. These visits are carried out approximately every six months to ensure that data are 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 traffic levels on the two roads are approximately 17,000 (Average Annual Daily Traffic [AADT]) (23% heavy vehicles) for the N7 and approximately 200 AADT (15% heavy vehicles) for the low-volume road (M538) (2011 data).

#### 4 TEST SECTION BACKGROUND

##### 4.1 Road N7

The HVS study on Road N7 evaluated the performance of a rehabilitation strategy involving in-place full-depth reclamation of the existing pavement (thin surfacing over aggregate base (hornfels) using foamed bitumen and cement as a stabilizer and surfaced with hot-mix asphalt (HMA). Figure 1 shows the nominal pavement structures before and after construction, while the conditions under which HVS tests were conducted on the road section are shown in Table 1. The base was treated with 2.3 % foamed bitumen and 1.0 % cement by mass of dry aggregate. The subbase consisted of crushed stone and the subgrade of sand. Two HVS test sections (415A5 and 416A5) were investigated for Road N7 adjacent to the LTPP section (Theyse, 2004a). The site is located in a relatively flat sandy area with a moderate climate.

##### 4.2 Road M538

The HVS study on Road M538 was initiated to assess the performance of a pavement structure with a very thin surface seal. Figure 1 shows the pavement structure, while Table 1 presents the conditions under which HVS tests were conducted on the road section. The base consisted of quartzitic sandstone while the subbase consisted of residual quartzitic sandstone fragments in a matrix of residual and windblown quartzitic sand. Two HVS tests were conducted on Road M538 (419A5 and 420A5) (Theyse 2004b). The site is located in a relatively flat sandy area with a moderate climate.

##### 4.3 General LTPP Data

An indication of the general form of both the rut and deflection data collected during the LTPP experiment are shown in Figure 2 (rut) and Figure 3 (deflection) for Road N7. Figure 4 shows typical trends of average elastic modulus at different depths in the Road N7 pavement. The stiffness values on the outer

wheel path were consistently higher than the values for the inner wheel path. Figure 5 shows variations of density with pavement depth in the outer and inner wheel paths of the section. The figures indicate the general seasonal changes in the data. Similar trends were observed on the Road M538 pavement data.

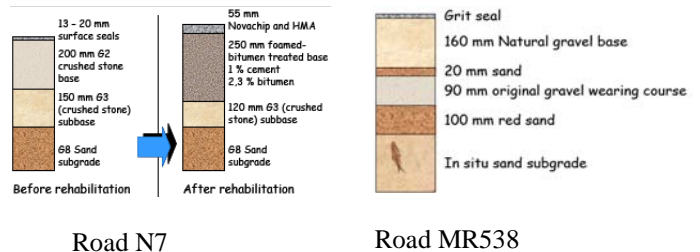


Figure 1. Nominal pavement structures of the two LTPP sections studied.

Table 1. Test conditions for HVS tests discussed in this paper.

Test conditions for Road N7 (HVS tests 415A5 and 416A5)		Wheel load (kN) / tire pressure (kPa)			
		Dry		Wet	
		40/620	80/800/850	100/880	80/800
Test section	415A5	0 to 48,628	48,628 to 423,374	423,374 to 498,863	--
	416A5	0 to 1,168,850	1,168,850 to 1,618,850	--	1,168,850 to 1,742,850
Test conditions for road M538 (HVS tests 419A5 and 420A5)		Wheel load (kN) / tire pressure (kPa)			
		Dry		Wet	
		40/620	80/820	40/620	80/820
Test section	419A5	0 to 15,268	15,268 to 310,000	--	--
	420A5	0 to 400,000	--	400,000 to 1,040,903	1,040,903 to 1,099,400

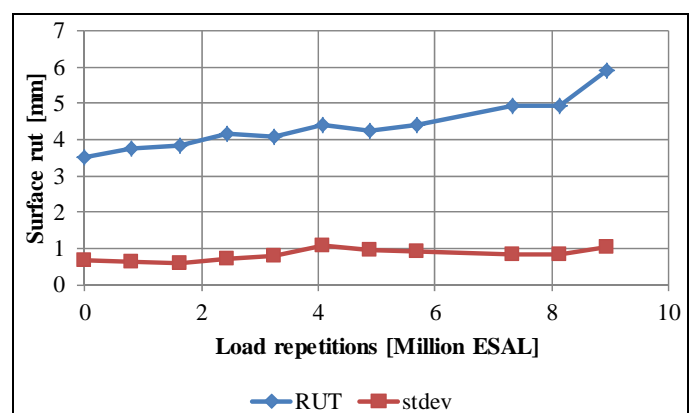


Figure 2. Rutting profile on N7.

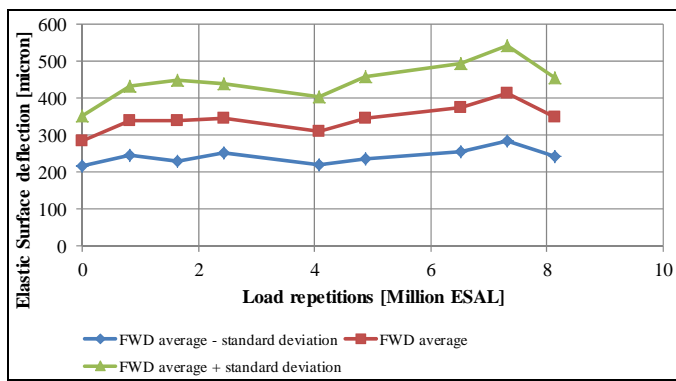


Figure 3. Average deflections on N7 LTPP section.

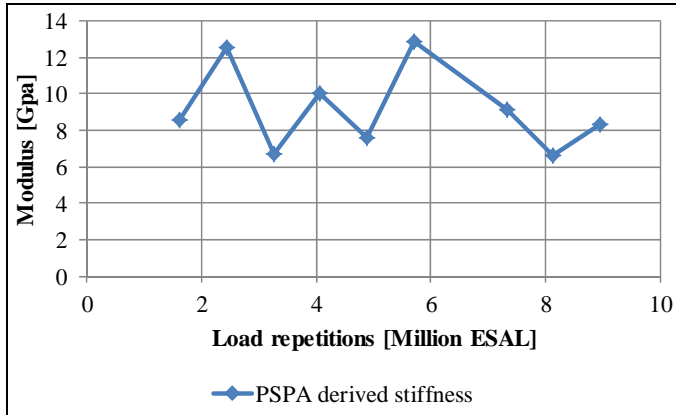


Figure 4. Stiffness trends on the N7 section at different depths.

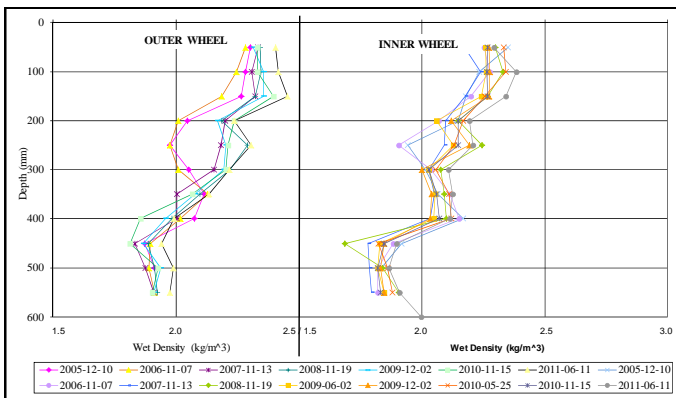


Figure 5. Variation of density with depth for LTPP section on N7 (refer to Figure 1 for layer thicknesses).

#### 4.4 Summary of Findings from Road N7

The various analyses of the data collected from Road N7 (Figures 2 and 3) indicated that (Theyse, 2004a; Long and Brink, 2004):

- Backcalculated resilient moduli from both FWD and MDD deflection measurements indicated an increase in the resilient modulus of the base layer in the early stages of the investigation as a result of the stabilization process. However, under trafficking, the initial relatively high resilient modulus was reduced to values more representative of unbound crushed stone materials. As in the case of other stabilized materials, two modes of behavior were identified for the foamed-bitumen-treated base, the first mode consisting of a gradual reduction in the resilient modulus of the

base layer, the second being the gradual permanent deformation of the layer;

- The structural bearing capacity of the pavement was ultimately determined by the permanent deformation and should be between 10 and 30 million standard axles (ES30 design traffic class) if the surfacing is well maintained. The permanent deformation increased and the structural bearing capacity decreased when water was allowed to penetrate the base layer during the wet test on Section 416A5;
- Water at the interface between the base layer and the HMA surfacing resulted in erosion of the base layer. This may lead to functional distress in the form of surface irregularity, and
- The dry density of the recycled base appeared to be less than that of the crushed stone base layer prior to recycling.

#### 4.5 Summary of Findings from Road MR538

The various analyses of the data collected from Road MR538 indicated that (Theyse, 2004a; Theyse, et al. 2006):

- The sandstone base layer material and light pavement structure performed well during the HVS tests, and laboratory results approaching those normally associated with crushed stone products were obtained for the sandstone gravel;
- The current CBR based material classification system correlated poorly to the performance of the sandstone gravel base layer in HVS tests. The shear strength and resilient modulus laboratory results were better indicators of performance and it is recommended that performance based specifications be developed for this class of pavement base layer;
- The light pavement structure of the HVS test sections was shown to be appropriate for application to low-volume roads and the structural bearing capacity of the pavement far exceeded the South African design traffic classes associated with low-volume roads (TRH4, 1996).
- The integrity and functional performance of the surfacing layer is a crucial aspect of pavement performance that will probably determine the service life of the road but could not be assessed with the HVS. LTPP projects are better suited to determining functional deterioration trends associated with the distress of the surfacing layer, especially on low-volume, light structures;
- The effect of density and degree of saturation was shown to be highly significant with regards to the mechanical properties of the sandstone gravel base layer material.

## 5 OUTCOME OF THE CASE STUDY

The analysis of the LTPP and APT data entailed a comparison of the surface rut and surface deflection measured for the respective sections. In the comparison, the average, as well as the average  $\pm 1$  standard deviation of the rut and deflection data, are shown for both the LTPP and APT data, to demonstrate the variability in pavement properties. The rut comparisons for the two roads (N7 and R538) are shown in Figures 6 and 7, while the deflection comparisons are shown in Figures 8 and 9.

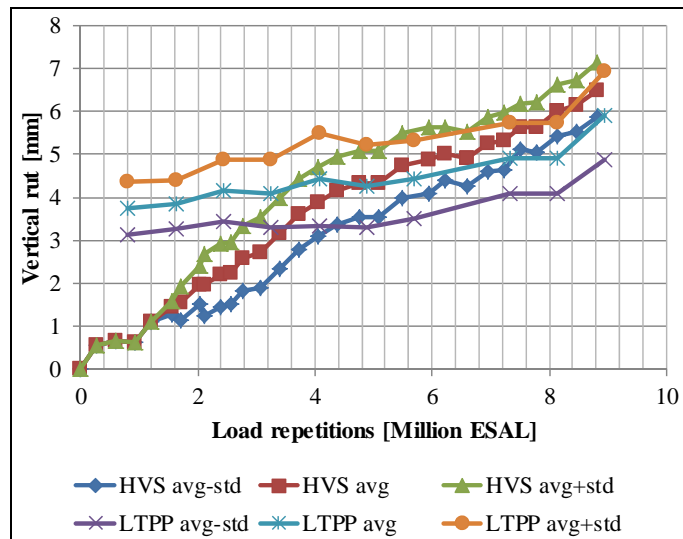


Figure 6. N7 rut correlation example.

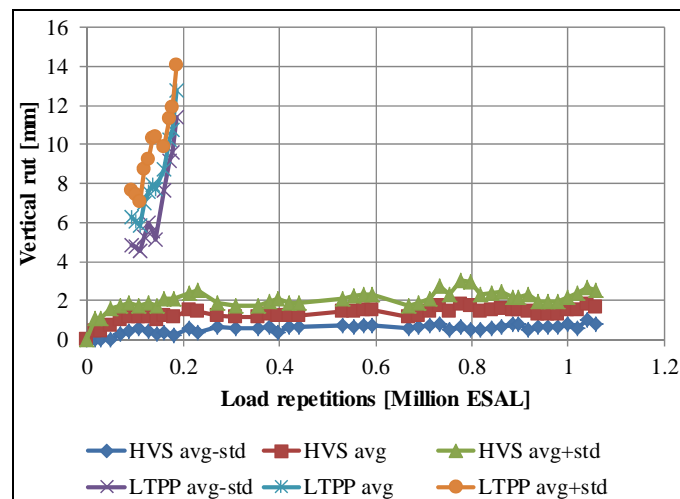


Figure 7. M538 rut correlation example.

Analysis of the data in Figures 6 to 9 indicates the following important points:

- Both the rut and the deflection data for the LTPP and APT sections on the higher trafficked section (N7) compare well;
- The damage exponent (used to calculate the equivalent traffic for the APT section on the N7 section) was 4.2 for both rut and deflection;
- The rut on the low-volume road (M538) showed significantly higher values for the LTPP (real traffic and environment) sections compared to the APT data. This may be linked to previous work in

this regard where it was indicated that for low-volume roads, environmental factors may have a more significant role in the performance of the pavement than the actual applied loads (Steyn and Sadzik, 1998);

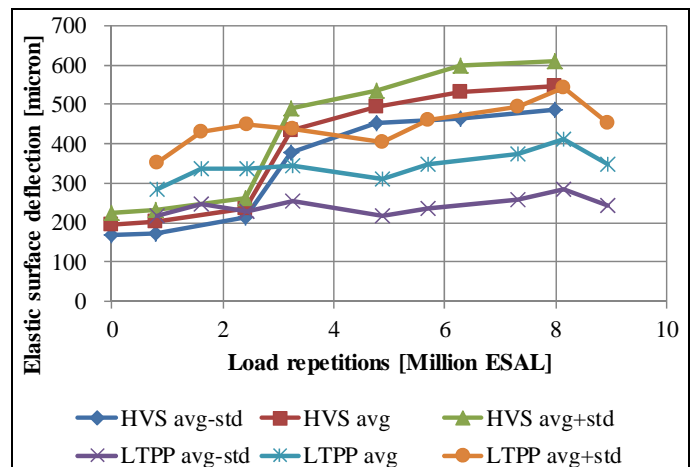


Figure 8. N7 deflection correlation example.

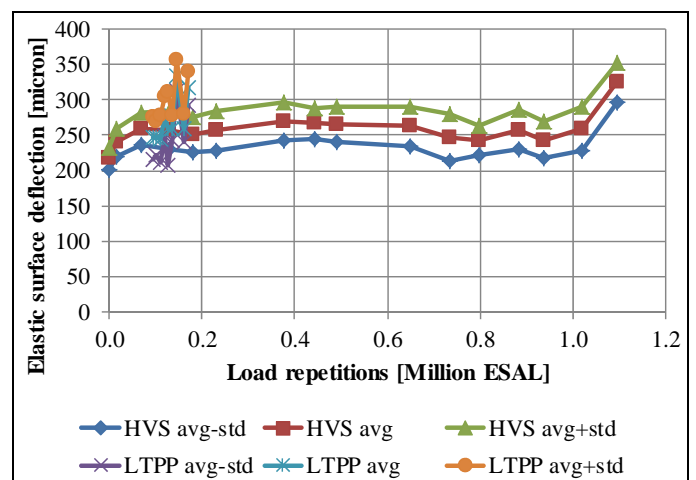


Figure 9. M538 deflection correlation example.

- The LTPP-measured deflections on the low-volume road (M538) were similar to the higher values (average plus one standard deviation) recorded towards the end of the APT testing. This supports the theory that environmental factors often have a bigger influence on the performance of low-volume roads than traffic;
- For the low-volume road it appears that the APT rut needs to be adjusted by a factor of five to obtain similar data to the LTPP (real life) data, while the load applications should be adjusted (decreased) by a time factor of six for the APT elastic surface deflections to be equivalent to the LTPP data (M538 elastic deflection shown in Figure 10 with load application scale for APT decreased by a factor six);
- The time factor used for the M538 elastic deflection data is necessary to ensure that the effects of season and time on the low-volume pavement be attributed correctly to the APT data, as the APT data excludes the effect of these variables, which



affect low-volume (light) pavements more significantly than higher volume (thicker) pavements.

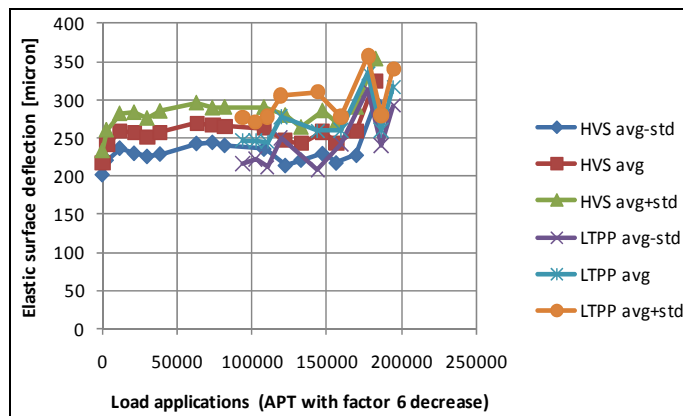


Figure 10. M538 deflection correlation example.

## 6 CONCLUSIONS AND RECOMMENDATIONS

Based on the data analyzed for this paper the following conclusions are drawn:

- The effects of environmental changes are visible mostly on the low-volume road (M538) through seasonal changes in parameters such as deflection, moisture content, and density;
- Less environmental influences were identified on the more heavily trafficked, thicker Road N7 pavement;
- Comparison of the rut and elastic deflection data for the Road N7 pavement indicated that a standard damage factor of 4.2 was sufficient to convert the different traffic loads used in the APT test data to the LTPP data;
- The light pavement structure (M538) required a factor of five increase in rut data and a load time factor decrease of six for the elastic deflection for the APT data to resemble the LTPP data, and
- The major distresses on the two LTPP sections are believed to have been caused by seasonal variation in moisture identified during the evaluation periods.

Based on the analyses shown in this paper the following recommendations are made:

- The scope of LTPP programs needs to be expanded to obtain additional and essential data to help improve the applicability and accuracy of pavement performance models for diverse pavement conditions in southern Africa;
- There is a need to establish a database of mechanical properties of pavement materials on all LTPP sections. These data are typically collected as part of the laboratory testing phase in APT tests. Laboratory tests for stiffness (modulus), permanent deformation, and cracking as well as yield strength properties will be essential to de-

velop calibrated Highway Development and Management (HDM-4) type models, and

- More LTPP sections are required close to APT sections covering a range of pavement types (light to heavy traffic design) to evaluate where the effect of environmental conditions start to become more important than that of traffic load equivalence.

## 7 ACKNOWLEDGEMENTS

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