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16. Abstract

In this study multidepth deflectometers (MDD) 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 normally an 18-wheel water tanker but was converted to a 14-wheel tanker for this study. For these tests, dual tires were used on the tandem drive axle with wide base single tires on the tandem trailer axle. Test runs were made under high inflation pressure conditions for the two tire types and the truck speed varying between 5 and 55 mph.

The vertical compressive strain in the subgrade is one of the parameters used in pavement design to prevent excessive rutting in the pavement structure. Deflections measured at several depths within the pavement by MDDs under dual and wide base single tires were used to calculate average vertical compressive strains. The vertical compressive strains measured at the top of the subgrade were used to estimate the allowable number of 18 kip equivalent single axle load (ESAL) repetitions for dual and wide base single tires.

The Asphalt Institute subgrade limiting strain criteria was used to estimate the reduction in pavement life which 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 the thin and thick pavement sections. At a speed of 55 mph and equivalent axle loading, it was found that the wide base single tires reduced the anticipated pavement life on the thin section by a factor of 4.85 and on the thick section by a factor of 2.21 over that predicted for standard dual tires.

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Wide-based Tires, Multidepth Deflectometers, Pavement Damage

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ESTIMATING DAMAGE EFFECTS OF DUAL
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by

T. Akram
T. Scullion

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Federal Highway Administration

by

Texas Transportation Institute
April 1992

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

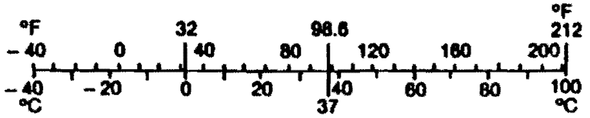
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

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* SI is the symbol for the International System of Measurements

ABSTRACT

In this study multidepth deflectometers (MDD) 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 normally an 18-wheel water tanker but was converted to a 14-wheel tanker for this study. For these tests, dual tires were used on the tandem drive axle with wide base single tires on the tandem trailer axle. Test runs were made under high inflation pressure conditions for the two tire types and the truck speed varying between 5 and 55 mph.

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The Asphalt Institute subgrade limiting strain criteria was used to estimate the reduction in pavement life which 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 the thin and thick pavement sections. At a speed of 55 mph and equivalent axle loading, it was found that the wide base single tires reduced the anticipated pavement life on the thin section by a factor of 4.85 and on the thick section by a factor of 2.21 over that predicted for standard dual tires.

DISCLAIMER

IMPLEMENTATION STATEMENT

This project has developed a field testing framework with which the Texas Department of Transportation can evaluate the consequences of new tire types, higher tire pressures, new axle configurations, etc on Texas pavements. The information generated in this study can be used to demonstrate to tire manufactures, legislatures and others the damaging effects of wide based, super single tires.

ACKNOWLEDGEMENTS

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CHAPTER 1
INTRODUCTION

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 due to the potential increase in highway pavement damage that may arise. The early concerns were related to an increase in tire inflation pressure that accompanied the change from bias-ply tires to radial-ply tires. One particular current concern is the use of single wide base tires (super single) (2,3,4,5,6). In a typical conversion, a single wide base tire replaces the two tires of a conventional dual tire assembly.

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 wide base single tires is their impact on pavement deterioration. This report describes a technique developed to monitor transient relative deflections and permanent deformations in pavement layers under moving vehicular loading. The device used for this purpose is called the multidepth deflectometer (MDD) (8). From the deflections measured at various depths, typically measured at the layer interfaces, it is possible to calculate average vertical compressive strains in each layer.

In this report pavement responses are compared 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 5 and 55 mph. Peak deflection profiles under the two tire types at different lateral offsets were compared. Vertical compressive strains measured near top of the subgrade were used to estimate and compare the allowable number of ESAL repetitions for dual and wide base single tires.

CHAPTER 2
FIELD TEST SET-UP

2.1 Measurement System

The multidepth deflectometer (MDD) is made up of modules with LVDTs (Linear Variable Differential Transformers) 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 feet below the pavement surface (9). A typical setup is shown schematically in Figure 2. The detailed description, installation techniques, data acquisition procedures 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) data acquisition board providing a maximum sampling rate of 5000 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 based on a response of any sensor greater than a preset trigger level. For trucks, typically 1000 data points per channel are stored. The files created are read directly into a spreadsheet software package for display and analysis.

2.2 Layout of Test Sections and Instrumentation

Two test sites (one thick, one thin) 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 an HMAC thickness of 1.5 inches and a crushed limestone base course thickness of 10 inches overlaying a sandy clay subgrade. The average value of international roughness index (IRI) for Section I is 95.82 in/mile. Section II has an HMAC thickness of 7 inches, a crushed

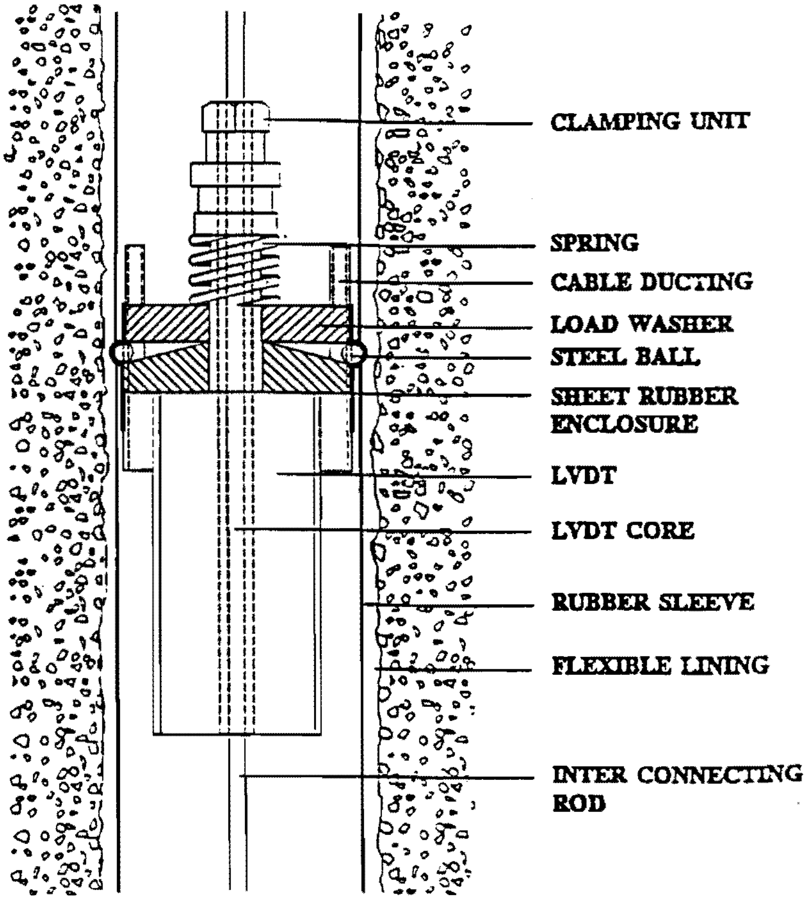

Figure 1. Multidepth Deflectometer Module

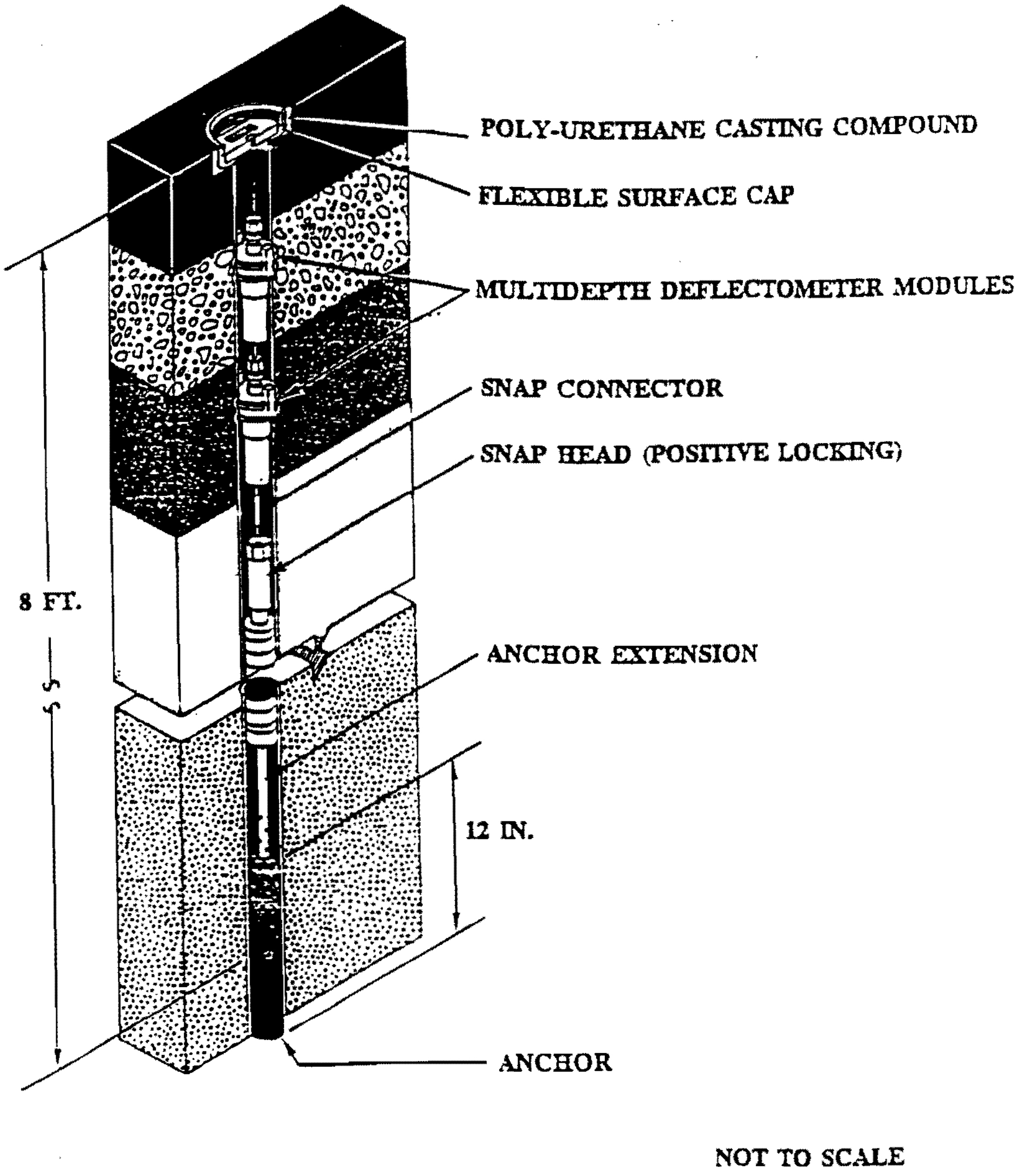

Figure 2. Typical Cross Section of MDD after Installation

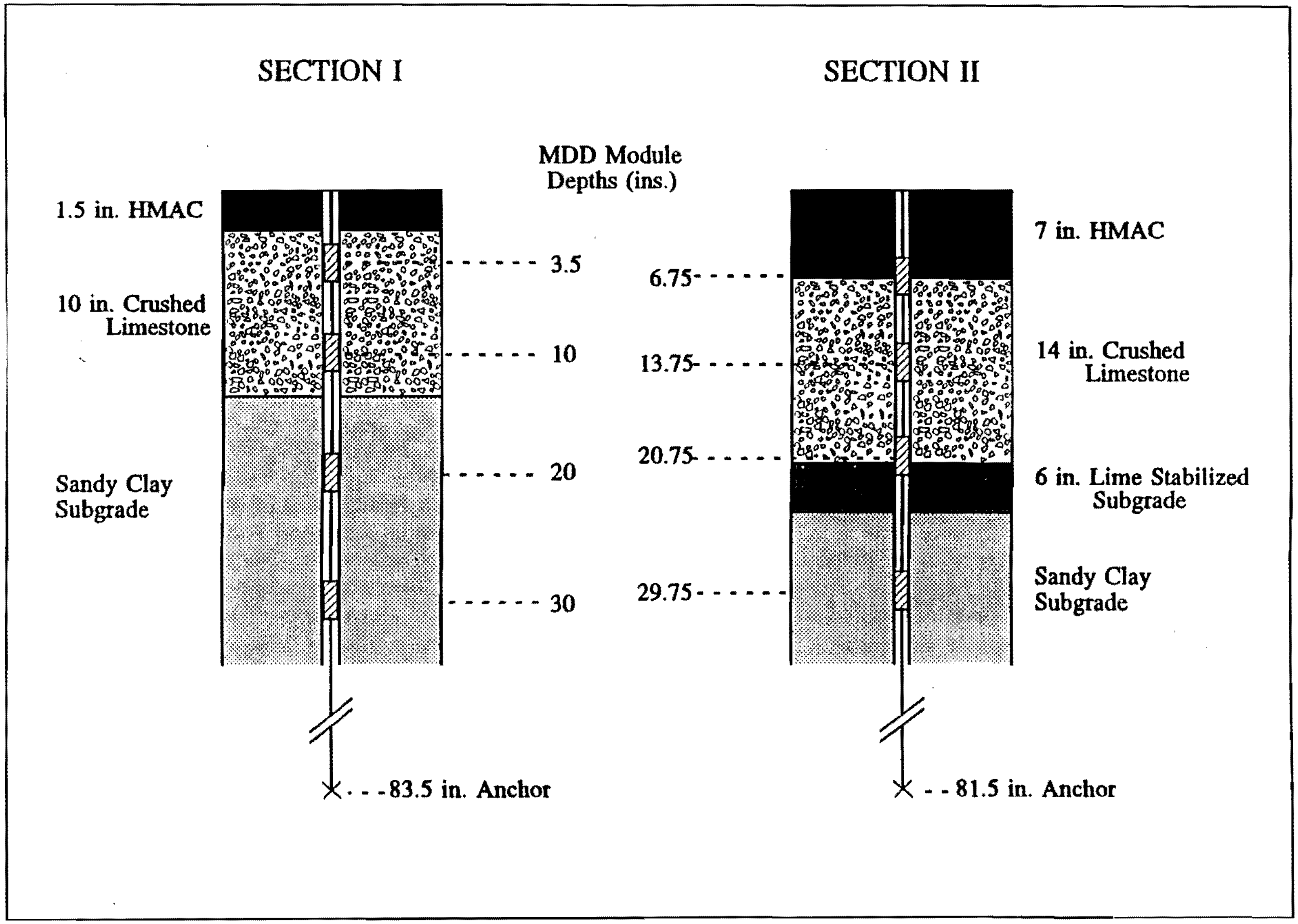

Figure 3. MDD Location in Test Pavements

limestone base course thickness of 14 inches, and a 6-inch lime stabilized subbase overlaying a sandy clay subgrade. The average value of international roughness index for Section II is 85.87 in/mile. In situ properties measured are shown in Table 1.

Table 1. In Situ Soils Data for the Test Sections

Section	Base (B) 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

2.3 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, 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.

The data set was collected with dual tires on the tandem drive axles and wide base single tires on the tandem 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 shown in Table 2.

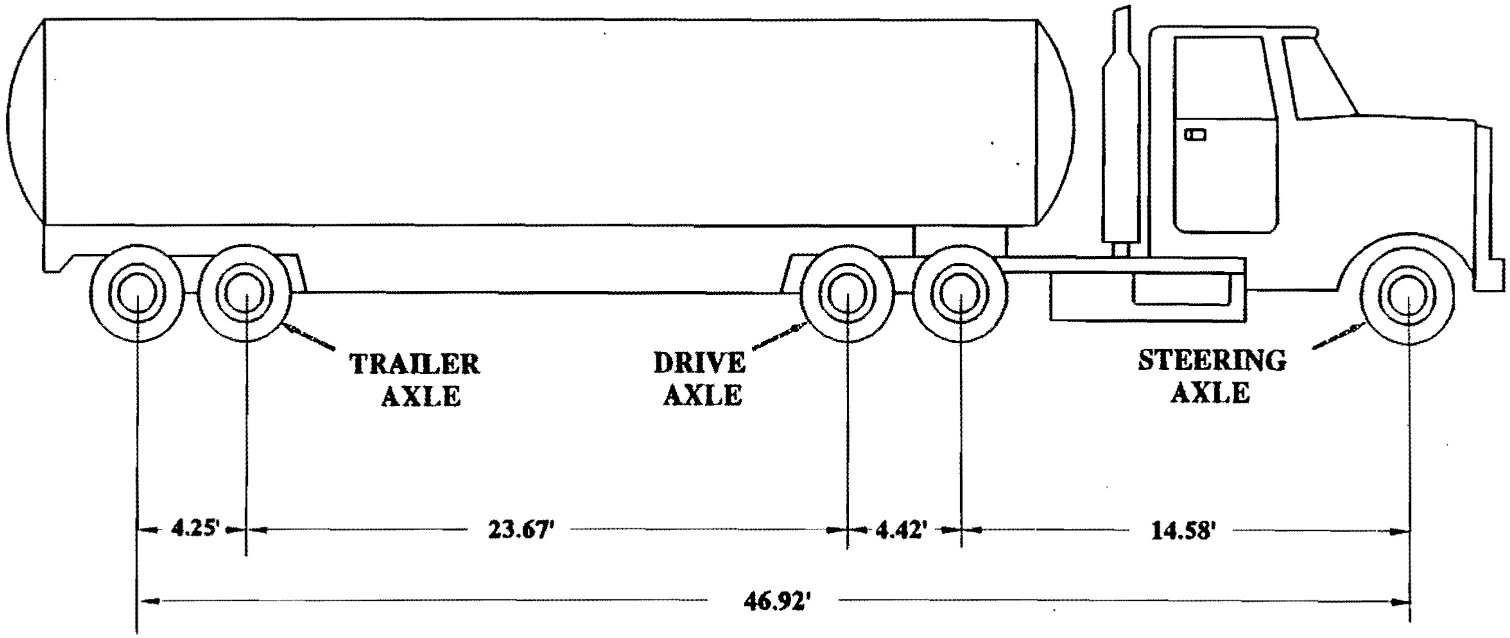

Figure 4. 3S2 Water Tanker Used for Testing

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
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

2.4 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 5a.

To determine the transverse position of the tires relative to the MDD location, a grid (6" x 6") 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 (towards 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 the two tire types were recorded at truck speeds ranging from approximately 5 to 55 mph. The average vertical compressive strain in each layer was calculated by subtracting the deflections at two adjacent LVDTs and dividing by their separation distance. Comparisons between the magnitude of the vertical compressive strains at top of the subgrade were made for both tire types at different speeds. In the analysis these calculated strains were used to compute allowable 18 kip Equivalent Single Axle Loads (ESALs) to failure using well known prediction equations. The predicted allowable ESAL repetitions are solely dependent on the test conditions and should be viewed solely as the relative damage difference due to the effects of dual and wide base single tires.

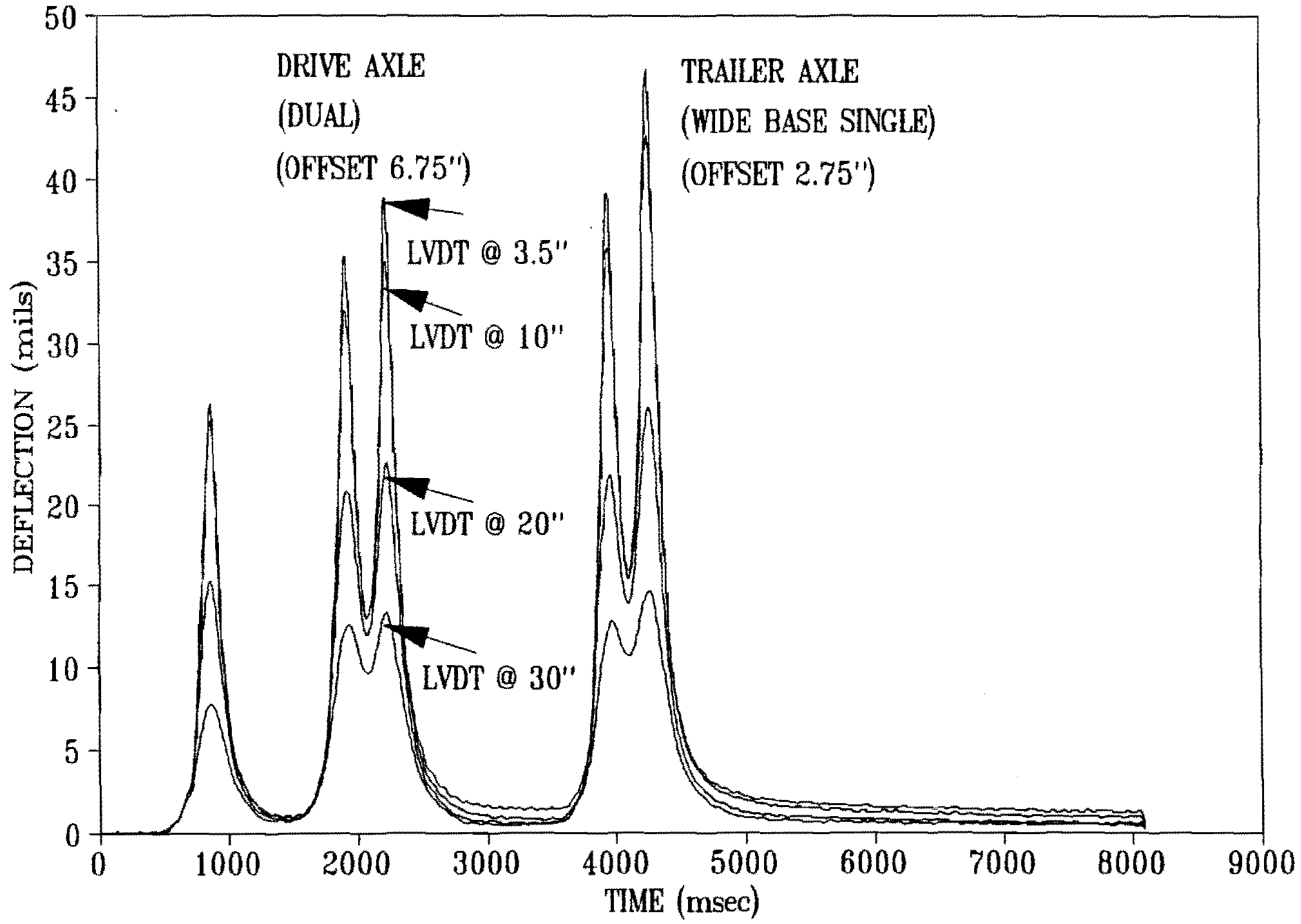

Figure 5a. Typical MDD Response from Section I under the Test Vehicle (5 axles) Passing at a Speed of 10 mph

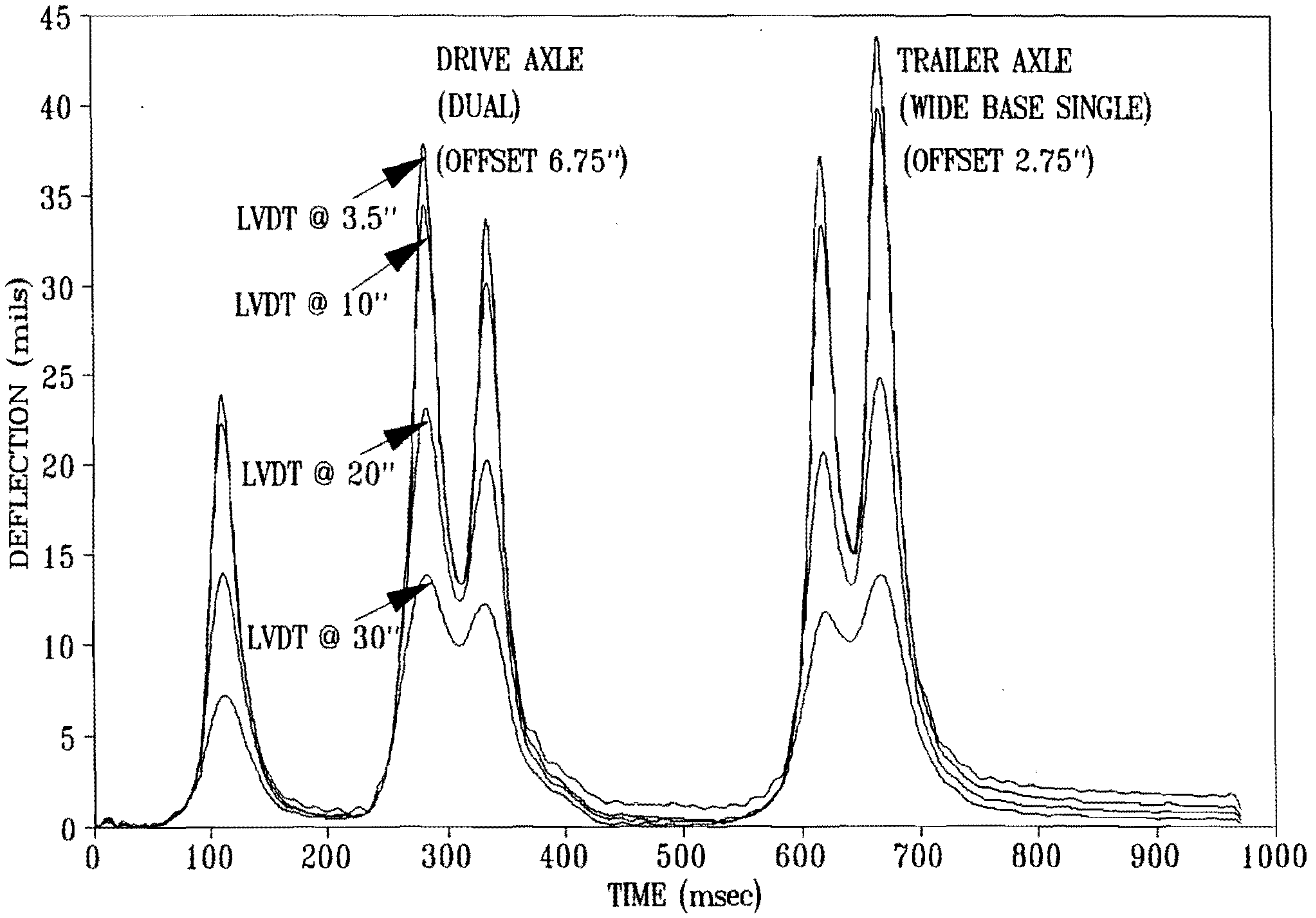

Figure 5b. Typical MDD Response from Section I under the Test Vehicle (5 axles) Passing at a Speed of 55 mph

CHAPTER 3
RESULTS OBTAINED AND ANALYSIS

3.1 Moving Tandem Axle Load Pulse Duration

As the moving truck approaches the MDD location, the deflection values recorded by the sensors increase steadily from their zero value. The deflections are maximum when the axle is directly over the MDD. As the axle moves away from the MDD location, the deflection curves drop off steadily to their zero position. Any residual deflection once the truck has passed is permanent deformation. Typical MDD responses for the vehicle travelling at speeds of 10 and 55 mph on Section I (Thin) are shown in Figure 5a and 5b. The curves represent the relative deflection response at depths of 3.5, 10, 20, and 30 inches. The pulse width is much narrower for the faster moving vehicle loading. The measured pulse durations for speeds of 10 and 55 mph under the tandem axle loading are 1053 msec and 180 msec respectively.

The duration of the load pulse in the subgrade under the single tire of the steering axle at 55 mph speed is about 2.8 times the pulse duration for the falling weight deflectometer (28-30 msec). The duration of the pulse is related to the loading rate, which may affect the material properties.

3.2 Deflections Under Dual and Wide Base Single Tires

Higher deflections were measured under the wide base single tires under similar test conditions. The plot of peak deflections (Figure 6) at the bottom of asphalt layer (MDD1), shows that the dual tires cause less deflection than the wide base single tires. The zero position for the wide base tire is at the center of the tire, the zero position for the duals is midway between the two tires. The offsets are measured in the lateral (transverse) direction.

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

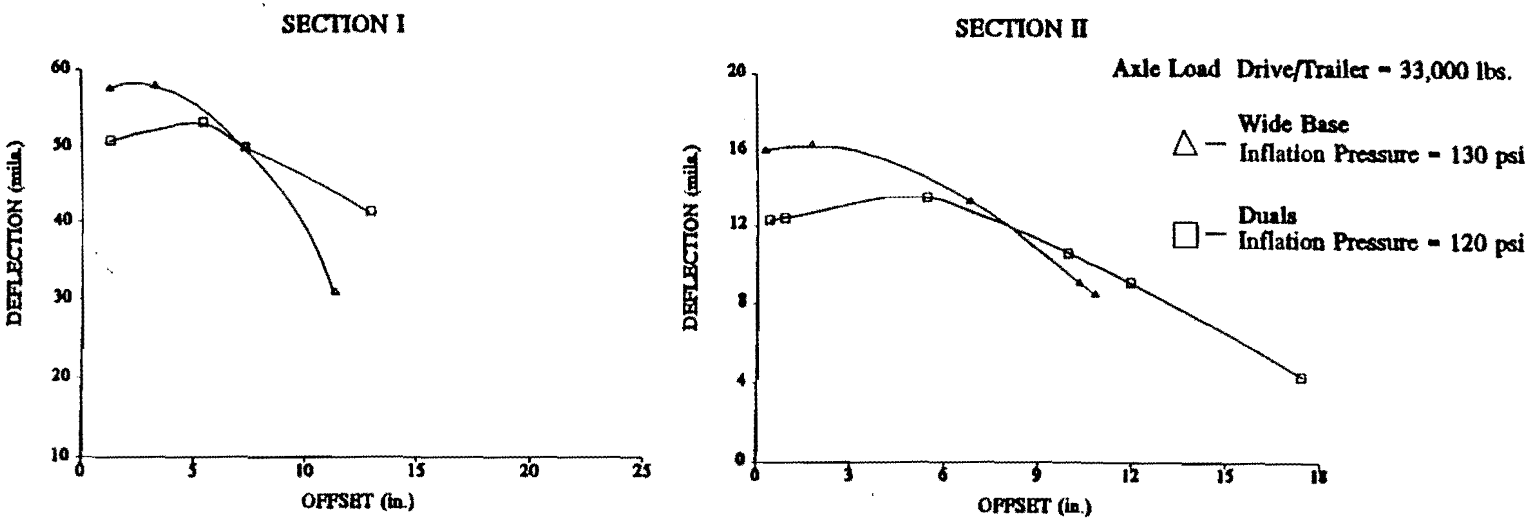

Figure 6. Peak Deflections under Dual and Wide Base Single on MDD#1 (Speed 40-60 mph) at Bottom of Asphalt Layer

(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 report is on induced rutting damage, these results indicate that wide base single tires may also generate more surface cracking at the edge of the tire.

3.3 Vertical Compressive Strain Measurement in the Base Course Layer and Top of the 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 were measured at top of the subgrade for both sections at different speeds and lateral offsets.

Strain in the Base Course Layer

Response curves for strains in the base course material are shown in Figures 7a and 7b. These response curves show dilation or extension in the base course material for both sections. Figure 7a 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 7b. In the thin section, the dilation is 7 times greater than the thick section. Uzan and Scullion (10) have observed similar behavior in the base course layer for thin sections under Falling Weight Deflectometer loadings. Also Figures 7a and 7b show a residual permanent strain of 30 to 50 microstrain after loading. This is attributed to permanent deformation in the base course.

Strain on Top of the Subgrade and Effect of Speed

Average vertical compressive strain at the top of the subgrade layer was computed. Multiple regression was performed to examine the relationship among dependent variable (vertical compressive strain) and independent variables (load, speed and offset). The fitted model was the one minimizing the sum of the squares of the residuals for the fitted line. The regression analysis results are shown in Tables 3a and 3b.

Using the regression models shown in Tables 3a and 3b, vertical compressive strains at top of the subgrade are predicted for both sections under the 33 kip load; these are shown in Tables 4a and 4b. Peak compressive

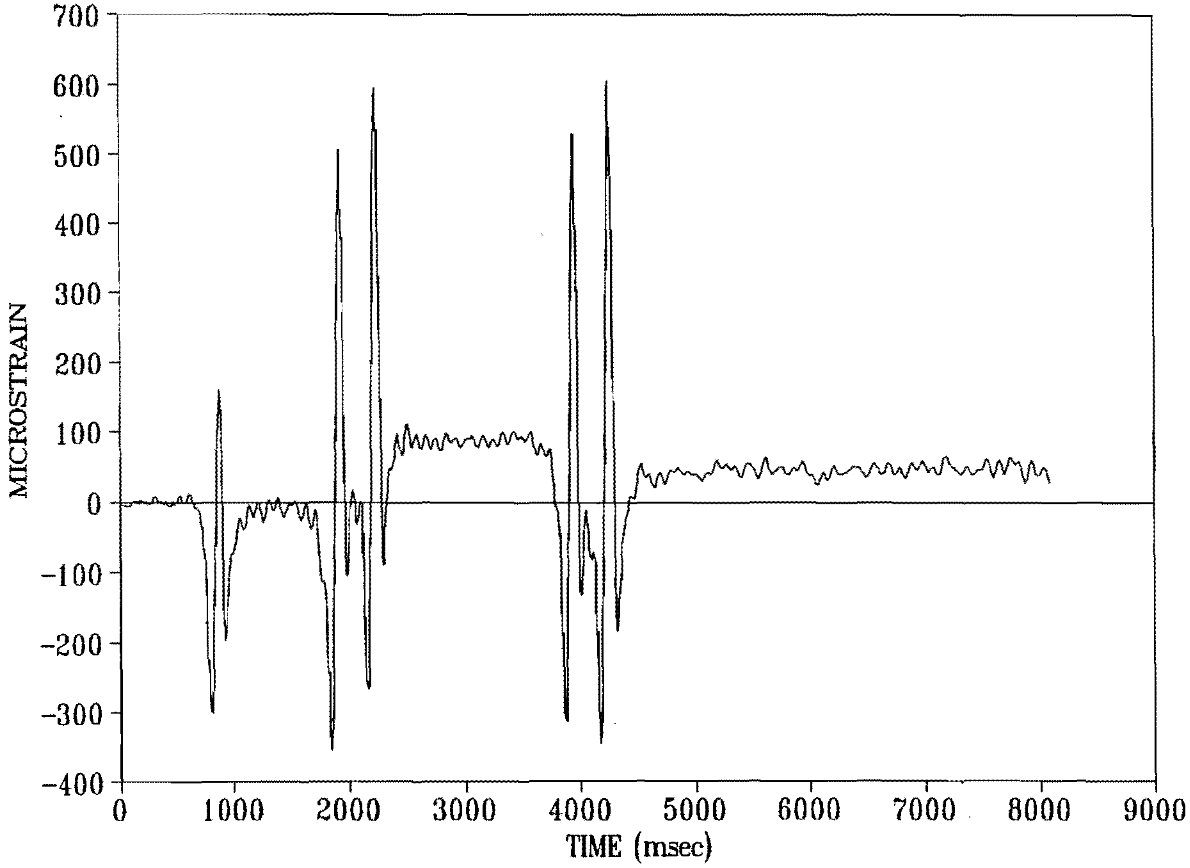

Figure 7a. Vertical Strain in the Granular Base Layer for Section I (Thin) at a Speed of 10 mph

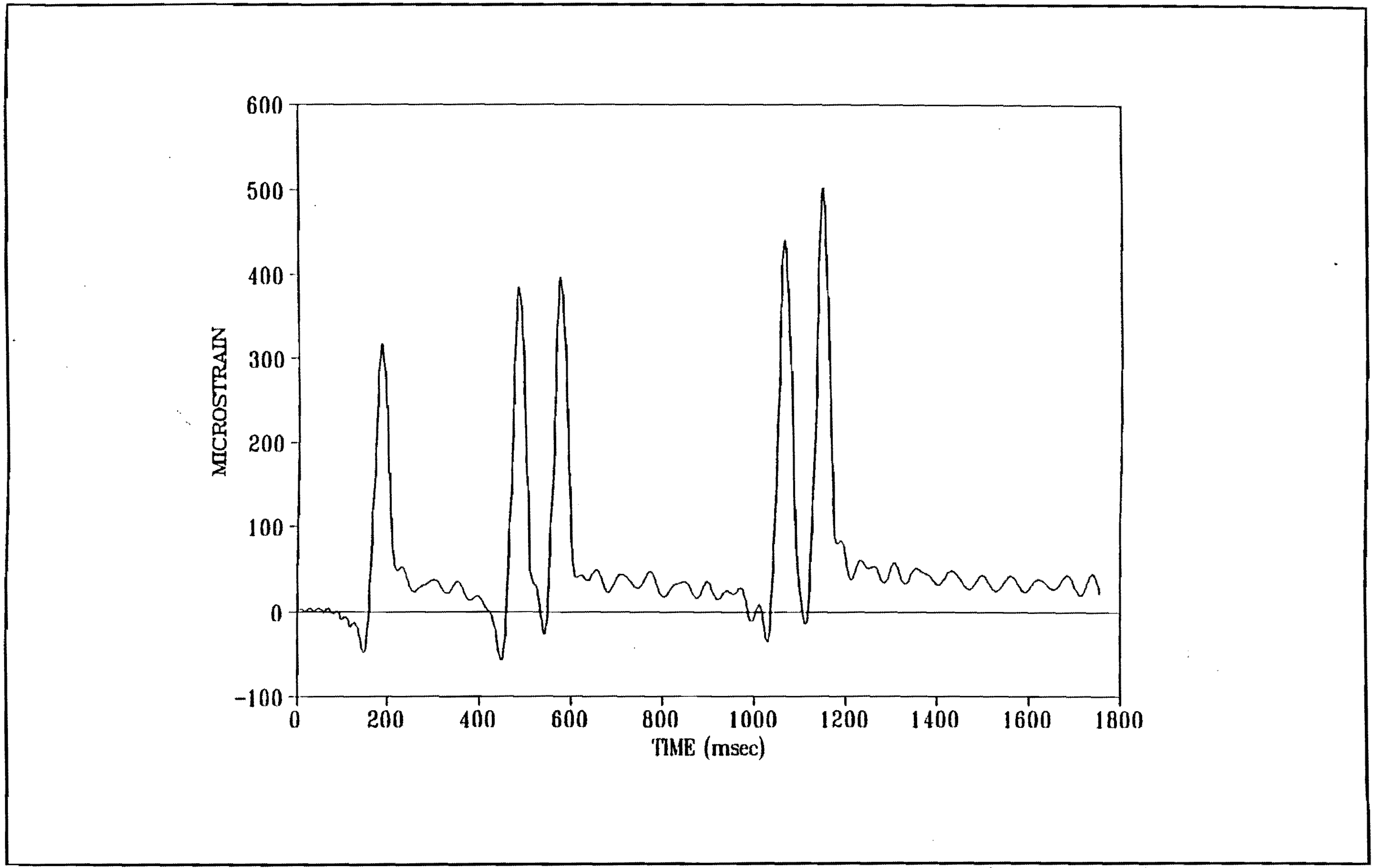

Figure 7b. Vertical Strain in the Granular Base Layer for Section II (Thick) at a Speed of 34 mph

Table 3a. Regression Analysis of Average Vertical Compressive Strain Data Measured at Top of the Subgrade for Section I (Thin)

Model Fitting Results for the Subgrade Strains for Section I (Thin)					
Dual Tires (Tandem Drive Axle)					
Independent Variable	**Coefficient**	**Error**	**t-Value**	**Sig-Level**	
Constant Speed (Offset-4)^2 R-SQ = 0.65	1260.73 -3.86 -6.49	48.38 1.23 1.05	26.05 -3.13 -6.16	0.0000 0.0057 0.0000	
Source	**Sum of SQ**	**DF**	**Mean SQ**	**F Ratio**	**P Value**
Speed (Offset-4)^2	8108 317136	1 1	8108 317136	0.97 37.95	0.3481 0.0000
Wide Base Single Tires (Tandem Trailer Axle)					
Independent Variable	**Coefficient**	**Error**	**t-Value**	**Sig-Level**	
Constant Speed (Offset)^2 R-SQ = 0.91	1663.36 -3.12 -5.63	25.92 0.73 0.61	64.15 -4.27 -9.20	0.0000 0.0009 0.0000	
Source	**Sum of SQ**	**DF**	**Mean SQ**	**F Ratio**	**P Value**
Speed (Offset)^2	200624 226741	1 1	200624 226741	74.92 84.67	0.0000 0.0000

Table 3b. Regression Analysis of Average Vertical Compressive Strain Data Measured at Top of the Subgrade for Section II (Thick)

Model Fitting Results for the Subgrade Strains for Section II (Thick)					
Dual Tires (Tandem Drive Axle)					
Independent Variable	**Coefficient**	**Error**	**t-Value**	**Sig-Level**	
Constant	285.89	5.66	50.51	0.0000	
Speed	-0.52	0.15	-3.32	0.0023	
(Offset-3)^2	-0.73	0.06	-10.63	0.0000	
R-SQ = 0.79					
Source	**Sum of SQ**	**DF**	**Mean SQ**	**F Ratio**	**P Value**
Speed	2703	1	2703	11.06	0.003
(Offset-3)^2	27645	1	27645	113.05	0.0000
Wide Base Single Tires (Tandem Trailer Axle)					
Independent Variable	**Coefficient**	**Error**	**t-Value**	**Sig-Level**	
Constant	332.28	9.37	35.46	0.0000	
Speed	-0.46	0.26	-1.77	0.0876	
(Offset)^2	-0.66	0.13	-4.88	0.0000	
R-SQ = 0.51					
Source	**Sum of SQ**	**DF**	**Mean SQ**	**F Ratio**	**P Value**
Speed	7280	1	7280	10.15	0.0034
(Offset)^2	17141	1	17141	23.91	0.0000

Table 4a. Average Vertical Compressive Strain Calculated at Top of the Subgrade for Section I (Thin) and Allowable ESAL Repetitions

Section	Tire	Axle	Speed (mph)	μStrain	Allowable ESAL Repetitions
I	Dual	Drive	5	1241	14393
I	Dual	Drive	10	1222	15440
I	Dual	Drive	15	1202	16583
I	Dual	Drive	20	1183	17831
I	Dual	Drive	25	1164	19195
I	Dual	Drive	30	1144	20690
I	Dual	Drive	35	1125	22329
I	Dual	Drive	40	1106	24130
I	Dual	Drive	45	1087	26112
I	Dual	Drive	50	1067	28296
I	Dual	Drive	55	1048	30709
I	Super Single	Trailer	5	1647	4043
I	Super Single	Trailer	10	1632	4220
I	Super Single	Trailer	15	1616	4406
I	Super Single	Trailer	20	1600	4603
I	Super Single	Trailer	25	1585	4810
I	Super Single	Trailer	30	1569	5029
I	Super Single	Trailer	35	1553	5260
I	Super Single	Trailer	40	1538	5504
I	Super Single	Trailer	45	1522	5763
I	Super Single	Trailer	50	1506	6036
I	Super Single	Trailer	55	1491	6325

Table 4b. Average Vertical Compressive Strain Calculated at Top of the Subgrade for Section II and Allowable ESAL Repetitions

Section	Tire	Axle	Speed (mph)	μStrain	Allowable ESAL Repetitions
II	Dual	Drive	5	283	10857186
II	Dual	Drive	10	280	11317317
II	Dual	Drive	15	278	11801523
II	Dual	Drive	20	275	12311310
II	Dual	Drive	25	272	12848289
II	Dual	Drive	30	270	13414194
II	Dual	Drive	35	267	14010883
II	Dual	Drive	40	265	14640357
II	Dual	Drive	45	262	15304768
II	Dual	Drive	50	259	16006431
II	Dual	Drive	55	257	16747841
II	Super Single	Trailer	5	329	5478381
II	Super Single	Trailer	10	327	5654298
II	Super Single	Trailer	15	325	5837174
II	Super Single	Trailer	20	323	6027335
II	Super Single	Trailer	25	320	6225129
II	Super Single	Trailer	30	318	6430919
II	Super Single	Trailer	35	316	6645091
II	Super Single	Trailer	40	313	6868051
II	Super Single	Trailer	45	311	7100229
II	Super Single	Trailer	50	309	7342079
II	Super Single	Trailer	55	306	7594081

strains are predicted under the middle of the wide base single tire and at 3 to 4 inches away from the middle of the dual tire assembly. As shown in Figures 8a and 8b the predicted strains decrease with the increase in offset for both of the sections and tire types. However, the strains are found to be maximum under the wheel in case of wide base single tires, but in case of dual tires the peak strains occur at an offset between 3 to 4 inches away from the middle of the dual tire assembly. This is under the inner edge of one of the dual tires. This confirms that the peak deflections and strain under the dual tire assembly do not occur at middle of the assembly but under either of the two tires. It is also observed that the rate of decrease in strain with the increase in offset is greater for the wide base single tires than for the dual tires. It shows that the load spreadability under the dual tires is larger than the wide base single tires.

The effect of speed on vertical strain at top of the subgrade is shown in Figures 9a and 9b. Increasing the speed from 10 to 55 mph decreased the measured strains on top of the subgrade for both sections. For the same loading conditions, with an increase of speed from 5 to 55 mph, the predicted strain at the top of the subgrade at Section I (Thin) decreased by 15.55% for dual tires and by 9.5% for wide base single tires. For similar conditions on Section II (Thick), the predicted strain at top of the subgrade decreased by 9.21% under dual tires and 7% under wide base single tires.

At a speed of 55 mph, the predicted vertical compressive strains under similar loading conditions at the top of the subgrade for Section I are found to be 42.23% 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 19.3% higher than under the dual tires.

Additional tests were conducted with this test set-up. The wide based tires were placed on both the drive and trailer axles in Figure 4. In either position the wide based were found to be more damaging than the dual tires.

3.4 Estimating Reduction in Pavement Life

The Asphalt Institute rutting criteria is widely used in pavement design (11). The criteria predicts the allowable number of ESAL

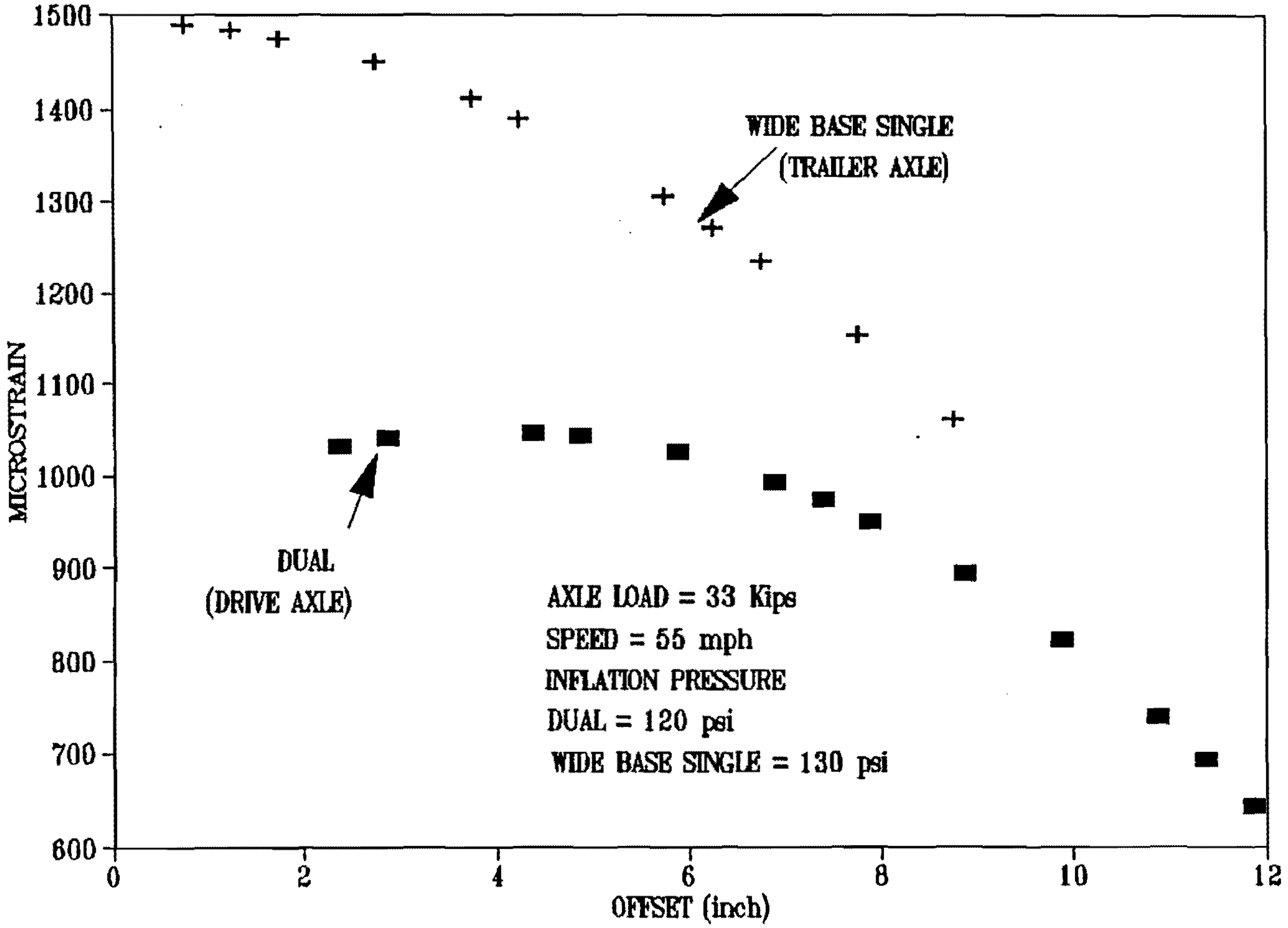

Figure 8a. Average Vertical Compressive Strain at Top of the Subgarde Under Dual and Wide Base Single Tires for Section I (Thin)

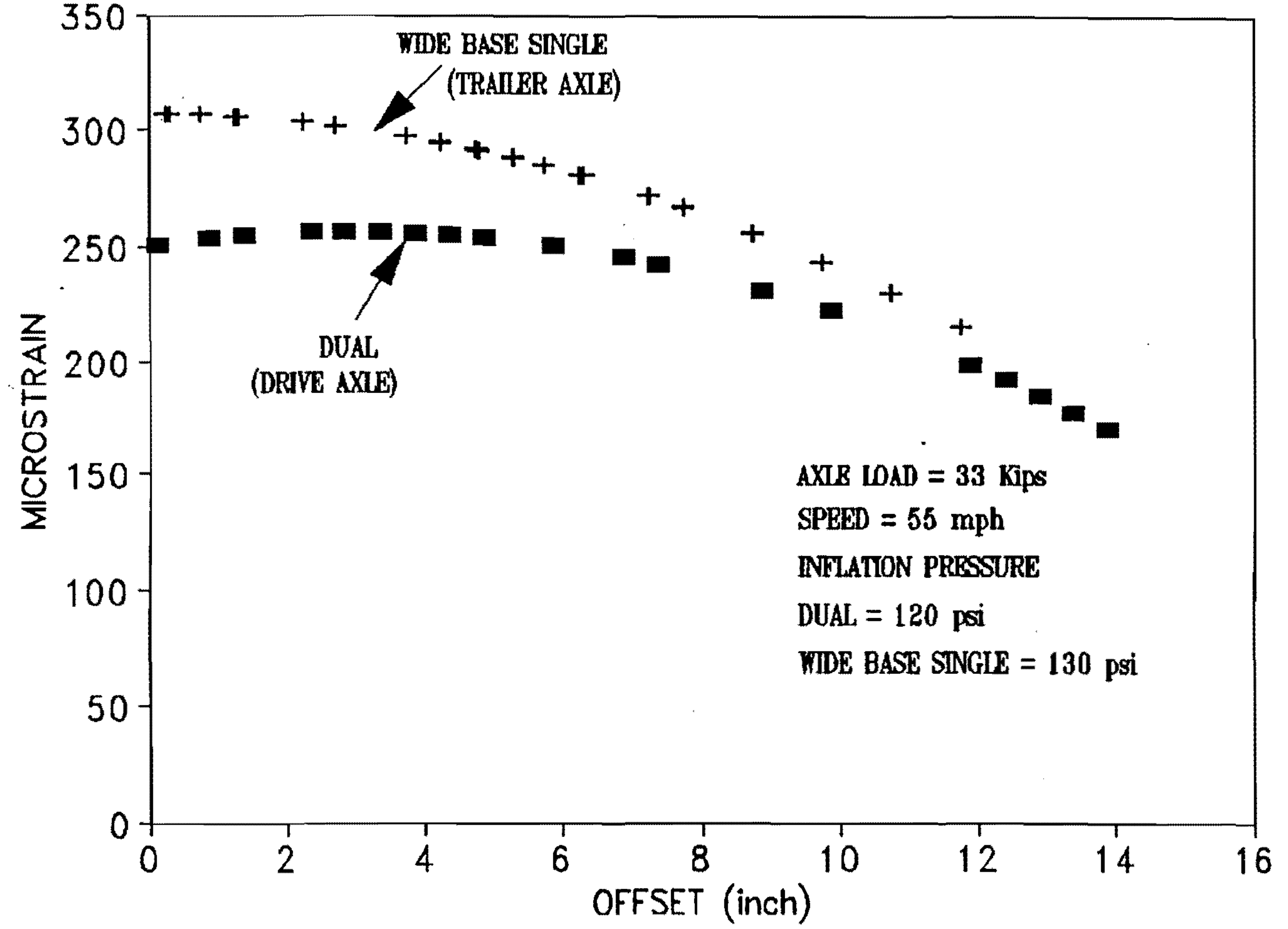

Figure 8b. Average Vertical Compressive Strain at top of the Subgrade Under Dual and Wide Base Single Tires for Section II (Thick)

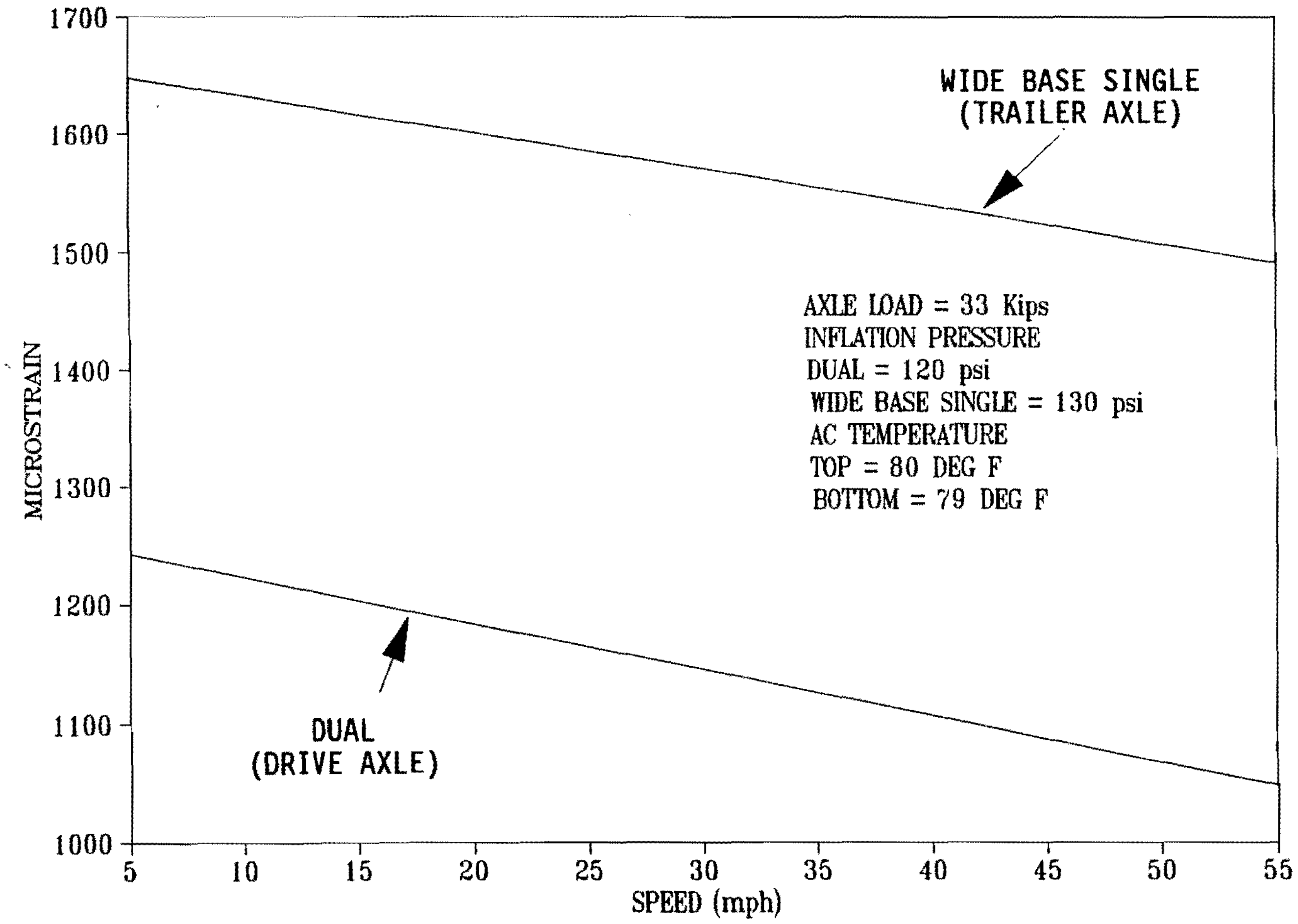

Figure 9a. Effect of Speed on Average Vertical Compressive Strain at Top of the Subgrade Under Dual and Wide Base Single Tires for Section I (Thin)

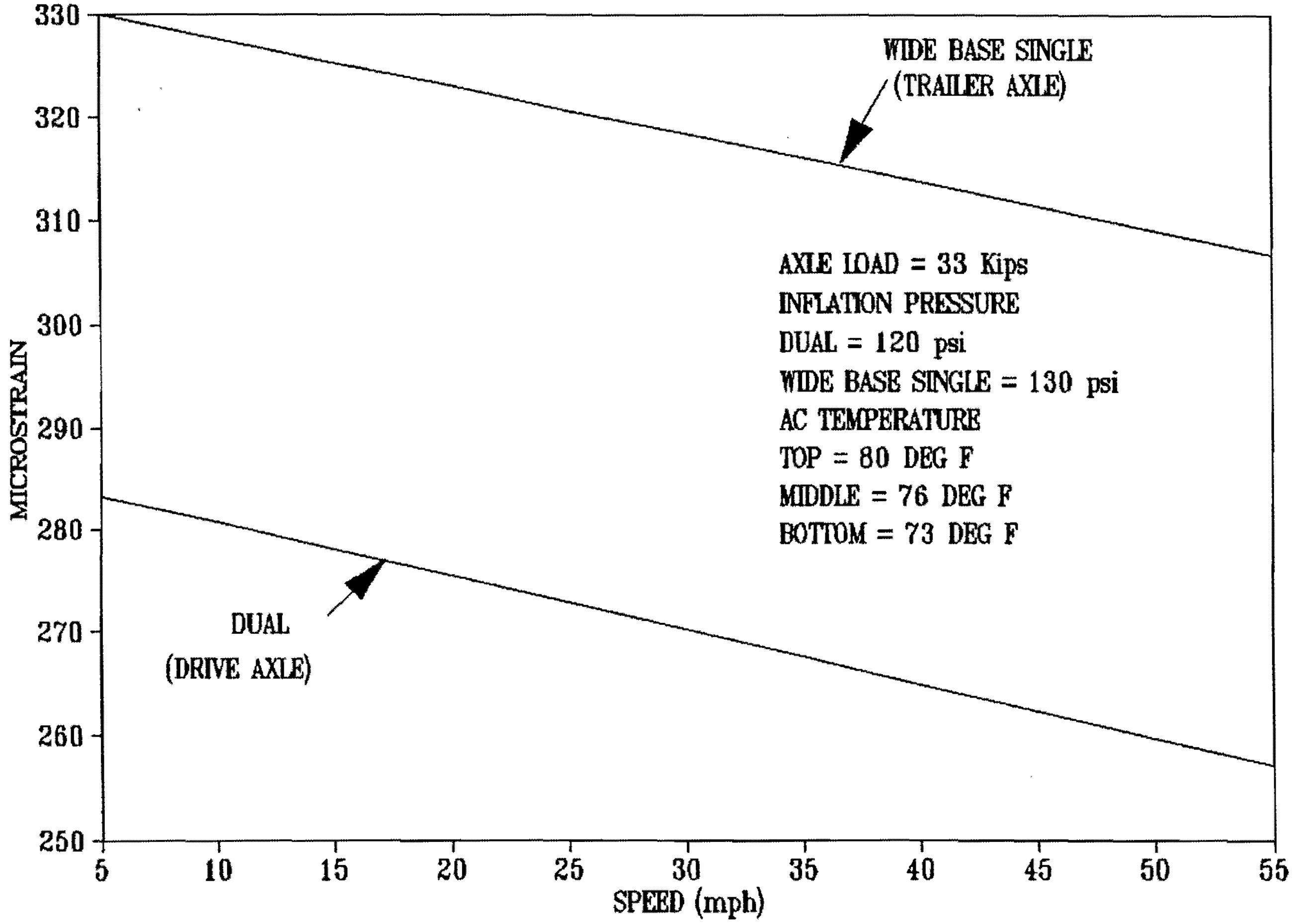

Figure 9b. Effect of Speed on Average Vertical Compressive Strain at Top of the Subgrade Under Dual and Wide Base Single Tires for Section II (Thick)

repetitions for various levels of compressive strain at the surface of the subgrade and are expressed in the form:

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

where

N = Permissible number of ESAL's,
ϵ_v = Subgrade vertical strain,
L = 1.05×10^{-2}, and
m = 0.223.

Typical allowable number of ESAL repetitions at different speeds and strain levels for both sections are tabulated in Tables 4a and 4b. Figures 10a and 10b show that the number of repetitions increase with speed for both tire types. On Section I (Thin), with an increase of speed from 5 to 55 mph, the predicted allowable number of dual and wide base single tire repetitions increased by approximately 113% and 56% respectively. For the same speed increase on Section II (Thick), the number of dual and wide base single tire repetitions increased by approximately 54% and 39% respectively.

At a speed of 55 mph and similar test conditions, the wide base single tires were found to be 4.8 times more damaging than the dual tires on Section I (Thin). Under similar test conditions on Section II (thick), the wide base single tires were found to be 2.2 times more damaging. This indicates that wide base single tires are more damaging to thin bituminous pavements than to thick pavements.

3.5 Prediction of Surface Cracking

The main focus of this report is estimating the rutting 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.

Several authors (12, 13, 14 and 15) have related the Surface Curvature under wheel loads to the tensile strain at the bottom of the asphalt layer. It is these strains which are widely used in mechanistic analysis to predict the onset of fatigue cracking in the asphalt layer. The Surface Curvature Index is defined as the difference in surface deflection when the wheel is directly over the test position to the

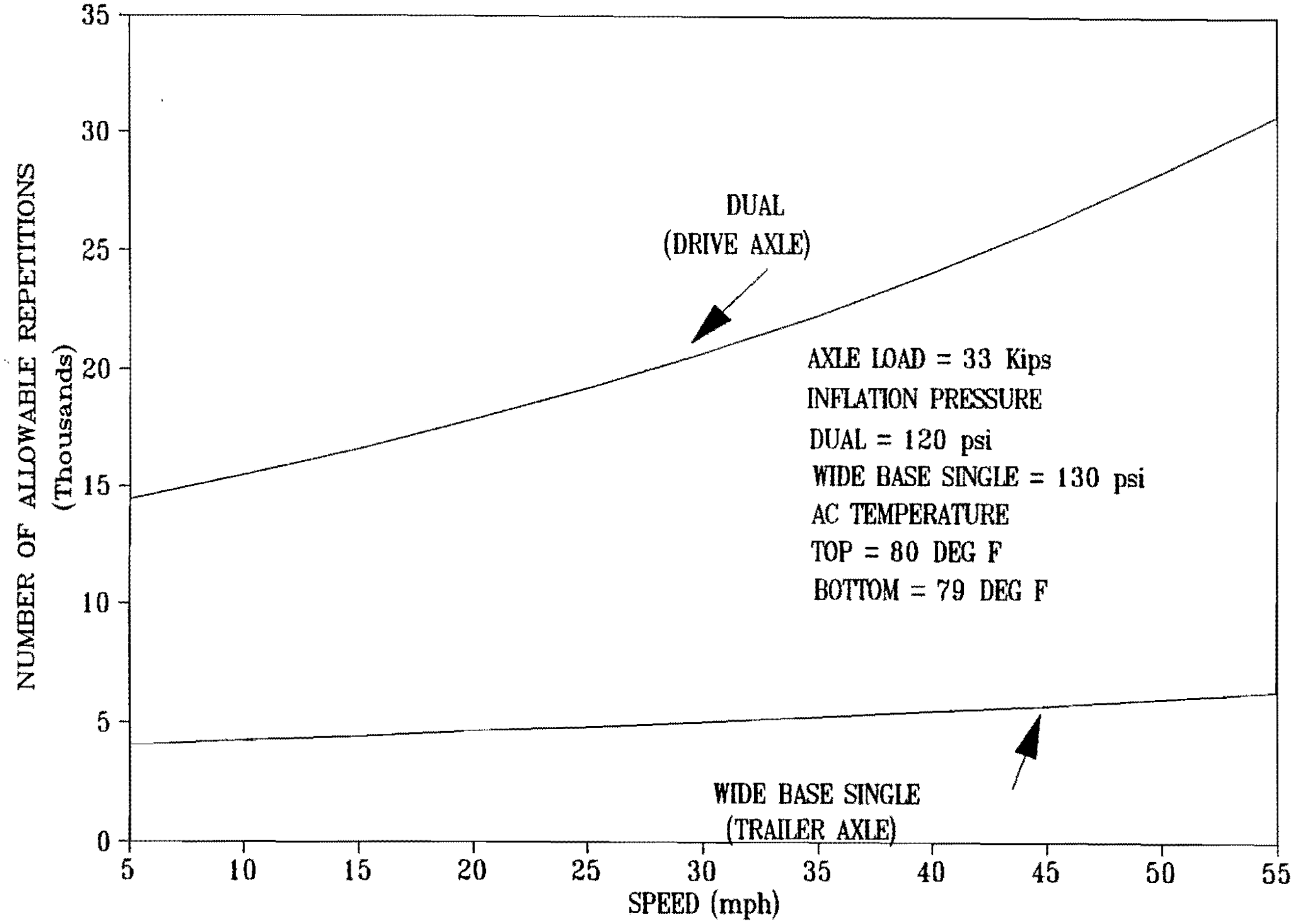

Figure 10a. Effect of Speed on Allowable Number of Passes Under Dual and Wide Base Single Tires for Section I (Thin)

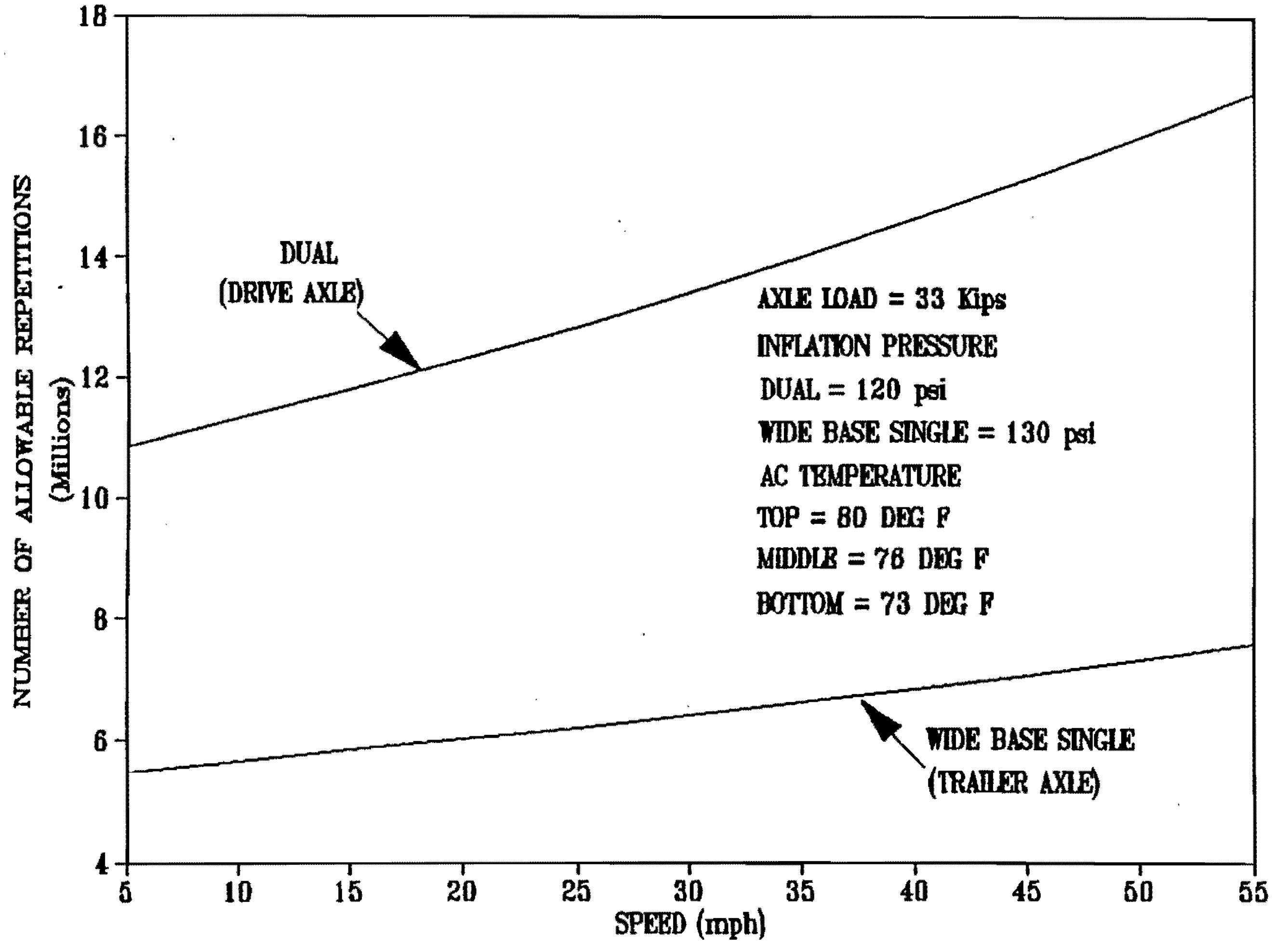

Figure 10b. Effect of Speed on Allowable Number of Passes Under Dual and wide Base Single Tires for Section II (Thick)

deflection measured at some distance before the test position. Molenaar (14) used 0.5 meters as that distance, in the U.S. the distance is usually specified as 12 inches.

The MDD does not directly measure surface curvature as the top sensor is located at the bottom rather than the top of the surfacing. However, the MDD does produce longitudinal deflection profiles as the wheel load approaches and leaves the test location. Figure 11 shows such a deflection profile obtained from the top MDD sensor on the thin section. The SCI defined in Figure 11 is not that measured at the surface rather it is measured at some depth within the pavement. (For the thick section the top MDD is located at the bottom of the asphalt, given that this layer is very stiff compared with the underlying layers the SCI at depth will be similar to that measured at the surface).

To interpret the SCI measured at depth, Akram (16) generated a series of theoretical regression equations for both the thin and thick sections for dual and wide-based tire types relating the SCI at depth to tensile strain. Examples of these equations are shown below:

- Dual tires, thick pavement, low pressure

$$\epsilon_t = -20.36 + 36.73\ SCI \ \ldots\ r^2 = 0.94$$

- Wide base tires, thick pavement, low pressure

$$\epsilon_t = -45.54 + 57.95\ SCI \ \ldots\ r^2 = 0.98$$

In all the field data collected the wide based tires induced higher surface curvature indexes than the standard dual tires (16). As described in (16), multiple passes of the test vehicle were made and the measured SCI was correlated with tire type, tire pressure, axle load, asphalt temperature and offset position. The regression equations developed were used to predict SCI for any combination of loading or temperature, an example is given in Figure 12. The higher SCI values translate to higher induced tensile strains which implies shorter pavement life until fatigue failure.

For predicting pavement performance in fatigue for both the dual and wide base single tires, the cracking model developed by Finn et al. (17) was used. The model, shown below, predicts the number of equivalent single axle loads (ESAL) repetitions resulting in fatigue cracking equal to 10% of the wheelpath:

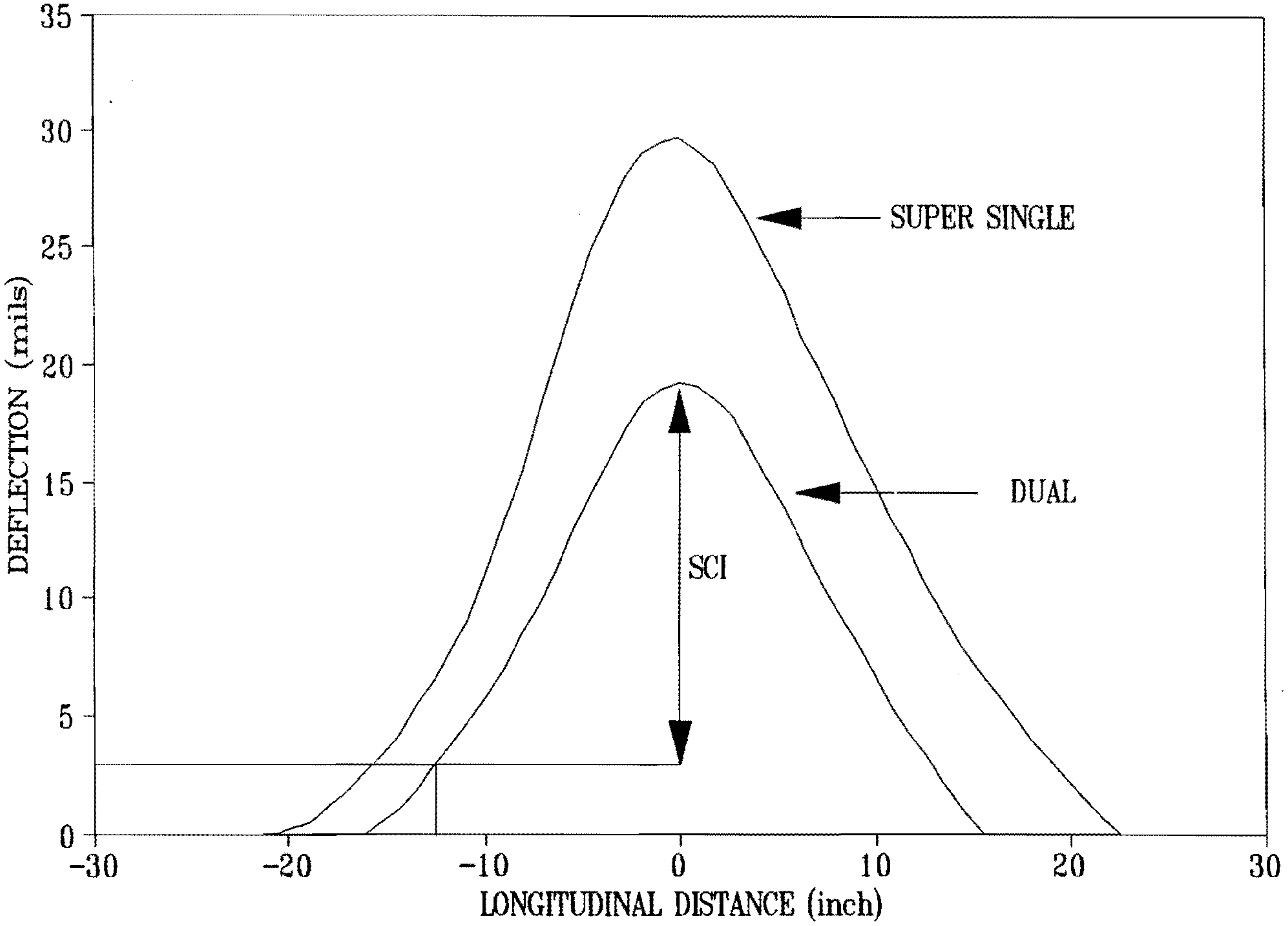

Figure 11. Measured Peak Longitudinal Deflections Profile under Dual and Wide Base Tire on Section I (Thin)

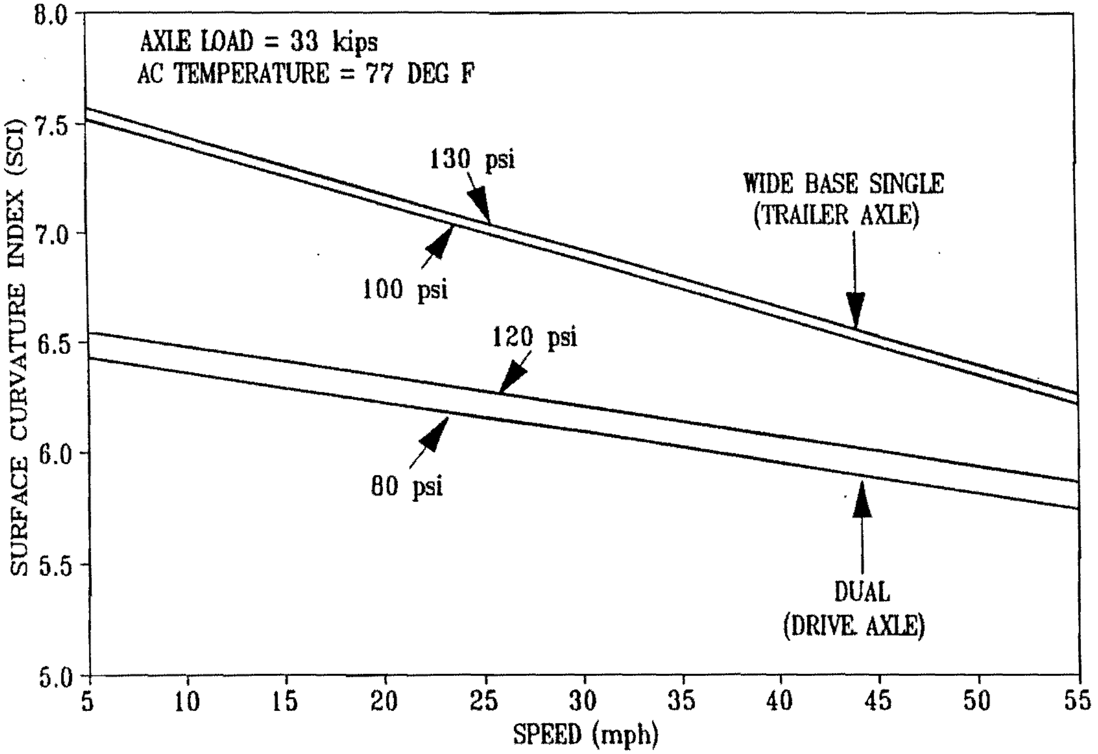

FIG. 12. Effect of Dual (Tandem Drive Axle) and Wide Base Single Tire (Tandem Trailer Axle) Speed on the Predicted SCI for Section II (Thick)

$$\log_{10} N_f = 15.947 - 3.291 \log_{10}\left(\frac{\epsilon_t}{10^{-6}}\right) - 0.854 \log_{10}\left(\frac{S_{mix}}{10^3}\right)$$

where

N_f = The Number of 18 Kip ESAL to predict 10 percent cracking in the wheel path area,

ϵ_t = Repeated tensile strain, and

S_{mix}= Asphaltic concrete stiffness.

The performance evaluation showed longer pavement fatigue life under dual tires than wide base single tires under similar test conditions on both Section I (Thin) and Section II (Thick). At the 33 kips tandem axle loading, 77 degree Fahrenheit asphalt concrete layer temperature, high tire inflation pressure, and 55 mph truck speed the wide base single tires were found to be 2 and 5 times more damaging than dual tires on Section I (Thin) and Section II (Thick) respectively. Complete discussion of the analysis procedure and results is found in (16).

It appears that the wide base tires not only generate more permanent deformation damage, but the implication from this section is that they also produce more cracking damage. In the case of cracking, the wide base tires are predicted to do more relative damage to the thick pavement than the thin.

CHAPTER 4

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 while taking into account the transverse position with respect to the multidepth deflectometer. This report examines the effect of speed on pavement response under dual and wide base single tires for one set of loading and tire pressure conditions. The major conclusions drawn are as follows:

1. The multidepth deflectometer is an excellent tool for measuring vertical strains and deflections in the pavement structure under actual truck loading.
2. Under similar test conditions, wide base single tires produced higher deflections than dual tires.
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 in the subgrade under a single tire at 55 mph speed is about 2.8 times (78 msec) the pulse duration for a falling weight deflectometer (25-28 msec). The duration of the pulse is related to the loading rate, which may affect the material properties. This aspect needs 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 4.8 times more damaging than dual tires on the thin pavement section and 2.2 times more damaging on the thick section for a speed of 55 mph based on rutting criteria using the measured vertical compressive subgrade strains.

The plan for future work includes pavement material characterization under Falling Weight Deflectometer (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.

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