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16. Abstract

Following the testing of test pad N1 on northbound US 281 in Jacksboro, Texas, the TxMLS was moved to pad N2. The test plan was to traffic the pad with the tire pressure set at 750 kPa. All other controllable variables remained identical to those used for the testing of N1. The N2 pavement's structural composition is essentially the same as that for N1, with no thermal cracks in the central 6 m of the test pad. However, the pavement's response to the falling weight deflectometer (FWD) load differed.

A total of 500,000 load applications were completed on each pad. Data were collected during the testing and supplemented with other relevant information from the Jacksboro test program. The results obtained from test pad N2 were then compared with those from test pad N1 and analyzed diagnostically to determine whether the effect of the increased tire pressure could be quantified. In the same vein, the aim was to validate the analytical model that was used in Report 1814-1 (Hugo et al. 1999a). This report presents the findings.

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RUTTING PERFORMANCE OF DUSTROL REHABILITATION UNDER TxMLS TRAFFICKING WITH INCREASED TIRE PRESSURE

by

Fred Hugo

Research Report Number 1814-4

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Project Title: MLS Research Management System – Phase III

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THE UNIVERSITY OF TEXAS AT AUSTIN

and the

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY SYSTEM

and the

THE UNIVERSITY OF TEXAS AT EL PASO

June 2000

DISCLAIMERS

Frederick Hugo, P.E. (Texas No. 67246)
Research Supervisor

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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The TxMLS program is a project comprising dedicated individuals working toward achieving the enhancement of pavement engineering. The efforts include fieldwork, laboratory work, analytical work, and synthesis and reporting. The following persons warrant special mention for their efforts toward the success of this phase of the study:

TxMLS Field Crew	John E. Barrett, Cody Smith, Patrick Ball, Terry Ludwig, Lance Broussard, Ron Broussard, and Mitchell Corliss
TxDOT (Pavements)	Dr. Dar-Hao Chen, John Bilyeu, Mike Finger, and Sherwood Helms
TTI —Texas A&M University System	Dr. Amy Epps, Dr. Dallas Little, Gene Schlieker, and Sidney Greer
The University of Texas at El Paso	Dr. Soheil Nazarian and Dr. Deren Yuan
CTR—The University of Texas at Austin	Ray Donley and Michael E. Gray
ITT (University of Stellenbosch)	Lubinda Walubita, André de Fortier Smit, and Pieter Poolman

Special thanks are due to Dr. Deren Yuan (The University of Texas at El Paso) for analyzing the seismic test data.

ABSTRACT

Following the testing of test pad N1 on northbound US 281 in Jacksboro, Texas, the TxMLS was moved to pad N2. The test plan was to traffic the test pad with the tire pressure set at 750 kPa. All other controllable variables remained as for the testing of N1. The N2 pavement's structural composition is essentially the same as that of N1, with no thermal cracks in the central 6 m of the test pad. However, deflections under the falling weight deflectometer (FWD) load were less.

A total of 500,00 load applications were completed on each pad. Relevant data were collected during the testing and supplemented with other relevant information obtained from the Jacksboro test program. The results from test pad N2 were then compared with those from test pad N1 and analyzed diagnostically to determine whether the effect of the increased tire pressure could be quantified. In the same vein, the aim was to validate the analytical model that was used to analyze the results of test pad N1.

The rutting analysis was for an independent experiment using the methodology previously developed by Hugo et al. (1999b). In this case, all parameters of the mathematical model

$$\text{Total Affected Rut(s)} = \alpha \; (F_t^{\beta_t} * F_s^{\beta_s} * F_m^{\beta_m} * F_l^{\beta_l} * F_{ltp}^{\beta})\; BR$$

were known. The objective was to determine whether this previously formulated analytical model would be satisfied and/or to what extent the factors in it could be quantified.

It was found that the results obtained from the four wheelpaths constructed with two different materials were all close in terms of a measure of the α and β factors in the mathematical model. The values of α were found to be equal to 1 within +/-3%. The values of β that had been selected (all taken as 1 except in the case of the structural factor, where it was assumed to be 0.5) did not need adjustment.

A further measure of the success of the validation lies in the use of the same overload power function exponent for N1's RWP, as was used before by Hugo et al. (1999b) for determining the impact of wheel load on the rutting performance, namely, 6.6 for an overload of 7%.

The findings indicate that the effect of tire pressure on rutting performance was directly proportional to the respective tire pressures. This finding is further evidence of the impact of tire pressures. On the other hand, the results did indicate that the wheel-load effect (F_l) was much more pronounced than that of the tire pressure (F_{tp}). In fact, it was 5 times more. In this regard it is important to remember that the contact pressures can be much higher than the tire pressure (De Beer et al. 1999). The effect of this contact pressure was not investigated, though there is clearly a need to explore this aspect more comprehensively.

Despite the limited scope of the study, these findings can be viewed as validation of a useful methodology for analyzing rutting performance under controlled conditions. Of course, there is a need for further investigations into the phenomenon in order to increase the confidence in the use of the methodology.

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RUTTING PERFORMANCE OF DUSTROL REHABILITATION UNDER TxMLS TRAFFICKING WITH INCREASED TIRE PRESSURE

INTRODUCTION

Following the testing of test pad N1 on northbound US 281 in Jacksboro, Texas, the Texas Mobile Load Simulator (TxMLS) was moved to pad N2. The test plan was to traffic the pad with the tire pressure set at 750 kPa.* All other controllable variables remained identical to those used for the testing of N1. (A report on the N1 testing, including details of the general site conditions, was published as Research Report 1814-1 [Hugo et al. 1999a].) The N2 pavement's structural composition is essentially the same as that of N1; that is, there were no thermal cracks in the central 6 m of the test pad. However, its response to the falling weight deflectometer (FWD) load differed, as will be shown later.

Figure 1 shows the general layout and configuration used for the TxMLS test pads (See page 3 for definitions of acronyms). This layout was followed for test pad N2.

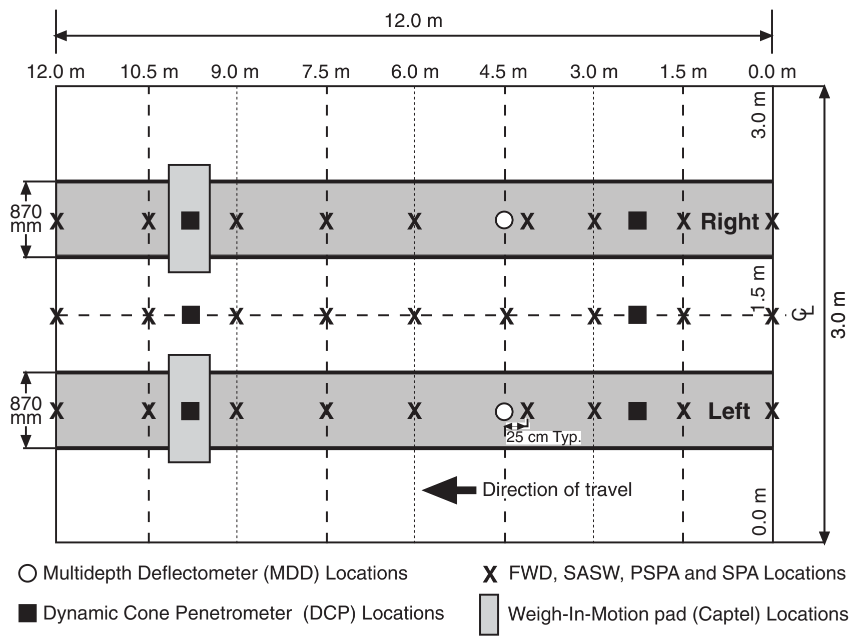

Figure 1. General Layout Used for TxMLS Tests

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* Given that researchers working in the area of accelerated pavement testing (APT) use metric units, and given that TRB Task Force A2B52 on APT has set guidelines that include the exclusive use of metrics for capturing APT data, the author has elected to use metric units exclusively in the report proper. See Appendix A for some useful metrication guidelines.

Figure 2 shows the typical structural composition of the two northbound pavements. A total of 500,000 load applications were completed on each pad (trafficking continued beyond this on N1 to a total of 750, 000). Data were collected during the testing and supplemented with other relevant information from the Jacksboro test program. The results from test pad N2 were compared with those from test pad N1 and analyzed diagnostically to determine whether the effect of the increased tire pressure could be quantified. In the same vein, the aim was to validate the analytical model that was used in Report 1814-1 (Hugo et al. 1999a). The present report documents the findings.

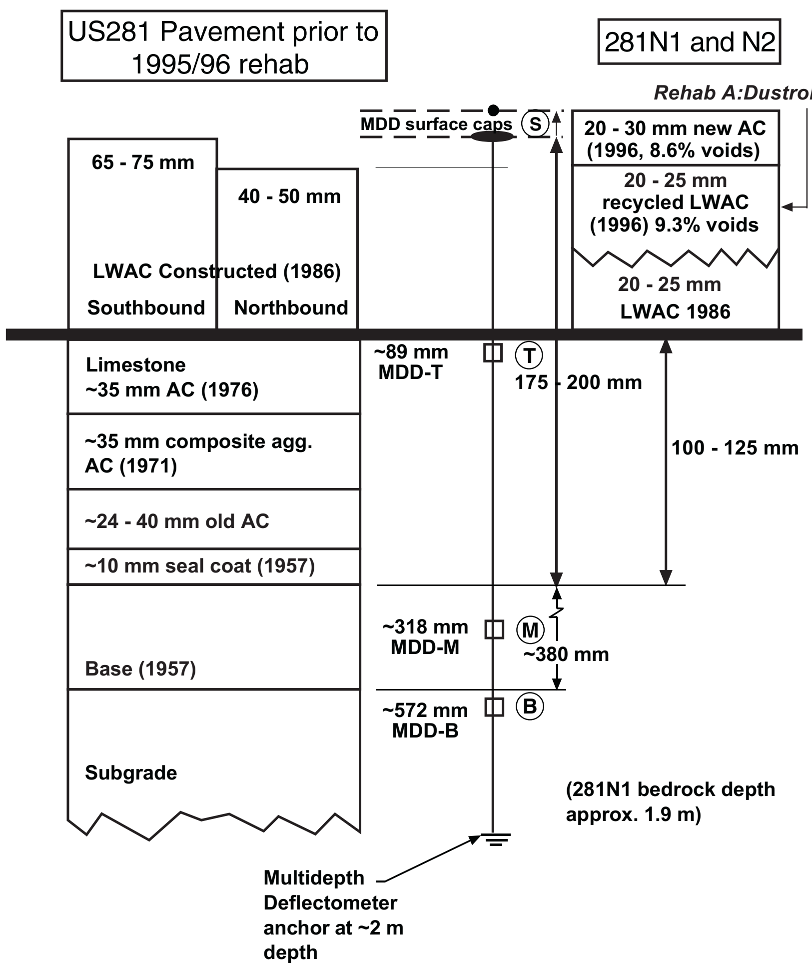


Figure 2. Typical Structural Composition of Test Pads N1 and N2

ANALYSIS OF TEST DATA

The primary factors considered in this comparative study were:

- Climatic conditions during testing
- Falling weight deflectometer (FWD) response
- Rutting profiles
- Seismic wave propagation in the pavement layers as measured by:
  - Spectral Analysis of Surface Waves (SASW), and
  - Seismic Pavement Analyzer (SPA)
  - Portable Seismic Pavement Analyzer (PSPA)
- Laboratory characteristics of the asphalt mixes
- Wheel load and tire pressure

Climatic Conditions

Climatic conditions were monitored prior to and during the testing. The moving average of two temperatures of the test pavement at a depth of 13 mm during TxMLS trafficking of pads N2 and N1 is shown in Figures 3(a) and 3(b), together with the cumulative axle load repetitions on each pad.

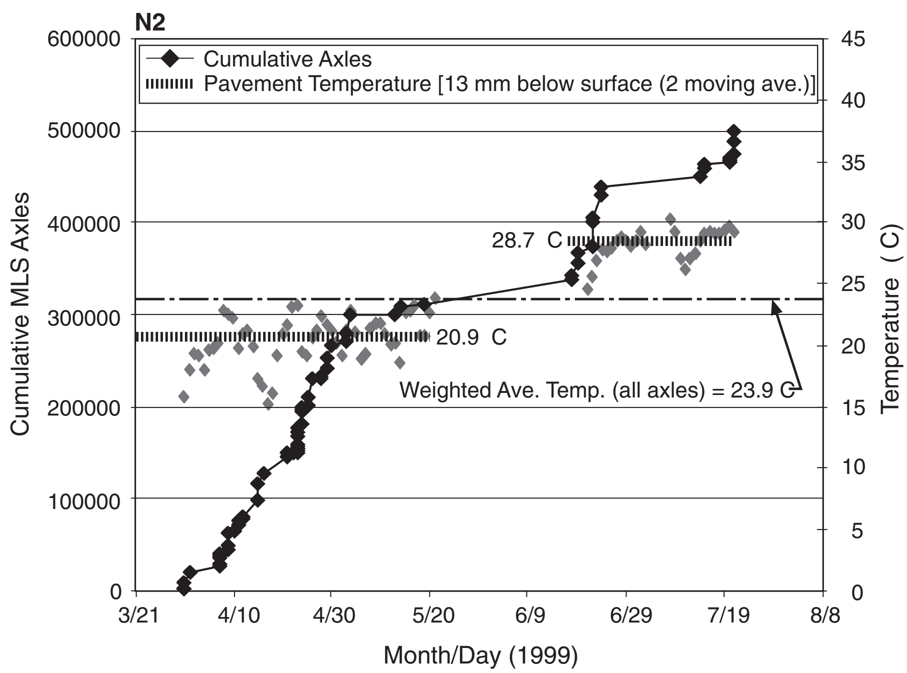


Figure 3(a). Pavement Temperature during TxMLS Trafficking — Test Pad N2

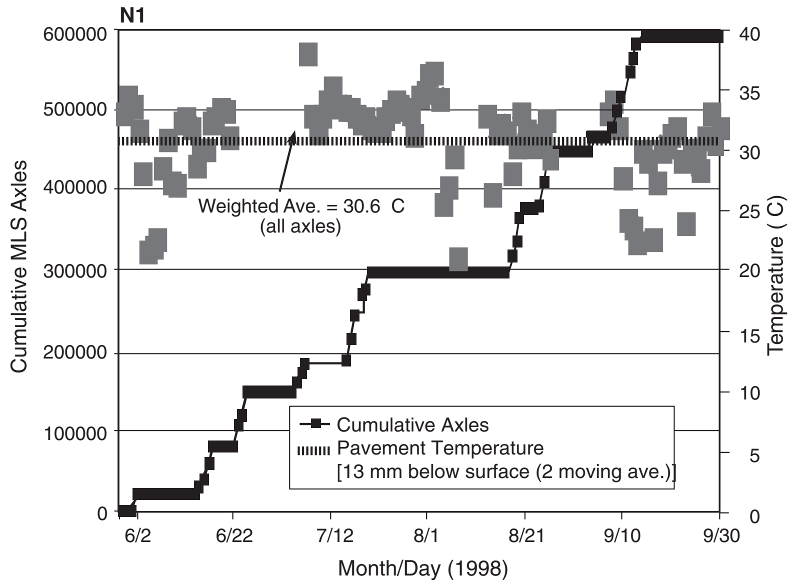


Figure 3(b). Pavement Temperature during TxMLS Trafficking — Test Pad N1

It can be seen that the conditions prevailing during the two tests differed — a consequence of the tests being run out of phase relative to the seasons. In the case of N1, the temperature of the upper layer of the pavement was 30.6 ºC, whereas the temperature of pad N2 was 23.9 ºC. This temperature differential affected the relative performance of the asphalt mixes.

In terms of precipitation, there was little difference, simply because the tests were run during dry periods. Figures 3(c) and 3(d) show the relative rainfall data together with the cumulative axles that were applied.

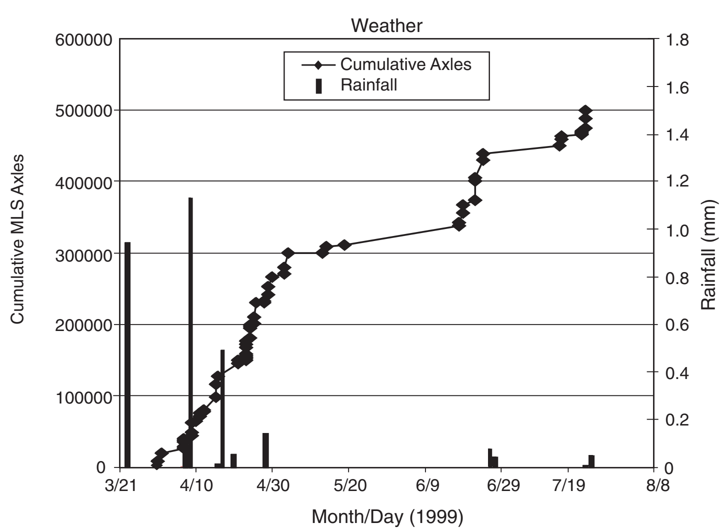


Figure 3(c). Rainfall during TxMLS Trafficking — Test Pad N2

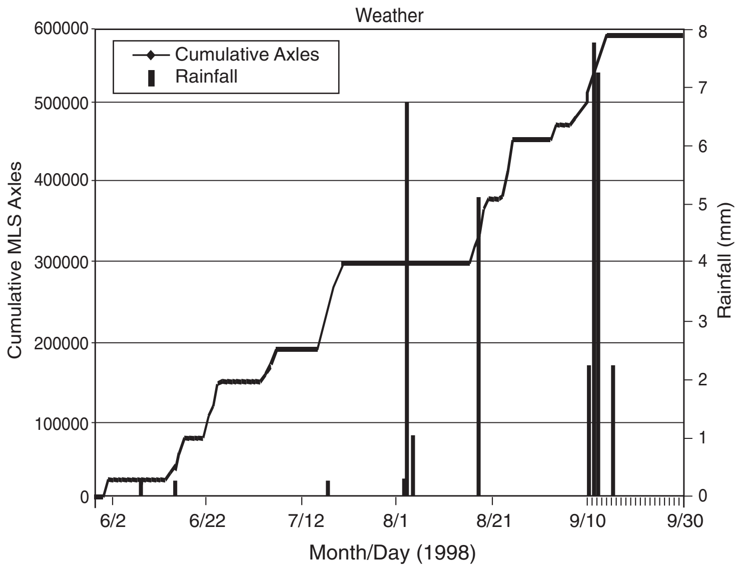


Figure 3(d). Pavement Temperature during TxMLS Trafficking — Test Pad N2

FWD Test Results

FWD deflections were normalized to a temperature of 20 ºC. The conversion curves previously used and reported in Report 1814-1 (Hugo et al. 1999a) were utilized again. Figures 4(a) and (b) show the average W1 deflection values as measured during the test period.

Care was taken to ensure that thermal cracks did not interfere with the primary test sections in each pad, namely, >3m and <9 m. The W1 deflections were accepted as representing the structural integrity of the pavement system, with the information used later in the comparative analysis. It was apparent that the two test sections (N1 and N2), though geographically close, had different FWD responses. Furthermore, the response of the two wheelpaths also differed: The left wheelpath was the stronger of the two wheelpaths in both test pads.

Accordingly, the project team decided to treat each wheelpath separately. This difference between the two wheelpaths was also found to be true of the response and performance of the surfacing layers in the model mobile load simulator (MMLS3) tests that were documented in Report 1814-2 (Smit et al. 1999) and Report 1814-3 (Walubita et al. 2000). It was expected that this approach would provide better insight into the performance of the two pavement sections. It was also an innovative way of utilizing the ability of the TxMLS to track two wheelpaths concurrently.

Changes in the response of the control (untrafficked) sections to the FWD testing during the test period are evident in Figures 4(a) and 4(b). These changes are important since they affect the interpretation of changes occurring in the trafficked wheelpaths. Nontraffic-related changes could be caused by environmental factors. The asphalt material undergoes volume changes and, if the surface is not trafficked, it can, for example, age or undergo thixotropy. These conditions can affect the stiffness of the pavement structure and will be reflected in response measurements. Because of this phenomenon, it is preferable to normalize the data in terms of the untrafficked centerline of the pavement. Normalization was done by determining the ratio of the LWP and RWP data points at each cross section, relative to the value on the centerline.

The results are shown in Figures 4(c) and 4(d). It is evident that there is an increase in the deflection of the RWPs in both test sections (N1 and N2). In N1 it occurs more rapidly. While the LWP of N2 has very little change, N1 has an initial increase followed by a continuous reduction thereafter. It was found that these responses were compatible with the seismic stiffnesses that were measured in the pavement structure (as discussed later in this report).

Multidepth Deflectometer (MDD) Results

Because the *FWD w1* measurements in test pad N2 were so small, it was concluded that it would not be meaningful to consider the response of the different layers, since the greater percentage of the deformation had previously been shown to occur in the upper 90 mm of the pavement. Instead, the surface rut data were compared.

Rutting Performance

Test pad N2 exhibited less rutting than N1, though once again the left wheelpath rut was less than that of the right wheelpath. Figures 5(a) and 5(b) show the rutting performance in terms of normalised transverse profiles at the 6 m grid line, with maximum ruts for test pads N2 and N1, respectively. Figures 6(a), 6(b), 6(c), and 6(d) show the progressive maximum rut development along the length of the respective test pads in the left wheelpath (LWP) and right wheelpath (RWP). The final measurements of test N2 after 500,000 load applications are provided in Table 1. Since 500,000 axles did not represent a data collection point for test N1, the values had to be interpolated. These results are given in Table 2.

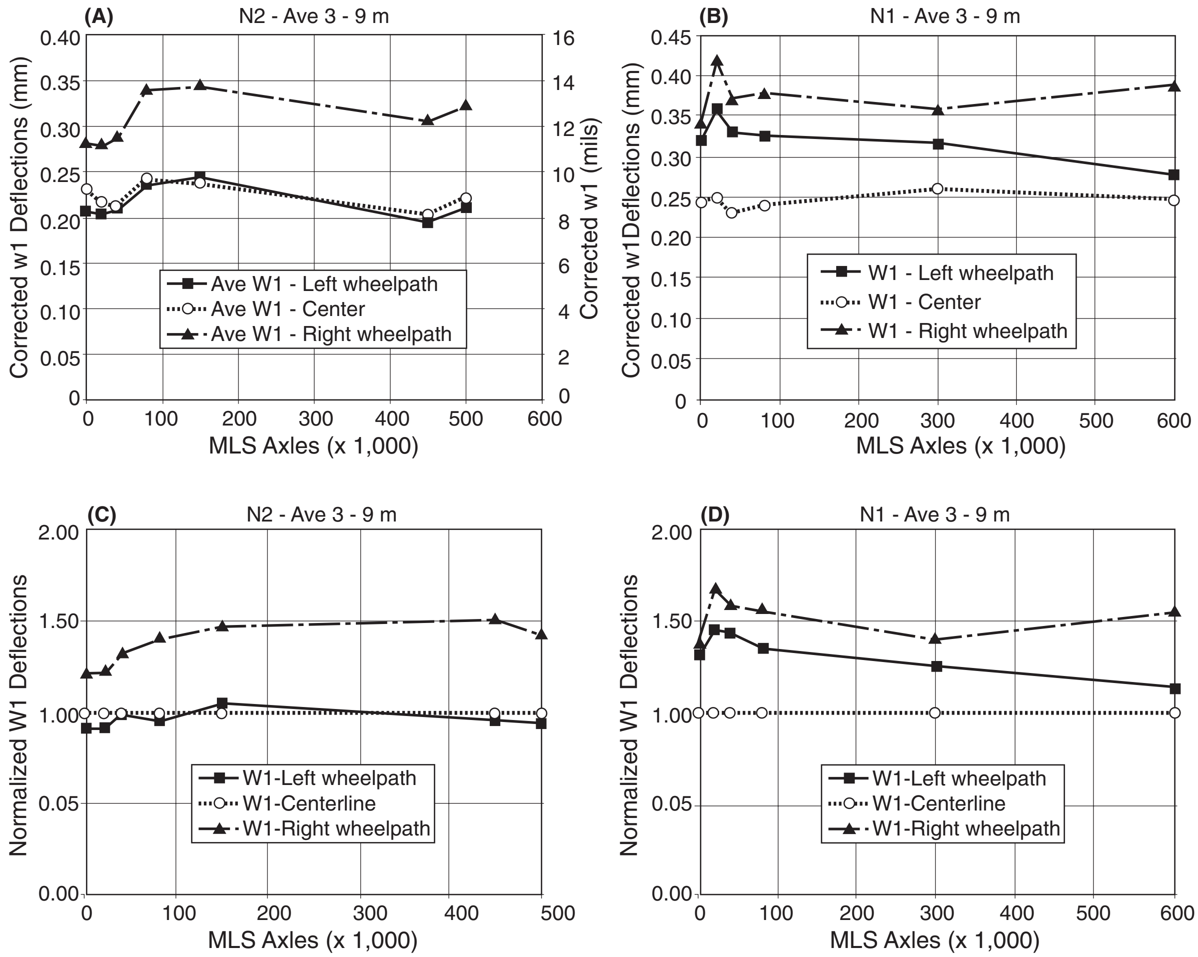
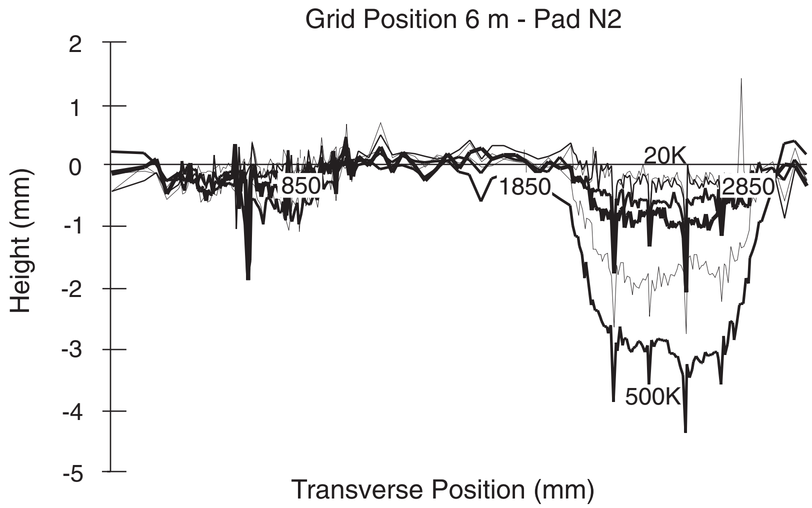
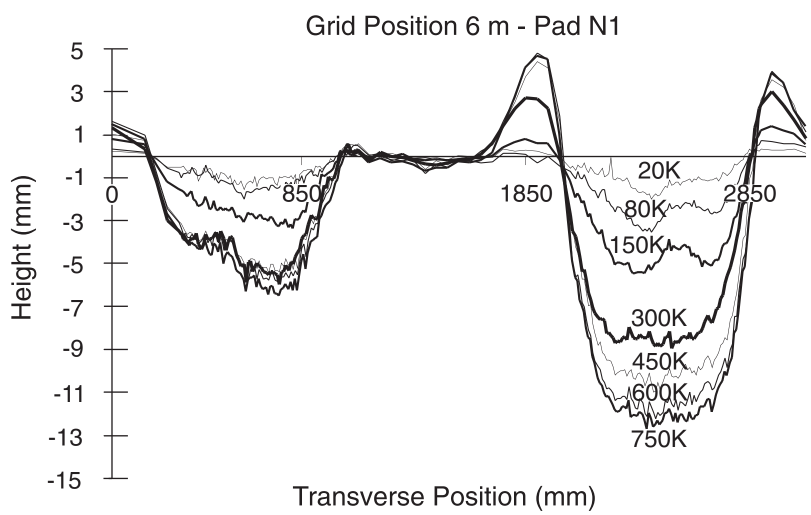


Figure 4. Average W1 Deflections vs. Axle Repetitions for US 281 N2 and N1 (3–9 m)

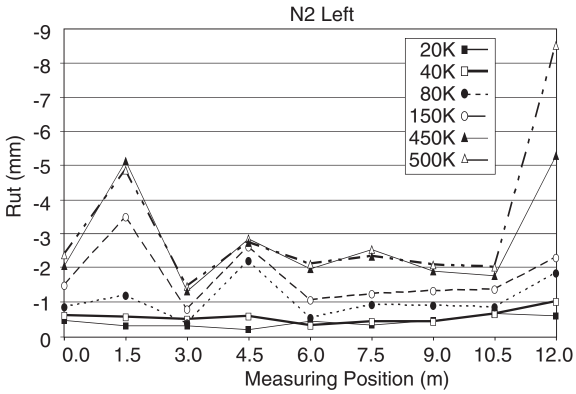


5(a). Progressive Transverse Surface Rut Development, N2

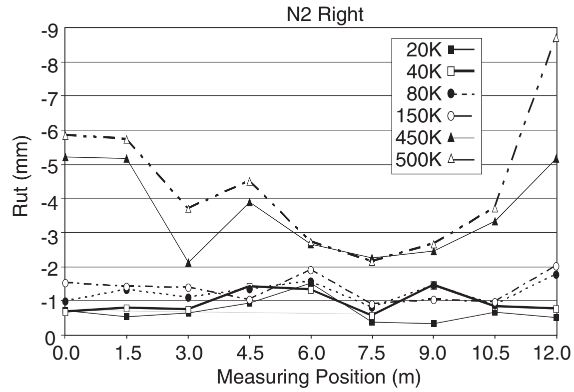


5(b). Progressive Transverse Surface Rut Development, N1

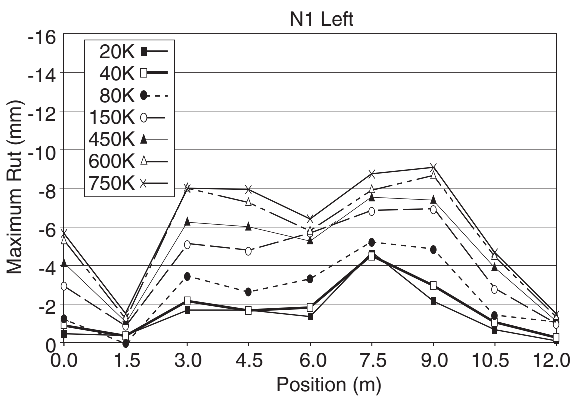
Figure 5. Progressive Transverse Surface Rut Development, N2 and N1



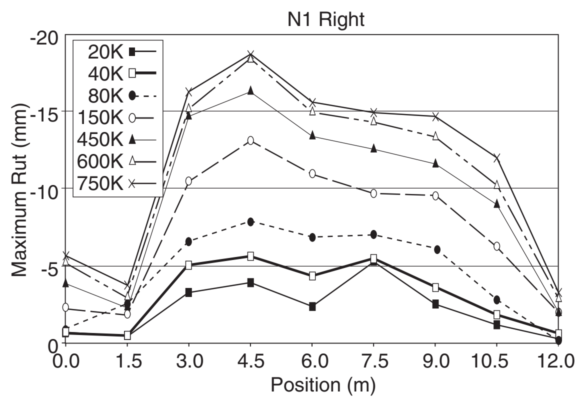
a) Progressive Longitudinal Surface Rut Development, N2 LWP



b) Progressive Longitudinal Surface Rut Development, N2 RWP



c) Progressive Longitudinal Surface Rut Development, N1 LWP



d) Progressive Longitudinal Surface Rut Development, N1 RWP

Figure 6. Progressive Longitudinal Surface Rut Development, N2 and N1, LWP and RWP

Table 1. Maximum Surface Rut at Grid Positions Between 3 and 9 m after 500,000 Axles, Pad N2

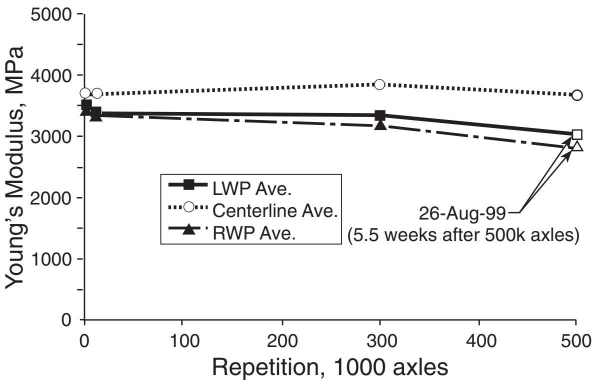
N2	**Max Rut Depth at 500k**	
m	**mm**	**mm**
Grid Position	**LWP**	**RWP**
3	-1.46	-3.70
4.5	-2.75	-4.50
6	-2.13	-2.74
7.5	-2.34	-2.14
9	-2.10	-2.65
Mean	-2.16	-3.15

Table 2. Maximum Surface Rut at Grid Positions Between 3 and 9 m after 500,000 Axles, Pad N2

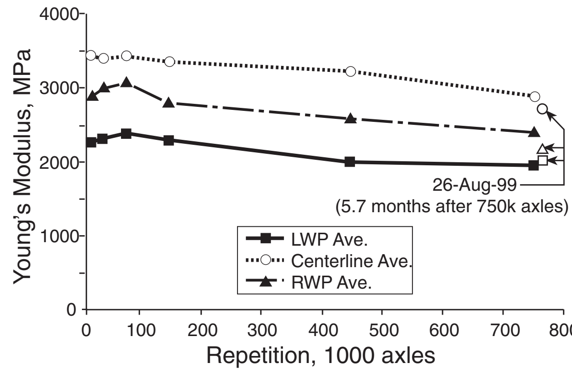
N1	**Max Rut Depth at 500k**	
m	**mm**	**mm**
Grid Position	**LWP**	**RWP**
3	-7	-12
4.5	-6.5	-13.75
6	-5.5	-11.25
7.5	-7.75	-10.75
9	-8	-10
Mean	-6.95	-11.55

The Seismic Stiffness Measurements

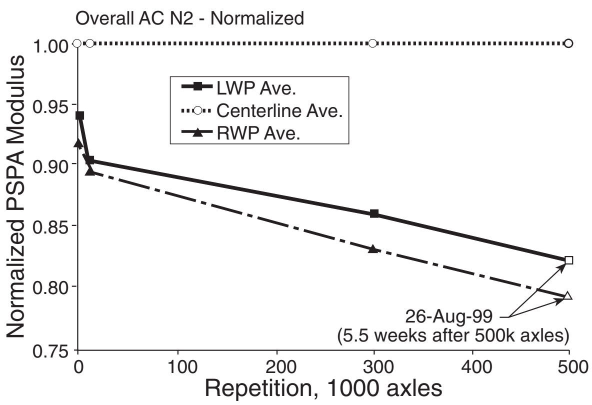
The project team followed the standard procedure for seismically monitoring the changes in stiffness or modulus caused by trafficking and other factors (Yuan et al. 1998; Hugo et al. 1999b; and Nazarian et al. 1999). The results from both N2 and N1 are shown in Figures 7(a)–7(d), 8(a)–8(h), and 9(a)–9(h), respectively, for the overall asphalt concrete (AC), the individual AC layers, and the base course and subgrade. In each case, the data were normalized with respect to the centerline whenever a measurement was made. Such normalization was performed to ensure that possible changes in nontraffic-related conditions were eliminated or at least minimized, allowing a more comparative evaluation to be made of the relative performance of the different wheelpaths. Prior to normalization, the data was corrected for temperature and frequency. The temperature correction was done on the basis of the findings of Chen, as reported in Hugo et al (1999a). The frequency collection was done similar to the procedure reported by Lee et al (1997).



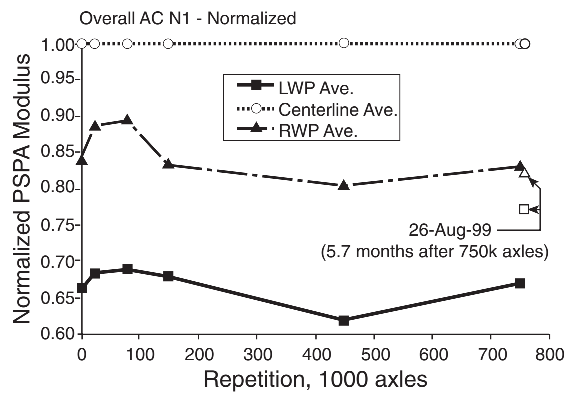
a). PSPA Young's Modulus vs. Axle Repetitions N2, Overall AC



(b). PSPA Young's Modulus vs. Axle Repetitions N1, Overall AC



(c). Normalized PSPA Modulus vs. Axle Repetitions N2, Overall AC



(d). Normalized PSPA Modulus vs. Axle Repetitions N1, Overall AC

Figure 7. PSPA Young's Modulus vs. Axle Repetitions, N2 and N1, Overall AC

The PSPA measurements illustrated in Figure 7 represent an average of the total AC structure. In the case of N2 (Figures 7[a] and [c]), the findings showed a net reduction in the modulus of both wheelpaths, while N1 (Figures 7[b] and [d]) had essentially no net change after an initial increase in both wheelpaths. To gain better insight into the performance of the total pavement structure of both sections and in order to obtain the response of the individual layers to be measured, the project team performed SASW tests. These responses to these tests are shown in Figure 8 and Figure 9.

The upper AC of N2 (Figures 8[a] and 8[c]) increased in both wheelpaths initially, returning to the starting values after some trafficking. In the case of N1 (Figures 8[b] and

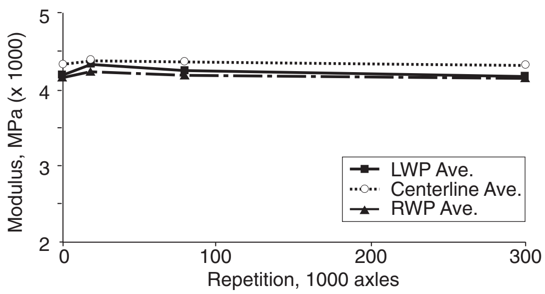
8[d]), the modulus of the LWP gradually increased to a peak and then dropped back to the initial value sharply towards the end of the test. By contrast, the RWP showed no increase but gradually lost stiffness until a sharp drop towards the end of the test, with a net loss in modulus. The lower AC of N2 (Figures 8[e] and 8[g]) had a net reduction in modulus in both wheelpaths, with a small increase shown in the LWP initially. The reduction in the RWP was greater than that of the LWP. Very little change occurred in the lower AC modulus of N1 (Figures 8[f] and 8[h]) throughout trafficking. It was evident that the AC in the RWP manifested greater cumulative change than that in the LWP.

Figure 9 shows the response of the base course and the subgrade of both N2 and N1. The base course (Figures 9[a]–9[d]) showed initial drops in modulus in both N2 and N1, whereafter the values fluctuated slightly up and down. However, in both cases the RWP had net losses at the end of trafficking, with very little change in the LWP. The subgrade followed a similar pattern, with a slight increase in the modulus of the RWP of both sections at the end of the tests (Figures 9[e]–9[h]).

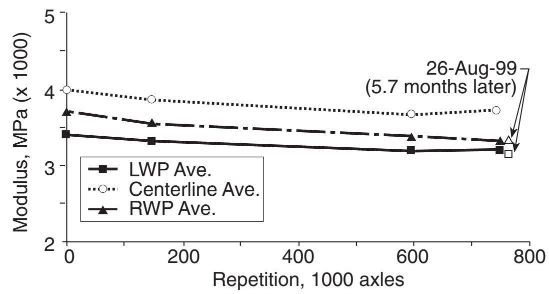
The measured modulus values were all reasonable and according to expectations for this type of pavement structure, with the exception that the modulus of the lower AC layer was considerably smaller than that of the upper AC layer. The problem appears to lie below the rehabilitation layers, corroborating the findings reported by Hugo et al. (1999b) and by Chen et al. (2000). This conclusion has also been reported elsewhere in terms of other parameters and test results (Hugo et al. 1999a; Smit et al. 1999; and Walubita et al. 2000).

The measured AC modulus values were also considered reasonable in terms of the performance of the two pavement sections (N2 and N1). It should, however, be noted that the SASW measured modulus values reported by Hugo et al. (1999b) for the asphalt surfacing layers of N1 in general correlated with the lower AC layer rather than with the upper AC layer values contained in this report. Reasons for this are not clear, though it should be noted that the methods of measurement differed. The values presented in this report were measured by Dr. Deren Yuan, one of the co-researchers (see acknowledgments), using an automated device. Those values reported by Hugo et al. (1999b) were measured manually. The latter values also showed a reduction of some 40% in modulus owing to trafficking. This reduction was not found by Dr. Yuan. The reason for this discrepancy is unknown. Both systems did however find, to a greater or lesser extent, an increase in the modulus during the early phases of trafficking.

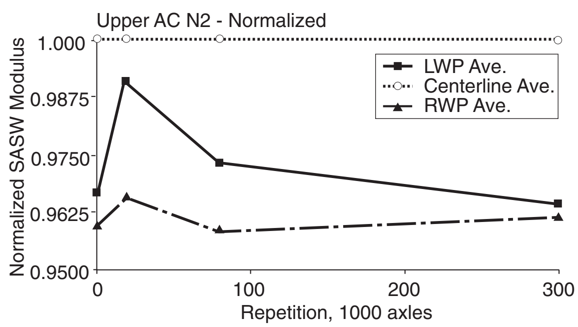
The relatively small decrease in modulus owing to trafficking in both test sections N2 and N1 is noteworthy. This finding is in contrast to the loss in stiffness or decrease in modulus occurring when the pavement — with water supplied to the surfaces — was trafficked with the Mk3 Model Mobile Load Simulator (MMLS3). The consequence of this finding is discussed in Report 1814-3 (Walubita et al. 2000).



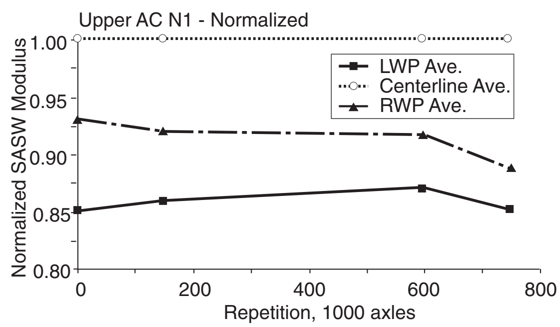
a) SASW Young's Modulus vs. Axle Repetitions N2, Upper AC



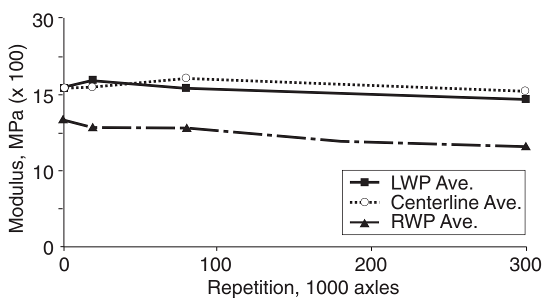
b) SASW Young's Modulus vs. Axle Repetitions N1, Upper AC



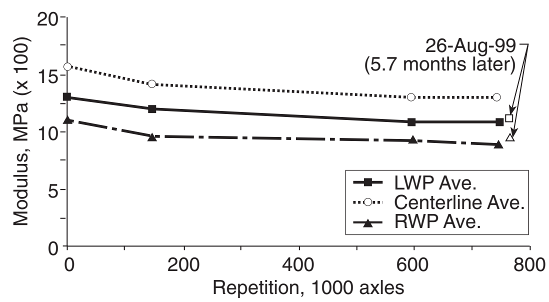
c) Normalized SASW Modulus vs. Axle Repetitions N2, Upper AC



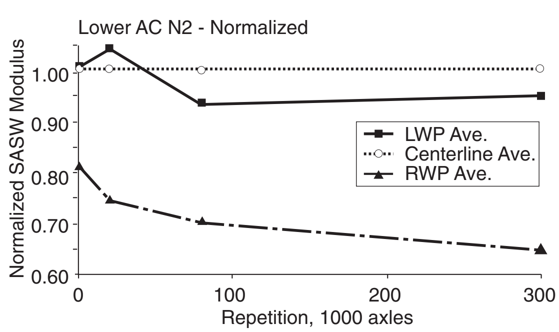
d) Normalized SASW Modulus vs. Axle Repetitions N1, Upper AC



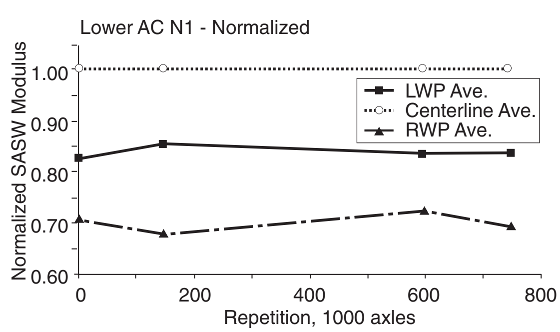
e) SASW Young's Modulus vs. Axle Repetitions N2, Lower AC



f) SASW Young's Modulus vs. Axle Repetitions N1, Lower AC

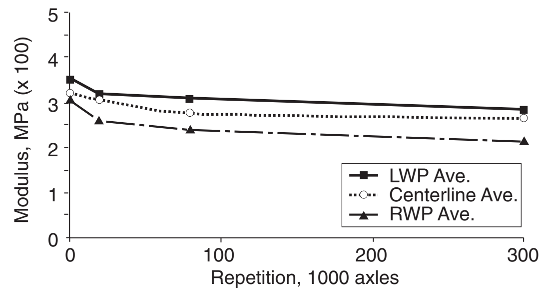


g) Normalized SASW Modulus vs. Axle Repetitions N2, Lower AC

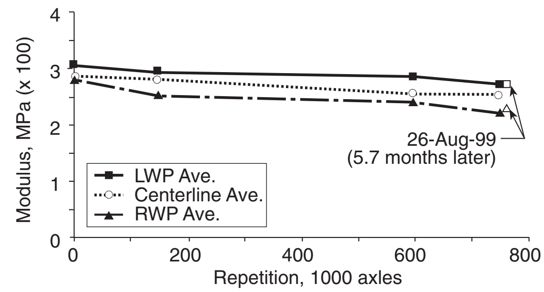


h) Normalized SASW Modulus vs. Axle Repetitions N1, Lower AC

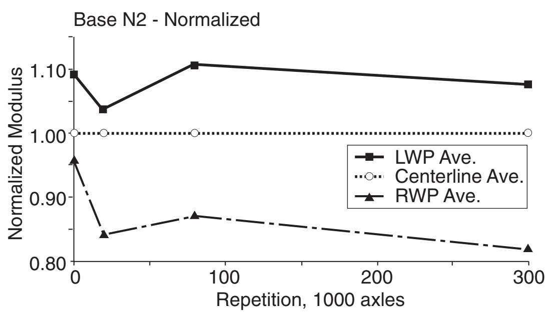
Figure 8. SASW Modulus vs. Axle Repetitions, N2 and N1, Upper and Lower AC



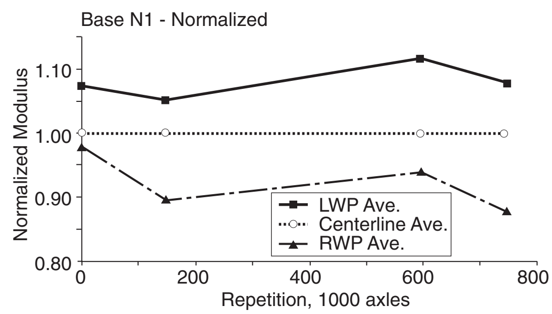
a) SASW Young's Modulus vs. Axle Repetitions, Base Course N2



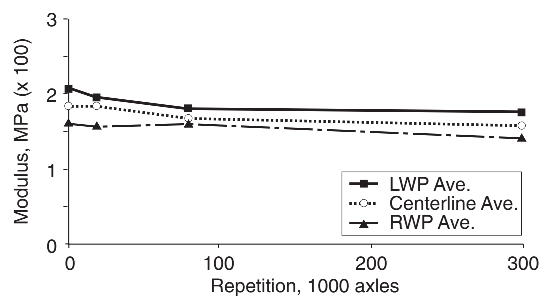
b) SASW Young's Modulus vs. Axle Repetitions, Base Course N1



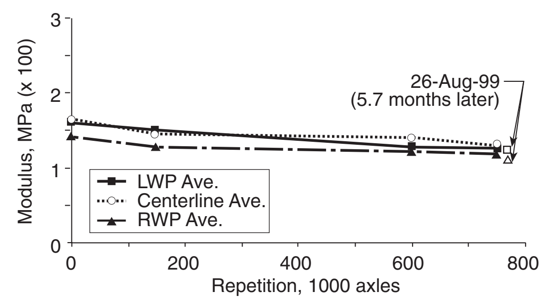
c) Normalized SASW Modulus vs. Axle Repetitions, Base Course N2



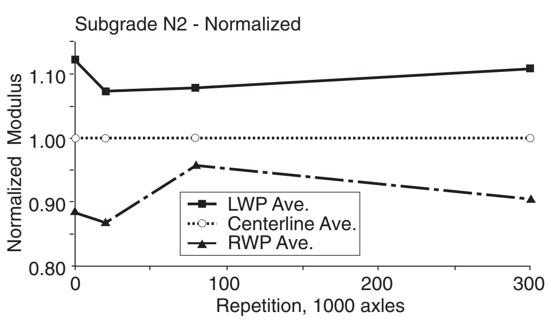
d) Normalized SASW Modulus vs. Axle Repetitions, Base Course N1



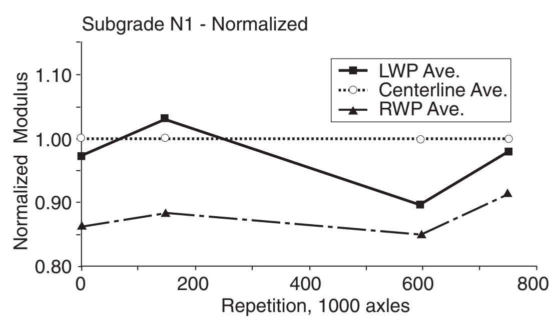
e) SASW Young's Modulus vs. Axle Repetitions, Subgrade N2



f) SASW Young's Modulus vs. Axle Repetitions, Subgrade N1



g) SASW Modulus vs. Axle Repetitions, Subgrade N2



h) SASW Modulus vs. Axle Repetitions, Subgrade N1

Figure 9. SASW Modulus vs. Axle Repetitions, N2 and N1, Base Course and Subgrade

QUANTITATIVE EVALUATION OF THE RUTTING PERFORMANCE

The quantitative analysis of the rutting performance is based on the assumption that the rut depth is determined by the cumulative effects of the following factors:

- Temperature *(F_t)*
- structural response *(F_s)*
- material compliance after processing *(F_m)*
- wheel load *(F_l)* and tire pressure *(F_{tp})*

Furthermore, it is accepted that these effects occur concurrently.

As described in Report 1814-1 (Hugo et al. 1999), the research team compared ruts in the different wheelpaths in terms of a *benchmark* pavement lane. In this study, the left-hand wheelpath of N2 was selected as the benchmark lane, since it had the least rutting. This choice does not influence the outcome. Therefore, based on the principle of superposition, the total affected ruts of the respective pavement lanes subjected to conditions that differed from those of the benchmark pavement lane (LWP N2) may be calculated as shown below:

$$\text{Total Affected Rut(s)} = \alpha\ (F_t^{\beta_t} * F_s^{\beta_s} * F_m^{\beta_m} * F_l^{\beta_l} * F_{ltp}^{\beta})\ BR \quad (1)$$

therefore log [Total Affected Rut(s)/BR]

$$= \log \alpha + (\beta_t \log F_t + \beta_s \log F_s + \beta_m \log F_m + \beta_l \log F_l + \beta_{tp} \log F_{tp}) \quad (2)$$

The assumptions, with respect to each of the influencing factors (temperature, structural response, material, wheel load, and tire pressure) and their quantification, are discussed below. As in the case of the first report (Hugo et al. 1999), a somewhat simplified approach was followed in quantifying the influencing factors.

Temperature (F_t)

This factor was taken into account using G* as defined in the Superpave system. Previously, it was based on a correction factor proposed by Sousa and Monismith (Lee et al. 1997). G* was found to provide a reasonable basis for temperature correction in the tests with the MMLS (Report 1814-3). It has also been reported as a good measure of rutting performance under different temperatures by Anderson et al. (2000). The average overall AC temperature during trafficking was 30 ºC and 24 ºC, respectively, for the N1 and N2 sections.

Structural Response (F_s)

The FWD response prior to testing was used as the basis for determining input parameters for the rehabilitation remaining life curves, as presented by Croney and Croney (1991). These curves provide a relationship between performance life and deflection. The FWD deflections were taken to be 50% of the creep deflections used by Croney and Croney.

Accordingly, the performance life ratios were based on initial FWD values of 0.21 mm, 0.28 mm, 0.32 mm, and 0.34 mm for pads N2 (LWP, RWP) and N1 (LWP, RWP).

Material Processing *(F_m)*

Since both N2 and N1 were of similar materials, this factor was taken to be equal to 1.

Wheel Load *(F_l)* ***and Tire Pressure*** *(F_{tp})*

Two aspects were considered in terms of trafficking, namely, load and tire pressure. In the case of load *(F_l)*, a factor of 1 was assumed, since the loads were the same for both pads, with the exception of the RWP of N1, where an overload of 7% was found. Accordingly, that load factor was taken as 1.57 (Hugo et al. 1999). The factor for tire pressure was determined by assuming the factor varied linearly according to tire pressure.

Analysis

The respective factors were thus determined in accordance with the above outline. Since all factors were known, the analysis was performed to determine whether the analytical model was satisfied. In other words, in each case it was possible to measure to what extent the predicted and measured comparisons were the same.

For the sake of simplicity, the α and β factors were initially set to equal 1, as was done in the analysis documented in Report 1814-1 (Hugo et al. 1999). However, upon analysis of the data and the results it was concluded that the structural response was overemphasized. The differential FWD response was in fact being generated by the AC layers — meaning that the effect of the AC was being reflected by the temperature and the structural factors. Accordingly, it was decided that a value for β_s would be determined heuristically. It was found that β_s =0.5 fit the data best. This value was then used for the analysis.

Hence:

$$\text{Total Affected Rut(s)} = F_t * F_s^{0.5} * F_m * F_l * BR \quad (3)$$

where:

BR = Benchmark Rut [2.16 mm] @ 500k

$$\text{and } \log\,[\text{Total Affected Rut(s)/BR}] = \left(\log F_t + 0.5\log F_s + \log F_m + \log F_l + \log F_{tp}\right) \quad (4)$$

The results of the analysis are shown in Table 3.

Table 3. Analysis and Interpretation of the Rutting Performance of Test Pads 281 N1 and 281 N2 at 500,000 TxMLS Axles

	281 N2								281 N1							
	LWP				RWP				LWP				RWP			
***Benchmark Rut* [BR]**	**2.16 mm**															
Average Field Ruts @ 500 k	**2.16 mm**				**3.15 mm**				**6.95 mm**				**11.55 mm**			
Affected Rut/BR = Ratio of Measured Rut relative to 281 N2 LWP Rut			**1**				**1.46**				**3.22**				**5.35**	
		Factors (F)		Log (F)		Factors (F)		Log (F)		Factors (F)		Log (F)		Factors (F)		Log (F)
Temperature factor based on G* (Superpave) – Report 1814-3		F_t	1	0		F_t	1	0		F_t	2.0	0.301		F_t	2.0	0.301
Structural response factor based on initial FWD (Croney and Croney see Report 1814-1)		F_s	1	0		F_s	2.00	0.301		F_s	3.07	0.487		F_s	3.54	0.549
		$F_s^{0.5}$		0		$F_s^{0.5}$		0.151		$F_s^{0.5}$		0.244		$F_s^{0.5}$		0.275
Material processing factor (all similar)		F_m	1	0		F_m	1	0		F_m	1	0		F_m	1	0
Load factor based on power function		F_l	1	0		F_l	1	0		F_l	1	0		F_l	1.56	0.193
Tire Pressure factor proportional to pressures (750/690)		F_{tp}	1	0		F_{tp}	1	0		F_{tp}	0.92	-0.037		F_{tp}	0.92	-0.037
$\left(\log F_t + 0.5\log F_s + \log F_m + \log F_l + \log F_{tp}\right)$				0				0.151				0.508				0.732
$(F_t{*}F_s^{0.5}{*}F_m{*}F_l{*}F_{tp})^{-1}$				1				1.42				3.22				5.40
α = *(Affected Rut/BR)* * $(F_t{*}F_s^{0.5}{*}F_m{*}F_l{*}F_{tp})^{-1}$		1.00				1.03				1.00				0.99		
Calculated Affected Rut with α=1	**2.16 mm**				**3.07 mm**				**6.96 mm**				**11.66 mm**			
Discrepancy between calculated ruts and measured ruts with α=1	**0 %**				**-3 %**				**0 %**				**+1 %**			

It can be seen that the value of α is very close to 1 (varying between 0.99 and 1.03). This finding was considered to be very significant, since this examination represented the second independent comparative analysis. Even more important was the fact that the effect of tire pressure had been accounted for as being directly proportional to the tire pressure.

In addition, the values of the calculated rut were very close to actual measured ruts. The discrepancy between the two was found to vary between –3% and 1%.

The relative contribution of each of the influence factors (e.g., temperature) toward the increase/decrease in rutting (affected rut – *BR*) can be calculated as follows on the basis of Equation 4:

Temperature effect (%) = [log F_t /(sum of the logs of the influence factors)]*100 (5)

= [log Affected Rut/BR] when α is 1 (6)

Using this methodology, the researchers calculated the contribution of the respective influence factors toward the increase in rutting from the *benchmark* value to the respective *affected rut* values in the four wheelpaths. The results are shown in Table 4. Of course, a zero percentage contribution simply means that the specific factor contributed nothing toward the increased rut.

Table 4. Rutting Proportions on 281 N2 and N1

	LWP		**RWP**	
	Log F	%	Log F	%
N2				
F_t	0	0	0	0
$F_s^{0.5}$	0	0	0.151	100
F_m	0	0	0	0
F_l	0	0	0	0
F_{tp}	0	0	0	0
Sum of Logs	0	0	0.151	100
N1				
F_t	0.301	59	0.301	41
$F_s^{0.5}$	0.244	48	0.275	38
F_m	0	0	0	0
F_l	0	0	0.193	26
F_{tp}	-0.037	-7	-0.037	-5
Sum of Logs	0.508	100	0.732	100

Of particular interest is the fact that the impact of an increase of 7% in the wheelload in the RWP of N1 on the rut in the wheelpath was found to be 26%. By contrast, the reduction of 7% in tire pressure caused a reduction of 5% in the rutting of the same wheelpath. From this limited experiment, it must be concluded that the wheel-load effect (F_l) was much more pronounced than that of the tire pressure (F_{tp}). In fact, it was 5 times more.

CONCLUSIONS FROM THE QUANTITATIVE ANALYSIS

The rutting analysis was for an independent experiment using the methodology previously developed by Hugo et al. (1999b). In this case, all parameters of the mathematical model

$$\text{Total Affected Rut(s)} = \alpha \; (F_t^{\beta_t} * F_s^{\beta_s} * F_m^{\beta_m} * F_l^{\beta_l} * F_{ltp}^{\beta}) \; BR$$

were known and the object was to determine whether this previously formulated analytical model would be satisfied and to what extent the factors in it could be quantified.

It was indeed very satisfying to find that the results of the four wheelpaths with two different materials were all close in terms of a measure of the α and β factors in the mathematical model. The values of α were found to be equal to 1 within +/- 3%. The values of β that had been selected (all taken as 1, except in the case of the structural factor, where it was assumed to be 0.5) needed no adjustment.

A further measure of the success of the validation lies in the use of the same overload power function exponent for N1's RWP as was used by Hugo et al. (1999b) for determining the impact of wheel load on the rutting performance (e.g., 6.6 for an overload of 7%). In the same vein, the successful use of an adaptation of the FWD deflections on the basis of Croney and Croney (1991) as a measure of the structural impact on the rutting performance is considered noteworthy information.

The results indicate that the effect of tire pressure on rutting performance was directly proportional to the respective tire pressure. This finding is further evidence of the impact of tire pressure. On the other hand, the results did indicate that the wheel-load effect (F_l) was much more pronounced than that of tire pressure (F_{tp}). In fact, it was 5 times more. In this regard, it is important to remember that the contact pressure can be much higher than the tire pressure (De Beer et al. 1999). While the effect of this was not investigated, there is clearly a need to explore this aspect more comprehensively.

Despite the limited scope of the study, these findings can be viewed as validation of a very useful methodology for analysing rutting performance under controlled conditions. Of course, further investigation of the interrelationships in vehicle-pavement interaction is needed to increase the confidence in the use of the methodology.

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Appendix A

Some Useful Metrication Guidelines	
SI-Metric	Conventional US Units
1m	39.4 in
1 mm	39.4 mil
°C	(°F-32)*5/9
100 kPa	14.5 psi