THE RESPONSE OF PAVEMENT TO HEAVY LOADS

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ABSTRACT

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Heavy-haul trailers present a pavement loading condition which does not fall into the normal realm of highway load-related analyses. This paper reports on a case study of a multi-wheeled trailer loaded to 480,000 lbs wherein both pavement surface deflections were measured and associated computer analyses were performed for a pavement structure located in Auburn, Washington. The results show that the trailer applied essentially one large deflection basin. The reported analyses suggest that "normal" truck traffic can exceed the damage done to the pavement by a heavy-haul trailer so configured.

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INTRODUCTION

Damage to pavement structures is attributed to two broad but primary causes: traffic loads and the environment (and the interaction of the two). For this paper, only the traffic related effects of an unusual loading condition is considered. Specifically, a case study is presented of the pavement response (both measured and calculated) of a heavy-haul trailer on a pavement structure within the city limits of Auburn, Washington (about 20 miles south of Seattle). The heavy-haul trailer that was evaluated was a configuration proposed by Shaughnessy and Co. (the trailer owner) for potential movement of Space Shuttle solid rocket boosters within the state of Utah.

Pavement damaged caused by wheel loads is related to pavement response which in turn in influenced by factors as load magnitude, rate and configuration. Generally, the higher the pavement response (such as pavement surface deflection), the greater the potential damage. Typical critical response locations are illustrated in Figure 1. The surface deflections are often used in pavement evaluation and overlay designs, the horizontal tensile strain is used to predict fatigue cracking in asphalt concrete surfaced pavements and the vertical compressive strain at the top of the subgrade is used to predict rutting primarily due to the subgrade soils.

Heavy-haul trailers present a condition which does not fall into the normal realm of highway load-related analyses. The load is distributed on a trailer which has many closely-spaced wheels and axles, although the total load magnitude is high, it does not necessarily create numerous loading and unloading cycles as axles on normal highway trucks [1, 2, 3]. This is illustrated in Figure 2 in which a hypothetical pavement response for a typical five axle truck is compared with that from a heavy-haul trailer. Thus, while one load cycle of the trailer could cause more damage than one truck load cycle, the number of axle load repetitions per truck is greater than the one repetition of the trailer. Additionally, it would

be expected that the number of trucks using a road would be orders of magnitude greater than the number of heavy-haul trailers.

On April 25, 1986, Shaughnessy and Co. of the Crowley Maritime Corporation conducted a full-scale load test of a heavy-haul trailer on 30th Street in Auburn, Washington in the presence of representatives from the state of Utah (state DOT and county officials) and the Hercules Corporation. Surface deflection measurements were taken on the pavement in vicinity of the trailer. These measurements and the subsequent analysis is the subject of this paper.

The objective of this study was to estimate the effects of the heavy-haul trailer on an actual pavement section and to compare the damage to that caused by typical 20,000 lb. legal single axle load.

This study was conducted by Joe Mahoney, David Newcomb and Sang Won Lee of the Department of Civil Engineering, University of Washington. The researchers did not represent any client and the reported analysis was prepared in an attempt to better understand pavement response to unusual loading configurations.

ANALYSIS

General

The information which follows describes specific data and analyses performed for 30th Street in Auburn, Washington which support the subsequent findings.

1. Pavement surface deflections caused by the HHT were measured using the Benkelman Beam.
2. The properties of a pavement test section were estimated by matching theoretically calculated deflections to measured ones using a pavement analysis computer program, ELSYM5.

3. Tensile strains (ε_t) were calculated at the bottom of the asphalt concrete (AC) and vertical strains (ε_{vs}) at the top of the subgrade underneath the heavy-haul trailer (HHT) and a 20,000 lb. single axle load using ELSYM5.
4. The critical loading points were located.
5. Failure criteria for fatigue [4] and rutting [5] were applied using established methods.
6. The expected damage caused by HHT was compared with that expected from a 20,000 lb. single axle load.

Specific Data

The following data relate to the reported analysis and subsequent findings:

1. Test date: April 25, 1986
2. Air temperature during deflection measurements: 45° F
3. Test section: 30th Street, Auburn, WA.
4. Deflection measuring equipment: two Benkelman Beams (used in parallel to insure that the deflection basin did not extend beyond the Benkelman Beam closest to the HHT (or estimate how it influenced the Benkelman Beam)).
5. The basic pavement section is shown as Figure 3.
6. HHT configuration:
   (a) Total load = 480,000 lbs. (240 tons)
   (b) 14 axles x 8 tires/axle = 112 tires (total)
   (c) Tires: 8.25 x R15 Michelin radials
   (d) Load/tire = 4,330 lbs. each
   (e) Inflation pressure = 140 psi
   (f) Trailer configuration and dimensions: refer to Figure 4.

Calculations

The ELSYM5 layered elastic analysis computer program was used to estimate both pavement deflection and AC and subgrade strain responses. As will be shown, the

comparisons between the measured surface deflections (Benkelman Beam) and estimated deflections (ELSYM5) are fundamental to this study.

In using layered elastic analysis, certain assumptions are needed or were made. These include:

1. pavement-tire contact areas are circular,
2. load is equally distributed to all tires, and
3. the properties (modulus of elasticity and Poissons' ratio) of the asphalt treated base (ATB) are the same as those of the asphalt concrete surface layer.

The load configurations and calculation locations for the HHT are shown in Figure 5. Further, Points A1 through A7 are the same locations used for Benkelman Beam measurements. The measurements were made as the HHT was towed by the instrument at creep speed (less than 5 mph).

To use ELSYM5 to develop deflection estimates to compare against those actually measured, a trial and error process was used with ELSYM5 to match measured and estimated deflections in order to estimate the pavement layer resilient moduli (Poisson's ratios were assumed). The results of this process are shown below.

Pavement Layer	Resilient Modulus	Poisson's Ratio
• AC & ATB	1,500,000*	0.35
• Gravel Base	30,000	0.40
• Subgrade	11,000	0.45

*Recall that the air temperature was 45° F during field testing (with rain, of course).

Following the above process, the estimated (calculated) deflections were determined and compared with the measured deflections as shown in Figure 6 for Points A1 through A7. As can be seen, the agreement between the calculated and measured pavement surface deflections is good. More importantly, the data in Figure 6 show evidence of the size of

the deflection basin created by the HHT. There is little pavement deflection change at the "interior" edge tires (Points A4 and A6) and midway between the tires (Points A3, A5 and A7). This suggests that other critical pavement response locations should be examined as well.

For the points shown in Figure 5, the estimated pavement surface deflections, tensile strains at the bottom of the asphalt concrete and vertical compression strains at the top of the subgrade were calculated by use of the ELSYM5 program. This was done both for the HHT and a 20,000 lb. single axle with dual tires. The results are shown in Table 1.

The "critical" pavement response values shown in Table 1(c) show that the pavement deflection for the HHT when compared to the single truck axle is 2.7 times larger (0.0418 in. vs. 0.0156 in.) but the tensile and vertical strains are only 10 and 20 percent larger, respectively.

The pavement deflections caused by the HHT made a large and relatively smooth basin; however, the estimated strains show a larger fluctuation (as plotted in Figure 7). For estimating the potential pavement damage (fatigue cracking and rutting), the strain fluctuations can be analyzed in at least three ways:

(a) Method A: one repetition of the whole HHT with the maximum strain.

(b) Method B: two repetitions of the maximum strain and 12 repetitions of the amplitude of strain fluctuation between axles.

(c) Method C: 14 repetitions of the maximum strain.

Method "A" is more likely to represent reality and Method "C" is probably too conservative.

These three approaches were used along with the failure criteria from References 4 and 5. A summary of the results is shown in Table 2. These results show that only use of the most conservative approach (Method C) results in the HHT causing more damage than a legally loaded five axle truck (with five separate single axles).

FINDINGS

The pavement measurements made on 30th Street in Auburn, Washington and associated computer analyses can be summarized as follows:

1. The measured pavement deflections (made with the Benkelman Beam) along the edge of the HHT show that essentially one large deflection basin is formed. This reduces the potentially damaging effects of the HHT as opposed to individual truck axles which each apply one complete deflection basin for each individual axle.

2. The estimated maximum pavement surface deflection is about 2.7 times larger for the HHT as compared to the 20,000 lb. single truck axle with dual tires; however, the maximum tensile strain at the bottom of asphalt concrete layers is only 10 percent more than the 20,000 lb. single axle load and the maximum vertical compressive strain at top of the subgrade is only 20 percent more than the 20,000 lb. axle.

3. An estimate of the maximum number of load repetitions required to cause fatigue cracking and rutting in the 30th Street pavement structure was made for both the HHT and the 20,000 lb. single axle. Essentially both loading configurations result in a large number of load repetitions to failure; however, there is some uncertainty as to how to evaluate the loadings applied by the HHT. If one assumes that there are five fully loaded single axles (20,000 lb. at 100 psi tire pressure) on a "typical" highway truck, then one pass of the "typical" highway truck can range from about four times more damaging in fatigue to about equity with the HHT. Similarly, one pass of the "typical" truck can range from about twice as damaging in rutting to about equity with the HHT. Even though there are inherent

uncertainties associated with the stated results, the HHT appears to be less damaging to 30th Street than a "conventional" five axle legally loaded truck.

4. The analysis described was based on measurements and the structural section represented by 30th Street in Auburn, Washington. Different pavement structures will react differently to the described loads and the trends may be reversed. Overall, the analysis performed shows that normal truck traffic can exceed the damage done to a pavement by heavy-haul trailer such as the HHT described in this paper.

REFERENCES

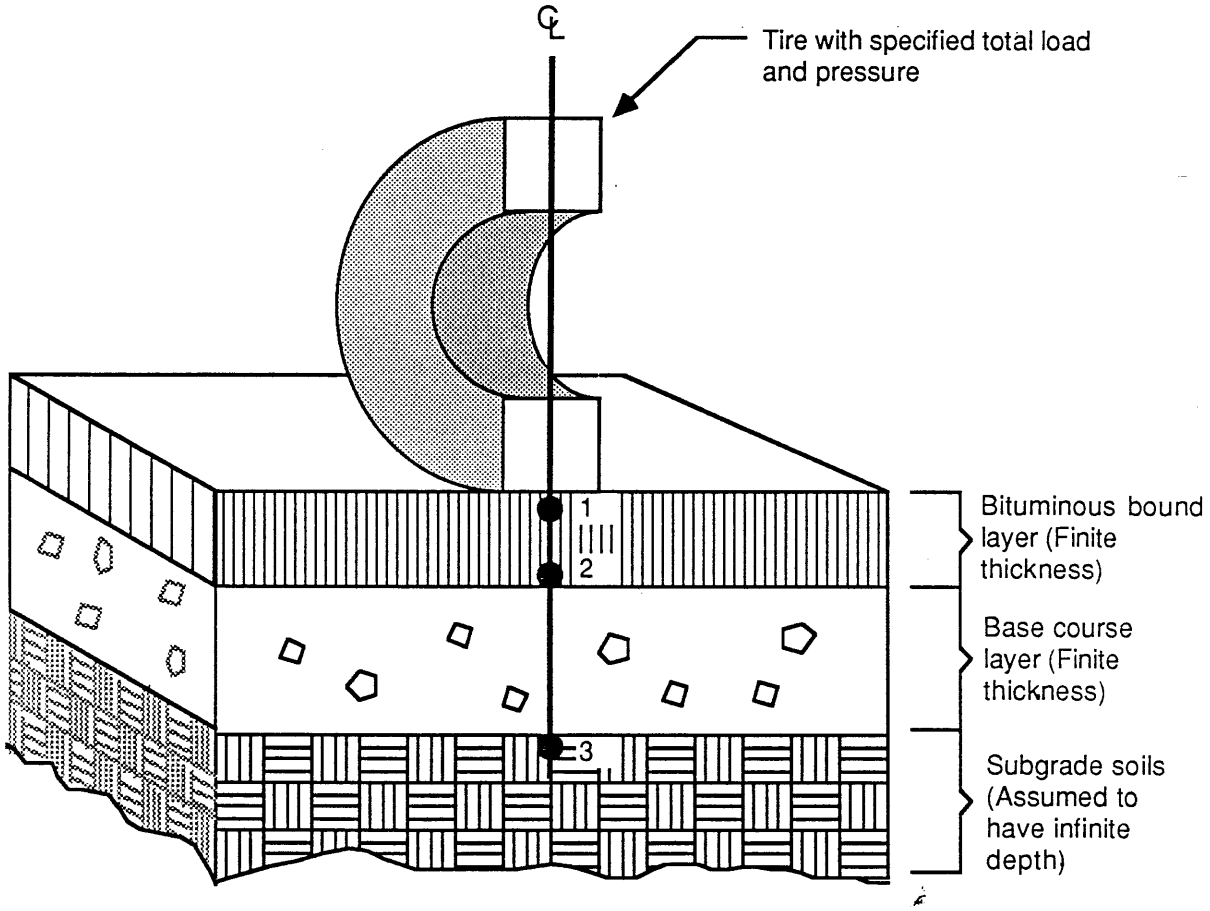
1. Mahoney, J.P., Lee, S.W. and Newcomb, D.E., "A Study of Heavy-Haul Trailer Effects on A Pavement Structure," unpublished paper, Department of Civil Engineering, University of Washington, Seattle, WA, June 1986.

2. Nokes, W.A., "Measuring Pavement Deflections Near A Super-Heavy Overload," paper to be published in the *Transportation Research Record*, Transportation Research Board, Washington, D.C., presented at the TRB Annual Meeting January 1988.

3. Terrel, R.L., and Mahoney, J.P., "Pavement Analysis for Heavy Hauls in Washington State," *Transportation Research Record* No. 949, Transportation Research Board, Washington, D.C., 1983.

4. Finn, F., Saraf, C., Kulkarni, R., Nair, K., Smith, W. and Abdullah, A., "The Use of Distress Prediction Subsystems for the Design of Pavement Structures," Proceedings, Fourth International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1977.

5. Shook, et. al., "Thickness Design of Asphalt Pavements — The Asphalt Institute Method," Proceedings, Fifth International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1982.



1. Pavement surface deflection
2. Horizontal tensile strain at bottom of bituminous layer
3. Vertical compressive strain at top of subgrade

Figure 1. Pavement Response Locations Used in Evaluating Load Effects

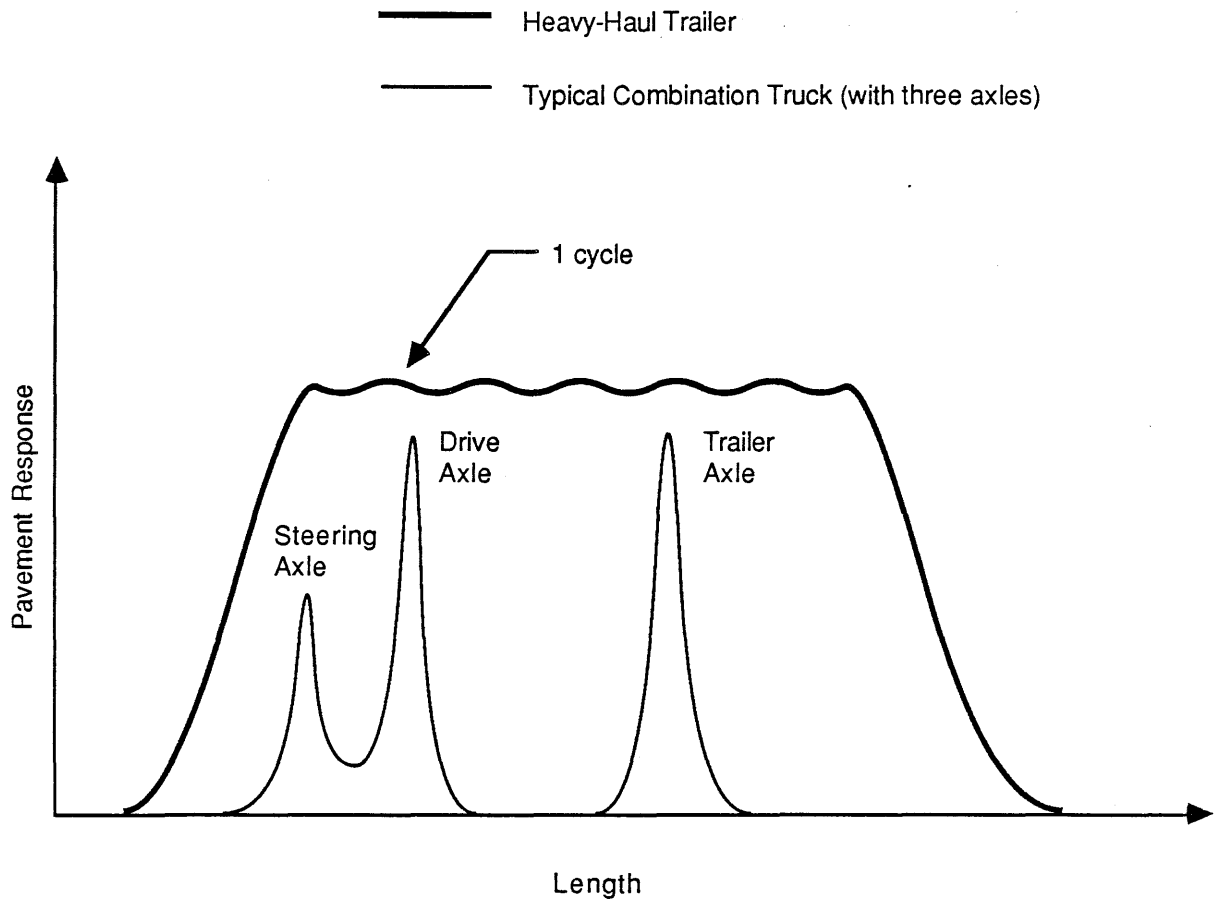


Figure 2. Idealized Pavement Response for Heavy-Haul Trailer and a Typical Truck

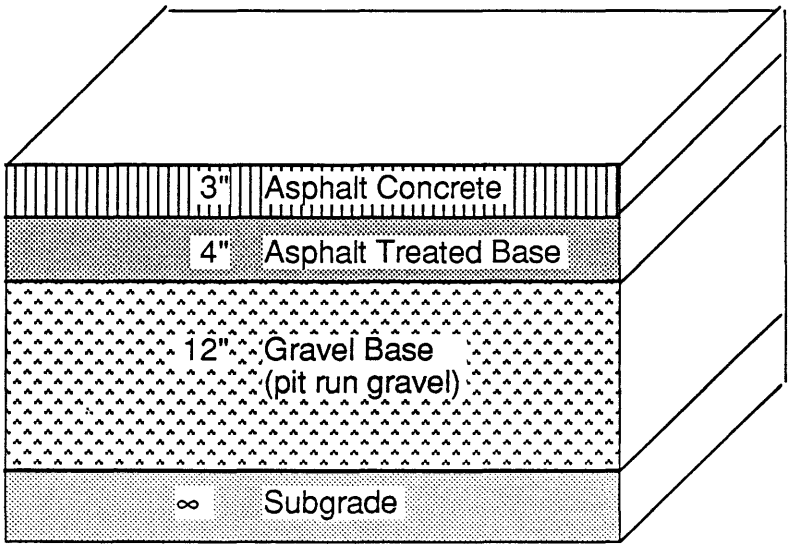


Figure 3. Pavement Section (30th Street) Used in the Analysis

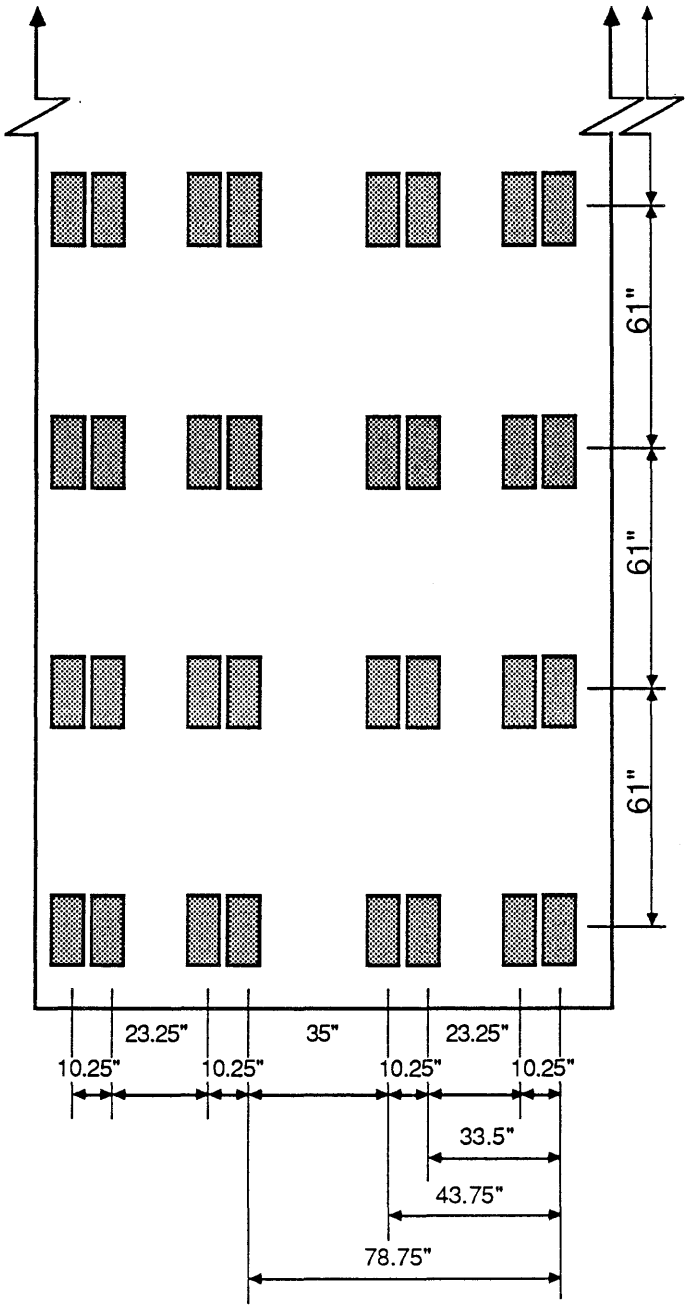
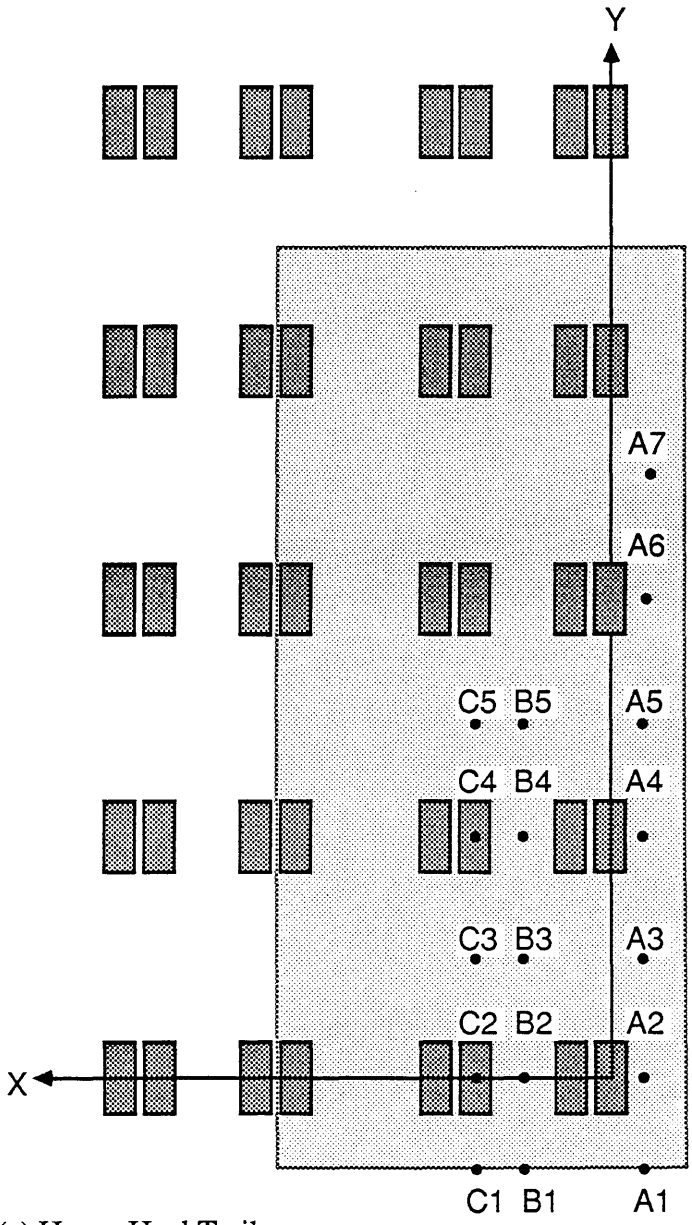
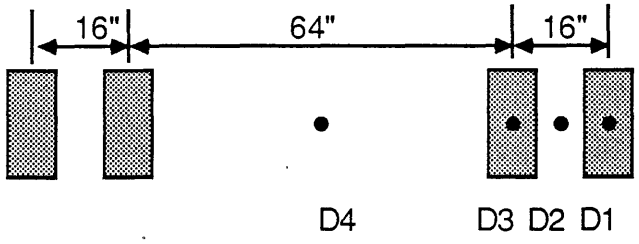


Figure 4. Configuration and Dimensions of Heavy-Haul Trailer



Coordinates of the Points	
Points	x, y (inches)
A1	-6.0, -30.5
A2	-6.0, -0.
A3	-6.0, 30.5
A4	-6.0, 61.0
A5	-6.0, 91.5
A6	-6.0, 122.0
A7	-6.0, 152.5
B1	21.9, -30.5
B2	21.9, 0
B3	21.9, 30.5
B4	21.9, 61.0
B5	21.9, 91.5
C1	33.5, -30.5
C2	33.5, 0
C3	33.5, 30.5
C4	33.5, 61.0
C5	33.5, 91.5

(a) Heavy Haul Trailer



Coordinates of the Points	
Points	x, y
D1	0.0, 0.0
D2	8.0, 0.0
D3	16.0, 0.0
D4	48.0, 0.0

(b) "Standard" 20,000 lb. Truck Axle
(Inflation Pressure = 100 psi)

Figure 5. Analysis Locations for ELSYM5

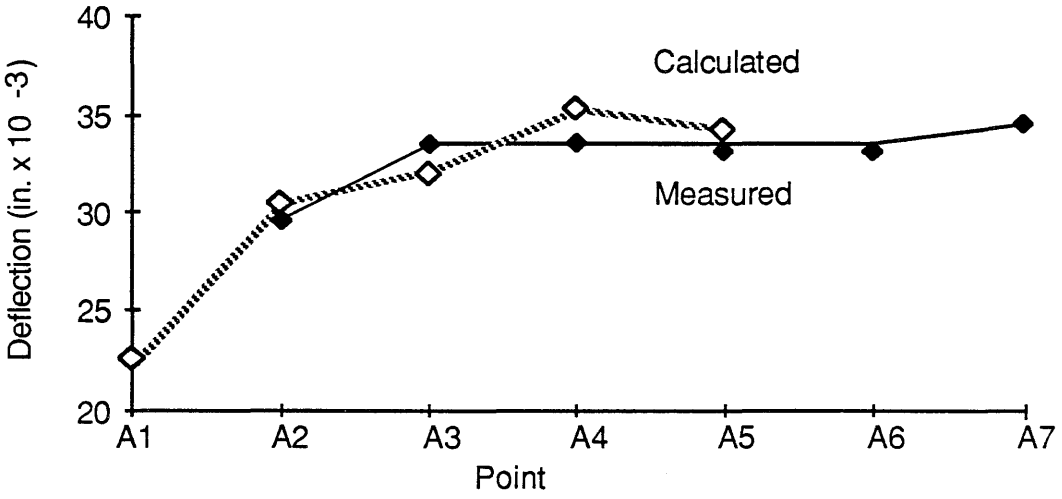


Figure 6. Comparison of Calculated and Measured Pavement Surface Deflections

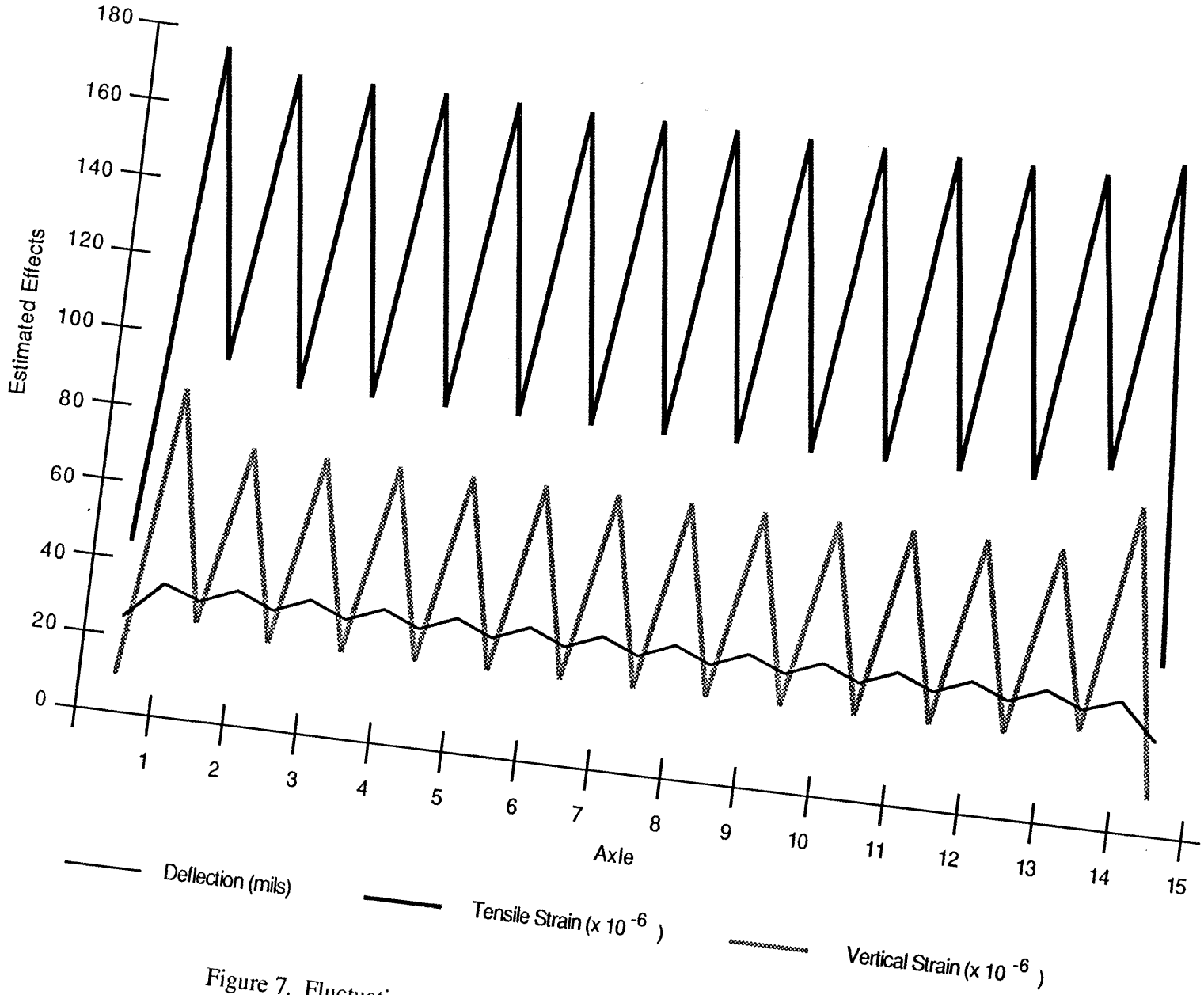


Figure 7. Fluctuation of Pavement Responses for the Heavy-Haul Trailer

Table 1. Determination of "Critical" Pavement Response Locations

(a) Heavy-haul trailer

Points	Deflection (10^{-3} in.)	Tensile Strain (10^{-6} in/in)	Vertical Strain (10^{-6} in/in)
A1	22.5	7.3	27.1
A2	30.2	52.4	115.8
A3	31.9	13.5	62.0
A4	35.1	46.2	114.5
A5	34.0	14.2	58.3
B1	23.2	14.8	45.5
B2	34.7	59.8	169.0
B3	36.8	26.0	98.7
B4	40.7	50.8	169.8
B5	40.5	27.2	94.7
C1	24.7	13.5	42.4
C2	36.1	83.9 *	172.2
C3	36.9	25.8	97.0
C4	41.8 *	74.9	172.9 *
C5	39.2	27.1	93.0

* The largest value

(b) 20,000 lb Single Axle (TKA)

D1	14.9	75.3	127.8
D2	5.1	73.2	144.6 *
D3	15.6 *	76.5 *	129.3
D4	13.0	22.6	48.3

* The largest value

(c) Comparison of "critical" values

Vehicle Type	Deflection (10^{-3} in.)	Tensile Strain (10^{-6} in/in)	Vertical Strain (10^{-6} in/in)
HHT	41.8	83.9	172.9
TKA	15.6	76.5	144.6
Ratio (HHT/TKA)	2.7	1.1	1.2

Table 2. Pavement Damage Summary

(a) Results

Load	Method	N_f Fatigue	N_f Rutting	N_f Controlling	Damage Ratio $\frac{N_f TKA}{N_f HHT}$
HHT	A	8.0×10^6	9.9×10^7	8.0×10^6	1.35
	B	2.1×10^6	4.2×10^7	2.1×10^6	5.14
	C	0.6×10^6	0.7×10^7	0.6×10^6	18.00
TKA	D	10.8×10^6	22.1×10^7	10.8×10^6	---

(b) Comparison with a typical truck with five 20,000 lb single axles

Method	Damage Ratio HHT/Truck
A	3.7
B	1.0
C	0.3