Estimating Damage Effects of Dual versus Wide Base Tires with Multidepth Deflectometers

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Multidepth deflectometers (MDDs) were successfully used to assess the relative damage of dual and wide base single tires. In this study MDDs were installed in two in-service asphaltic concrete highways (one thick, one thin) to measure the pavement response to vehicle loading. A specially configured 3S2 truck was used in the study. It is an 18-wheel water tanker that was converted to a 14-wheel tanker for this study. For the first set of data collection, dual tires were used on the tandem drive axle with wide base single tires on the tandem trailer axle. For the second set, wide base single tires were used on the tandem drive axle and dual tires on the trailer axle. Deflections measured at several depths within the pavement by MDD under dual and wide base single tires were used to calculate average vertical compressive strains. The Asphalt Institute subgrade limiting strain criteria were used to estimate the reduction in pavement life that will occur by using the wide base single tires in place of duals. Wide base single tires were found to be more damaging on both tandem drive and tandem trailer axle positions. At a speed of 55 mph and equivalent axle loading, it was found that the wide base single tires (trailer axle) reduced the anticipated pavement life on the thin and thick sections by a factor of between 2.5 and 2.8 over that predicted for standard dual tires.

Since the AASHO Road Test (*1*) several new tire types, sizes and configurations have been used by the trucking industry. Changes in tires and wheel configuration for heavy trucks have generated concern about the potential increase in highway pavement damage. Early concerns were related to an increase in tire inflation pressure that accompanied the change from bias-ply tires to radial-ply tires. Of particular current concern is the use of single wide base tires (super single) (*2–6*). In a conversion application, a single wide base tire replaces the conventional dual tire assembly, thereby reducing the typical "18 wheeler" to a "10 wheeler."

Proponents claim that using wide base single tires on truck tractors and trailers improves fuel consumption, ride, handling, and braking while reducing tire cost and increasing payload. Replacing duals also releases the vehicle designer from the requirements for demountable wheel or rim assemblies for access to the inside tire (*7*).

However, a major concern of highway agencies regarding using wide base single tires is their impact on pavement deterioration. A technique developed to monitor transient relative deflection and permanent deformation in pavement layers under moving vehicular loading is described here. The device developed for this purpose is called a multidepth deflectometer (MDD) (*8*). From the deflections measured at various depths, typically measured at the layer interfaces, it is possible to backcalculate the elastic moduli of the layers.

The aim of this paper is to present and compare pavement responses under dual and wide base single tires on tandem axles for different speeds. The deflection measurements were made on two in-service asphaltic concrete pavement sections. Measurements were made at vehicle speeds between 4 and 55 mph. Peak deflection profiles under the two tire types at different lateral offsets were compared. Vertical compressive strains measured near the top of the subgrade were used to estimate and compare the allowable number of equivalent single axle load (ESAL) repetitions for dual and wide base single tires.

MEASUREMENT SYSTEM

The MDD is made up of modules with linear variable differential transformers (LVDTs) as shown in Figure 1. The modules are locked into the different pavement layers to measure the relative movement in these layers with respect to an anchor point located approximately 8 ft below the pavement surface (*9*). A typical setup is shown schematically in Figure 2. The detailed description, installation techniques, and precautions for the installation of the MDD system are described in detail elsewhere (*8,9*).

A specialized data acquisition system has been developed at the Texas Transportation Institute to record the MDD pulse under both falling weight deflectometer (FWD) and truck loadings. A Compaq 386/20 microcomputer is used with a Data Translation (DT 2814) circuit board to provide a maximum sampling rate of 5,000 readings per channel per second. For recording truck data, the truck length is the input, the sampling rate is automatically calculated, and the data collection is automatically started by a response of any sensor greater than a preset trigger level. For trucks typically 1,000 data points per channel are stored. The files created are read directly into a spreadsheet software package for display and analysis.

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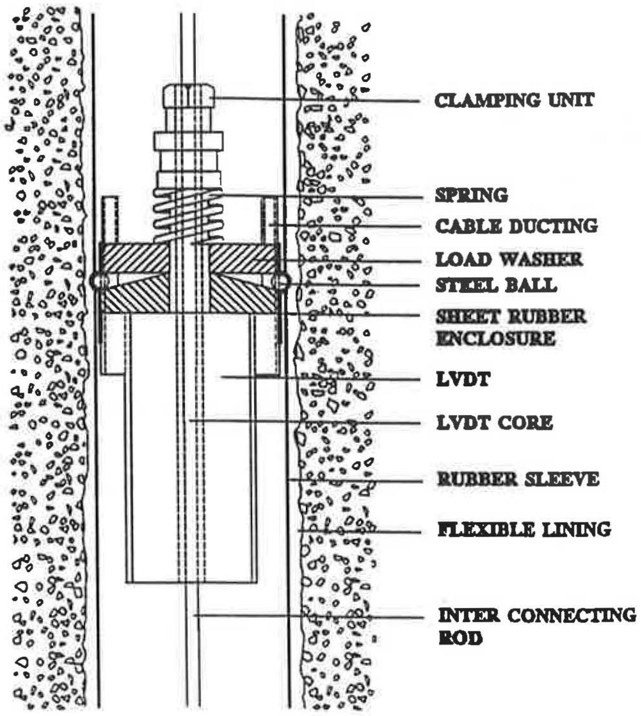

FIGURE 1 MDD module.

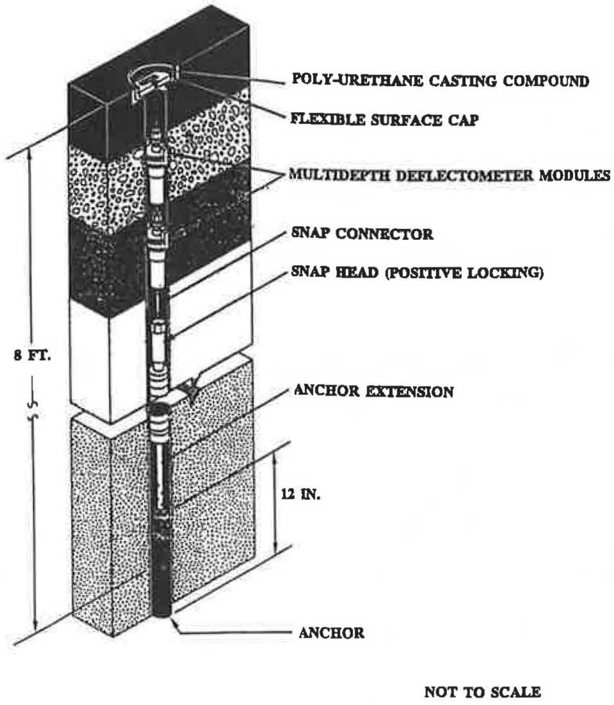

FIGURE 2 Typical cross-section of MDD after installation.

LAYOUT OF TEST SECTIONS AND INSTRUMENTATION

Two test sites were selected on in-service highways to investigate the effects of truck tire type and speed on both thick and thin asphaltic concrete pavements. MDDs with four LVDT modules each were installed in the outer wheel path at each site. The cross-sections of the test sections showing the locations of MDD sensors are shown in Figure 3.

Section I has a hot-mix asphalt concrete (HMAC) thickness of 1.5 in. and a crushed limestone base course thickness of 10 in. overlaying a sandy clay subgrade. The average value of the international roughness index (IRI) for Section I is 95.82 in./mi. Section II has an HMAC thickness of 7 in., a crushed limestone base course thickness of 14 in., and a 6-in. lime stabilized subbase overlaying a sandy clay subgrade. The average value of the IRI for Section II is 85.87 in./mi. In situ properties measured are presented in Table 1.

TEST VEHICLE

The test vehicle is a specially prepared 3S2 truck consisting of a steering axle, tandem drive axles, and tandem trailer axles. It is an 18-wheel water tanker that was converted to a 14-wheel vehicle by replacing dual wheels on one set of tandem axles with wide base single tires. Figure 4 shows the truck and the axle spacings.

To check if the loading sequence had any significant effect on the pavement response, two data sets were collected. The first set of data was collected with dual tires on the tandem drive axles and wide base single tires on the tandem trailer axles. The second data set was collected with the wide base single tires on the drive axles and dual tires on the trailer axles.

The dual tires were 11R22.5, inflated to 120 psi (cold). The wide base singles were 425/65R22.5, inflated to 130 psi (cold). The tanker was filled with water to develop the desired load. The loads on the tandem drive and trailer axles and other test conditions are presented in Table 2.

TRUCK DATA COLLECTION

MDD response to the truck loading was recorded for four speed groups: less than 10 mph, 10–20 mph, 30–40 mph, and 40–60 mph. Four runs were made for each speed group. A typical plot of the MDD response from Section I under the passing test vehicle (five axles) at 10 mph speed is presented in Figure 5.

To determine the transverse position of the right side tires relative to the MDD location, a grid (6 in. × 6 in.) was painted on the pavement surface next to the MDD hole. As the test vehicle passed over the MDD, the transverse (or lateral) position of the outer tires (toward the shoulder) relative to the MDD position was recorded by a video camera. Using the width of the tires, the transverse positions of the centerline of the single tire and dual tire assemblies relative to the MDD location were determined.

Deflections at various depths within the pavement structure caused by each loading condition under the two tire types were recorded at truck speeds ranging from approximately 4 to 55 mph. Comparisons between the magnitude of the vertical compressive strains at top of the subgrade were made for both tire types at different speeds. The predicted allowable ESAL repetitions are solely dependent on the test conditions

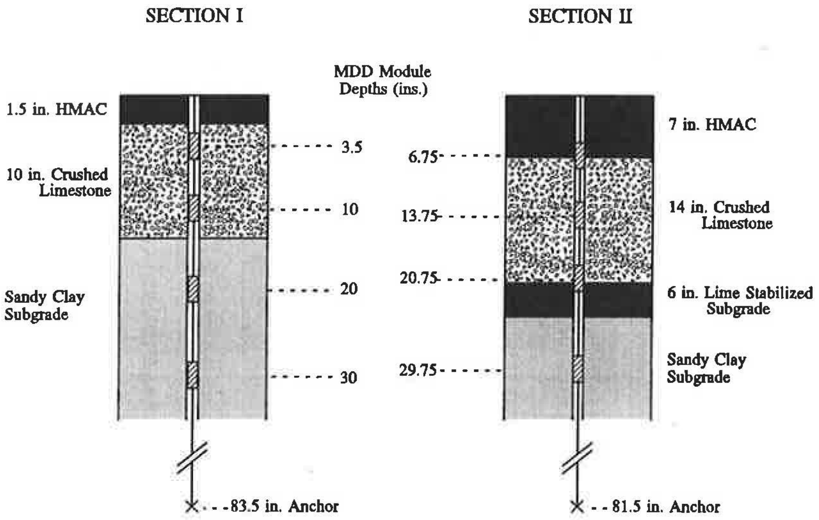

FIGURE 3 MDD location in test pavements.

TABLE 1 In Situ Soils Data for the Test Sections

Section	Base (B) or Subgrade (S)	Moisture Content (%)	Dry Density (pcf)
I	B	6.0	132.9
I	S	33.2	84.5
II	B	6.0	131.7
II	S	14.1	109.1

and should be viewed solely as the relative damage difference due to the effects of dual and wide base single tires.

MOVING TANDEM AXLE LOAD PULSE DURATION

As the moving truck approaches a point in the pavement, such as where the MDD is located, that point experiences vertical deflection, which increases until the wheel is directly over the point at which the deflection reaches its maximum value and then decreases as the wheel moves away. Typical MDD responses for the vehicle traveling at speeds of 10 and 55 mph on Section I are shown in Figures 5 and 6. The curves represent the relative deflection response at depths of 3.5, 10, 20, and 30 in. The pulse width is much narrower for the faster vehicle loading. The measured pulse durations for speeds of 10 and 55 mph under the tandem axle loading are 1,053 msec and 180 msec, respectively.

The duration of the load pulse under the truck loading for a tandem axle at 55 mph speed is about 6 times the pulse duration for the FWD (28–30 msec). The duration of the pulse is related to the loading rate, which may affect the material properties.

DEFLECTIONS UNDER DUAL AND WIDE BASE SINGLE TIRES

Higher deflections were measured under the wide base single tires in both drive and trailer axle positions, under similar test conditions. The plot of peak deflections (Figure 7) at the bottom of asphalt layer (MDD1) shows that the dual tires cause less deflection than the wide base single tires.

The maximum deflection under the wide base single tire generally occurs under the tire centerline, whereas the maximum deflection under dual tires can occur under either of the tires. The same phenomenon was observed by Sharp et

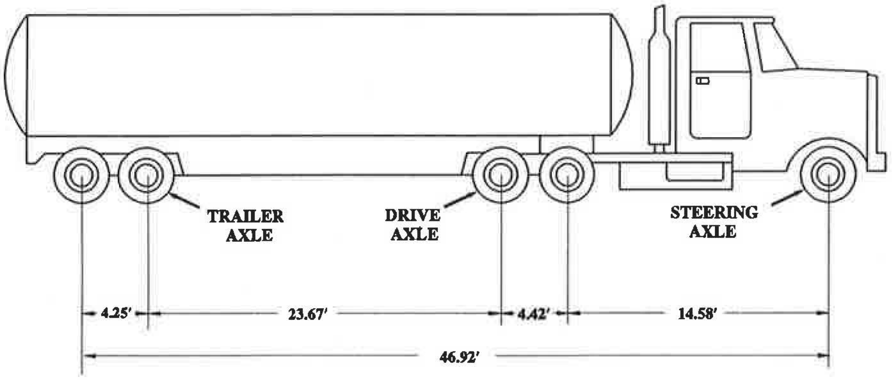

FIGURE 4 3S2 water tanker used for testing.

TABLE 2 Summary of Test Conditions

Section	Tire Type	Tandem Axle	Load (Kips)	Test Date		AC Temperature (°F)		
				From	To	Top	Middle	Bottom
I	Dual	Drive	33	11-13-90	11-13-90	80		79
I	Super Single	Trailer	33	11-13-90	11-13-90	80		79
I	Super Single	Drive	37	5-30-91	5-30-91	95		96
I	Dual	Trailer	37	5-30-91	5-30-91	95		96
II	Dual	Drive	33	10-15-90	10-16-90	80	76	73
II	Super Single	Trailer	33	10-15-90	10-16-90	80	76	73
II	Super Single	Drive	33	7-12-91	7-12-91	103	97	85
II	Dual	Trailer	33	7-12-91	7-12-91	103	97	85

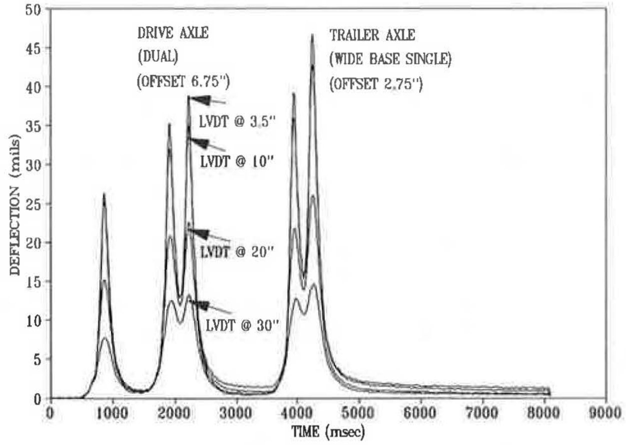

FIGURE 5 Typical MDD response from Section I under test vehicle (5 axles) passing at 10 mph.

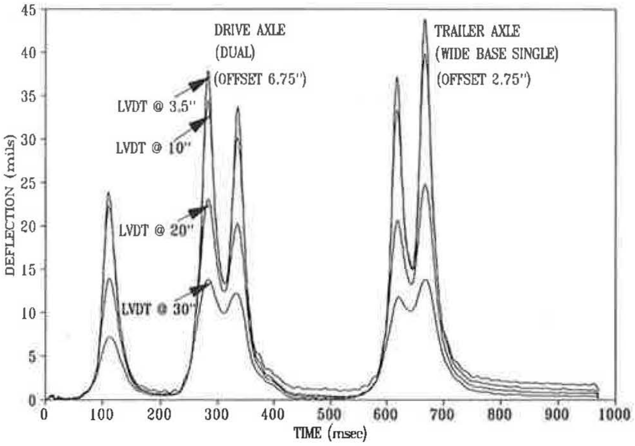

FIGURE 6 Typical MDD response from Section I under test vehicle (5 axles) passing at 55 mph.

al. (*4*). Another interesting feature of this plot is the rapid decrease in deflection at the edge of the wide base single. This is more significant in Section I (thin) than in Section II (thick), which indicates high shear forces at the edge of the wide base single tire. The deflection basin generated by the wide base single tires is deeper and more concentrated than that of regular dual tires. This phenomenon is no doubt detrimental to the pavement life. Although the focus of this paper is on induced rutting damage, these results indicate that wide base single tires may also generate more surface cracking.

VERTICAL COMPRESSIVE STRAIN MEASUREMENT IN BASE COURSE LAYER AND TOP OF SUBGRADE

The average vertical compressive strains within the pavement layers are calculated simply by subtracting the maximum deflection between two consecutive MDDs and dividing by the spacing between them. Compressive strains at top of the subgrade at different speeds for both sections are presented in Table 3.

Strain in the Base Course Layer

Response curves for strains in the base course material are shown in Figures 8 and 9. These response curves show dilation or extension in the base course material for both sections. Figure 8 indicates that in Section I (thin), the dilation occurs immediately before and after the wheel passes over the MDD. For Section II (thick), the dilation occurs only in front of each axle before the tire passes over the MDD, as shown in Figure 9. For the thin section the dilation is 7 times greater than the thick section. Uzan and Scullion (*10*) observed similar behavior in the base course layer for thin sections under FWD loadings.

Strain on Top of Subgrade and Effect of Speed

The effect of speed on vertical strain at top of the subgrade is shown in Figure 10. Increasing the speed from 10 to 55 mph decreased the measured strains on top of the subgrade for both sections. The wide base single tires were found to be more damaging than the dual tires in both drive and trailer axle positions.

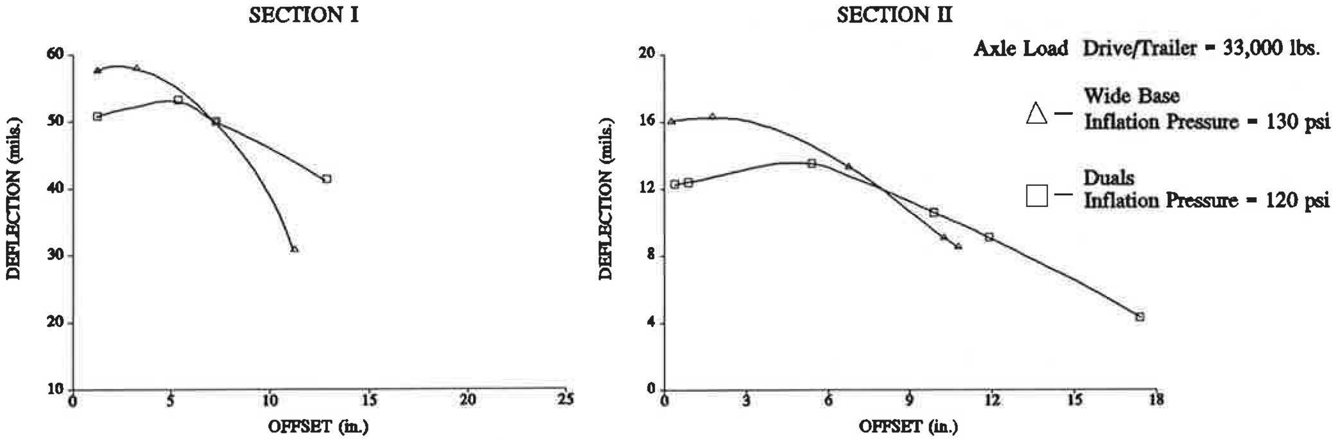

FIGURE 7 Peak deflections under dual and wide base single on MDD1 (speed 40–60 mph) at bottom of asphalt layer.

For the same loading conditions, with an increase of speed from 10 to 55 mph, the strain at the top of the subgrade at Section I decreased by 8 percent for dual tires and by 7 percent for wide base single tires. For similar conditions on Section II, the strain at top of the subgrade decreased by 13 percent under dual tires and 5 percent under wide base single tires.

At a speed of 55 mph, the measured vertical compressive strains under similar loading conditions at the top of the subgrade for Section I are found to be 26 percent higher under wide base single tires than for the dual tires. In Section II (thick), the strains under the wide base single tires are found to be approximately 23 percent higher than under the dual tires.

ESTIMATING REDUCTION IN PAVEMENT LIFE

The Asphalt Institute rutting criteria are widely used in pavement design (*11*). They provide the allowable number of ESAL repetitions for various levels of compressive strain at the surface of the subgrade and are expressed in the form

$$\varepsilon_v = L(1/N)^m$$

where

N = permissible number of ESALs,
ε_v = subgrade vertical strain,
$L = 1.05 \times 10^{-2}$, and
$m = 0.223$.

The allowable number of ESAL repetitions at different speeds and strain levels for both sections is tabulated in Table 3. Figures 11 and 12 show that the number of repetitions increases with speed for both tire types. On Section I, with an increase of speed from 10 to 55 mph, the predicted allowable number of dual and wide base single tire repetitions increased by approximately 45 percent and 39 percent, respectively. For the same speed increase on Section II, the number of dual and wide base single tire repetitions increased by approximately 87 percent and 26 percent, respectively.

At a speed of 55 mph under similar test conditions the wide base single tires were found to be 2.8 times more damaging than the dual tires on Section I. Under similar test conditions on Section II, the wide base single tires were found to be 2.5 times more damaging. This indicates that wide base single tires are more damaging to thin bituminous pavements than to thick pavements.

PREDICTION OF SURFACE CRACKING

The main focus of this paper is estimating damage caused by increasing vertical compressive strain at the top of the subgrade. However, it appears that the wide base single tires may produce more surface cracking than standard dual tires.

The results in Figure 7 show the transverse deflection patterns for both tires. Figure 13 shows typical longitudinal deflection patterns measured by the MDD at the bottom of the asphalt layer on Section I for each tire under the same test conditions. Using Figure 13, and assuming these deflections to be the same at the top of the asphalt layer for the thin section, it is possible to calculate a surface curvature index (SCI), which has been related by many authors to the tensile strain at the bottom of the asphalt layer (*12*). The SCI is defined as the difference between the maximum deflection underneath the load and the deflection at a distance of 12 in. preceding the maximum. The SCI is shown schematically in Figure 13. The following equation relating SCI to tensile strain was proposed by Scullion (*13*):

$$\varepsilon_t = -38.9 + 28.7\ SCI$$

Using that relationship, the data presented in Figure 13 can be used to estimate the tensile strains presented in Table 4. Results show that the tensile strains in the asphalt layer for Section I under wide base single tires are about 1.5 times higher than those for dual tires.

CONCLUSION AND FUTURE WORK

The overall aim of this study is to compare pavement response under dual and wide base single tires for various conditions of speed, load, and inflation pressure, taking into account the

TABLE 3 Average Vertical Compressive Strain Measured at Top of Subgrade and Allowable ESAL Repetitions

Section	Tire	Axle	Speed (mph)	μStrain	Allowable ESAL Repetitions
I	Dual	Drive	10	1355	9719
I	Dual	Drive	20	1332	10495
I	Dual	Drive	35	1294	11950
I	Dual	Drive	55	1246	14157
I	Super Single	Trailer	10	1690	3609
I	Super Single	Trailer	20	1665	3858
I	Super Single	Trailer	35	1623	4327
I	Super Single	Trailer	55	1570	5021
II	Dual	Drive	10	297	8782890
II	Dual	Drive	20	289	9926930
II	Dual	Drive	35	275	12402795
II	Dual	Drive	55	258	16511743
II	Super Single	Trailer	10	334	5187796
II	Super Single	Trailer	20	330	5475794
II	Super Single	Trailer	35	325	5863820
II	Super Single	Trailer	55	317	6557210
I	Super Single	Drive	10	2087	1401
I	Super Single	Drive	20	2081	1419
I	Super Single	Drive	35	2071	1450
I	Super Single	Drive	55	2060	1485
I	Dual	Trailer	10	1626	4291
I	Dual	Trailer	20	1617	4399
I	Dual	Trailer	35	1601	4600
I	Dual	Trailer	55	1581	4866
II	Super Single	Drive	10	390	2588858
II	Super Single	Drive	20	385	2743075
II	Super Single	Drive	35	382	2841008
II	Super Single	Drive	55	376	3050031
II	Dual	Trailer	10	361	3660915
II	Dual	Trailer	20	358	3800507
II	Dual	Trailer	35	354	3996905
II	Dual	Trailer	55	348	4315343

transverse position with respect to the MDD. The effect of speed on pavement response under dual and wide base single tires for one set of loading and tire pressure conditions was examined. The major conclusions follow.

1. The MDD is an excellent tool to measure vertical strains and deflections in the pavement structure under different conditions of actual truck loading.

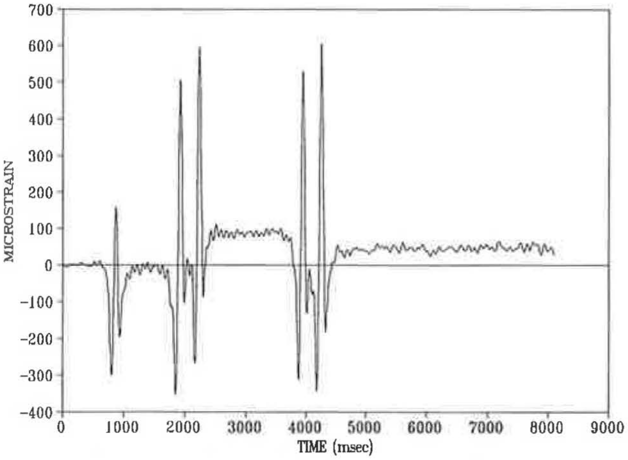

FIGURE 8 Vertical strain in granular base layer for Section I at speed of 10 mph.

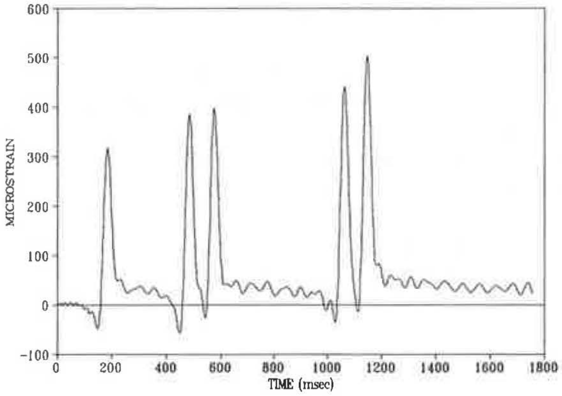

FIGURE 9 Vertical strain in granular base layer for Section II at speed of 34 mph.

2. Under similar test conditions, wide base single tires produced higher deflections than dual tires, whether fitted to tandem drive axles or tandem trailer axles.
3. The maximum deflection under the wide base single tire generally occurs under the tire centerline, whereas the maximum deflection under dual tires occurs under either of the two tires.
4. The duration of load pulse under truck loading for a tandem axle at 55 mph speed is about 6 times (180 msec) the pulse duration for a FWD (28–30 msec). The duration of the pulse is related to the loading rate, which may affect the material properties. This aspect requires further research.
5. The apparent dilation in the base course layer under the moving load requires further attention and investigation.
6. The measured pavement deflections under both dual tires and wide base single tires in all the layers decreased with increase in speed.
7. Under similar test conditions wide base single tires are 2.8 times more damaging than dual tires on the thin pavement section and 2.5 times more damaging on the thick section for a speed of 55 mph based on design equations using vertical compressive strain.

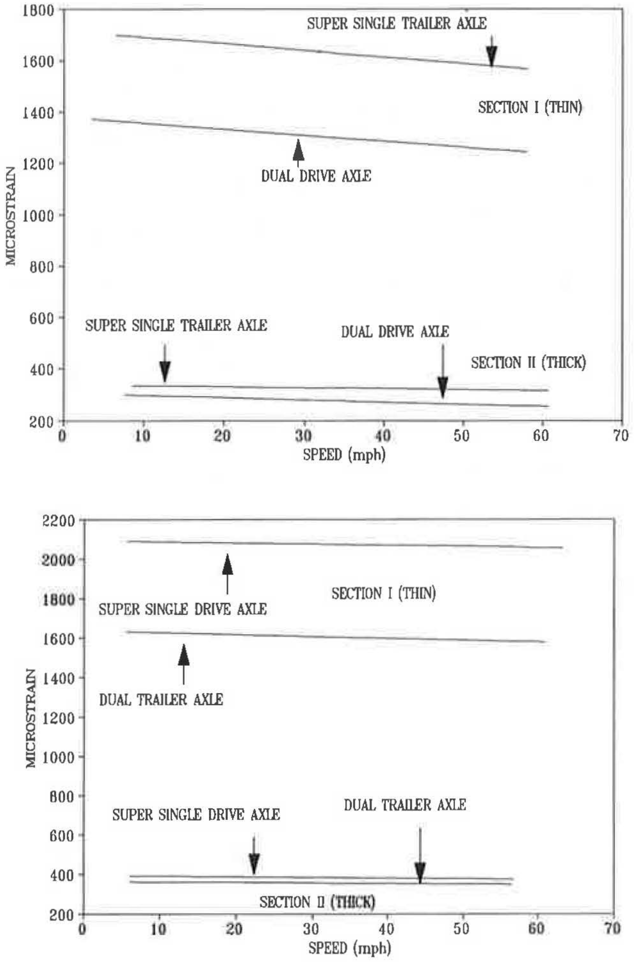

FIGURE 10 Effect of speed on vertical strain at top of subgrade (Sections I and II).

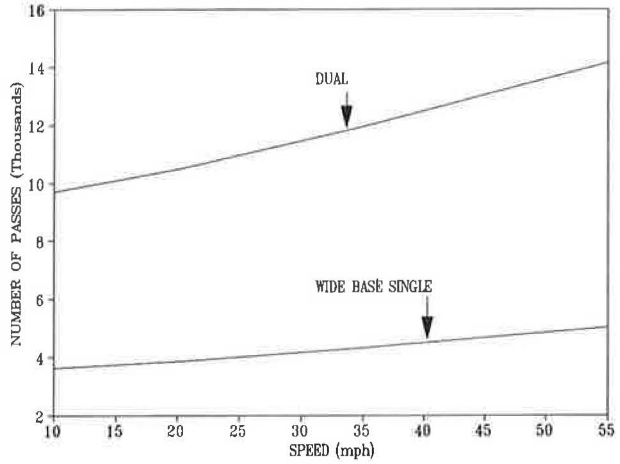

FIGURE 11 Effect of speed on allowable number of passes for Section I.

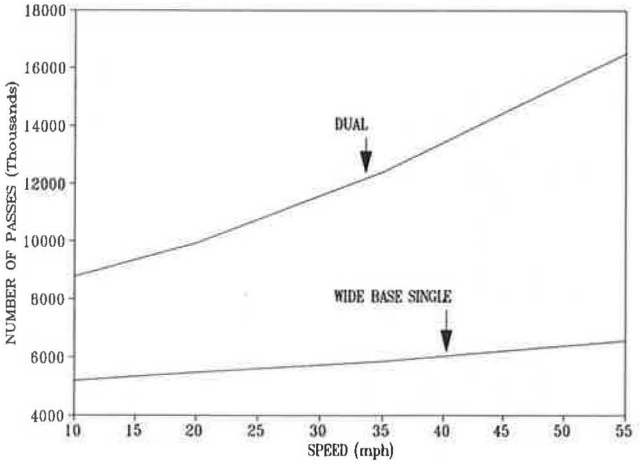

FIGURE 12 Effect of speed on allowable number of passes for Section II.

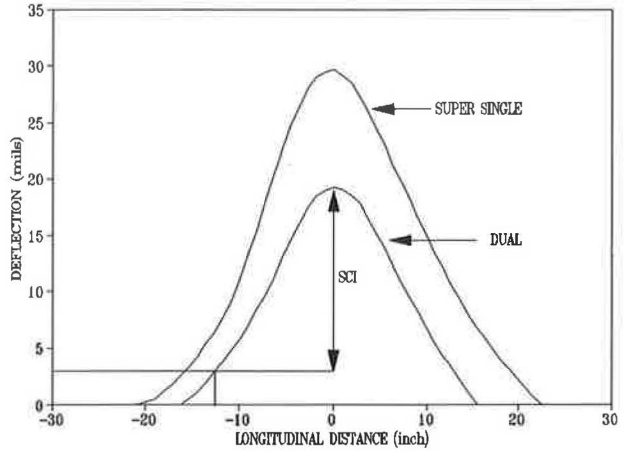

FIGURE 13 Measured peak longitudinal deflections profile under dual and wide base tire on Section I.

TABLE 4 Tensile Strain in the Asphalt Layer for Section I

Tire Type	Load (kips)	Tire Pressure (psi)	SCI	Tensile Strain (μStrain)
Wide base Single tires	33	130	19.078	592.73
Dual tires	33	120	15.835	405.23

The plan for future work includes pavement material characterization under FWD and vehicular loading using linear and nonlinear elastic backcalculation techniques. Testing under different loadings and inflation pressures is planned. Analysis of the measured data will be used to estimate the amount of pavement damage caused by the variation in these characteristics and their effects on thin and thick asphaltic concrete pavements service life.

ACKNOWLEDGMENTS

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