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A THEORY FOR EVALUATING THE DESTRUCTIVE TENDENCY OF HEAVY AXLE LOADS ON A CONCRETE PAVEMENT

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A THEORY FOR EVALUATING THE DESTRUCTIVE TENDENCY OF HEAVY AXLE LOADS ON A CONCRETE PAVEMENT

This study has as its objective the development of a rational mathematical theory for determining the destructive tendency of various types of commercial trucks on a concrete pavement. It is a part of the overall laboratory program of research on concrete pavement design. The theory which is presented in this report is based on the time-deflection pattern at a specific point on a concrete pavement which results from the passage of the successive axles of a given truck. In order to implement this study and make the results of the application of this theory quantitative it was necessary to obtain the following factual information:

1. The pavement deflection at a given point as an axle load approached, passed over, and receded from the given point.
2. The overlapping effect of closely spaced axles on pavement deflection.
3. The characteristics of single and tandem axles on pavement deflection.

Test Site

The site selected to study the effect of various commercial vehicles on pavement deflection was on US-27 just east of the Alma, Michigan city limits and across from the Office Building of the Leonard Refinery. In the summer of 1951 a concrete widening project was completed on this section. This widening which had an 8-inch thickness was constructed without a subbase. An analysis of the soil conditions at the test site is tabulated in Table 1. Pavement deflections were obtained on the east bound widening lane, as shown in Figures 1 and 2.

Test Vehicles

A permanent record was obtained of the deflection occuring at the eight test points during the passage of twenty-six commercial trucks. Some data on the type of trucks which took part in this test program are tabulated as follows:

Truck Type	Number Tested	Total Load (kips)		Distance Between Extreme Axles (Feet)	
		Min.	Max.	Min.	Max.
2S2	9	48	64	25.1	35.8
3S2	9	55	92	31.9	43.0
2S1-2	7	70	87	43.6	52.2
2S2-2	1	102		49.7	

TABLE 1

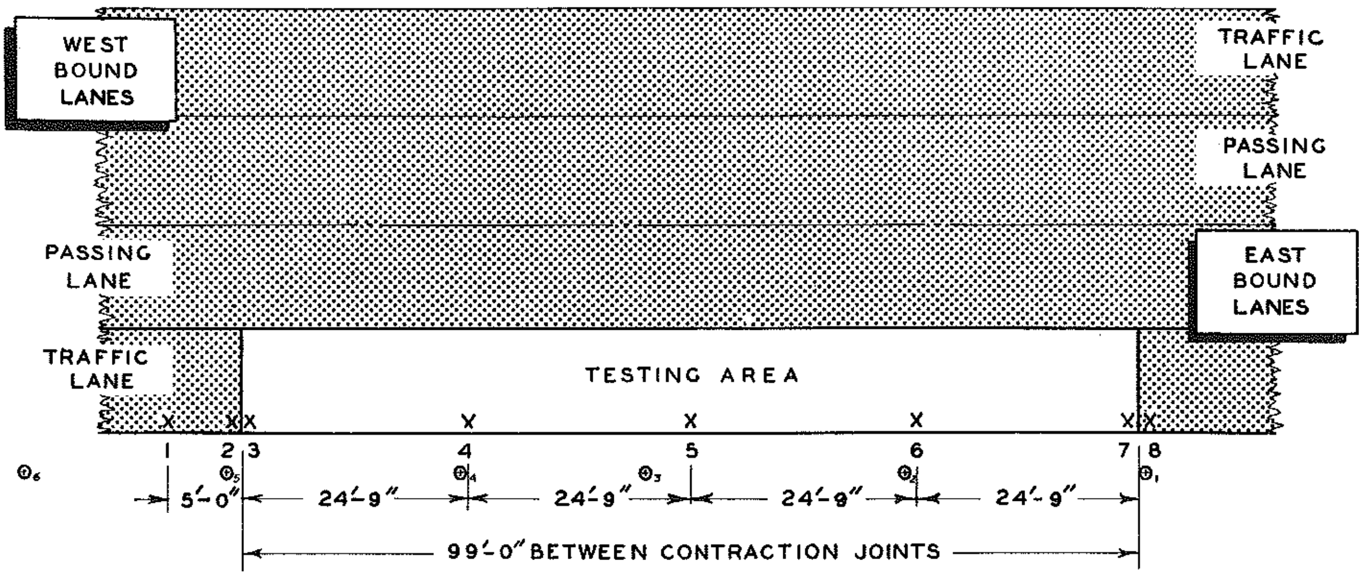
SOIL DATA AT TEST SITE

		Test Hole 1	Test Hole 2	Test Hole 3	Test Hole 4	Test Hole 5	Test Hole 6
	Sample of:	Clay (Sandy Loam)	Clay (Sandy Loam)	Clay (Sandy Loam)	Clay (Sandy Loam)	Clay (Sandy Loam)	Clay (Sandy Loam)
	Laboratory No.:	52 S - 717	52 S - 718	52 S - 719	52 S-720	52 S - 721	52 S - 722
	Date Sampled:	Sept. 3, 1952	Sept. 3, 1952	Sept. 3, 1952	Sept. 3, 1952	Sept. 3, 1952	Sept. 3, 1952
	Sampled from (depth)	12" - 24"	12" - 24"	24" - 36"	12" - 24"	24" - 36"	24" - 42"
Gravel	% Passing 3/4"	100	100	100	100	100	100
	" " 1/2"	100	100	100	100	100	100
	" " 3/8"	99	99	99	100	100	100
	" " No. 4	98	98	99	99	100	100
	" " No. 10	95	96	95	96	100	100
Coarse Sand	" " No. 18	92	94	93	94	99	95
	" " No. 20	91	94	93	94	99	95
	" " No. 35	87	91	90	88	95	91
	" " No. 40	86	88	88	86	94	90
Fine Sand	" " No. 60	73	78	78	74	85	79
	" " No. 140	57	62	61	57	67	61
	" " No. 200	47	54	54	47	59	52
Silt	" " No. 270	43	48	48	41	56	43
	" " 0.005 mm.	15	19	18	14	21	14
Clay	" " 0.001 mm.	0	0	0	0	0	0
	Colloids	0	0	0	0	0	0
	Field Moisture %	14.2	15.5	12.7	14.1	12.8	14.4
	Liquid Limit %	19	27	21	23	21	22
	Plasticity Index %	6	11	8	8	8	8

LOG OF SOUNDINGS

Test Hole	1	0'-4'	Firm to Hard Clay (Mi-Conover)
	2	0'-4'	Firm to Hard Clay
	3	0'-4'	Firm to Hard Clay
	4	0'-4'	Firm to Hard Clay
		4'+	Soft Clay
	5	0'-3'	Firm to Hard Clay
		3'-4'+	Soft Clay
	6	0'-4'+	Firm to Hard Clay

According to the Highway Research Board Soil Classification this soil would be the A-4 (4) type.



X = POINTS WHERE PAVEMENT DEFLECTIONS WERE OBSERVED

$\oplus_1$ = SOIL SAMPLES TAKEN FROM THESE NUMBERED TEST HOLES

X POINTS

1. 5'-0" AHEAD OF CONTRACTION JOINT
2. APPROACH SIDE OF CONTRACTION JOINT
3. LEAVING SIDE OF CONTRACTION JOINT
4. QUARTER-POINT BETWEEN CONTRACTION JOINTS
5. MID-POINT BETWEEN CONTRACTION JOINTS
6. QUARTER-POINT BETWEEN CONTRACTION JOINTS
7. APPROACH SIDE OF CONTRACTION JOINT
8. LEAVING SIDE OF CONTRACTION JOINT

THESE TEST POINTS WERE AS CLOSE AS FEASIBLE TO THE LONGITUDINAL FREE EDGE OF PAVEMENT

PLAN OF TEST SITE
FIGURE 1

FIGURE 2. SITE FOR PAVEMENT DEFLECTION STUDY.

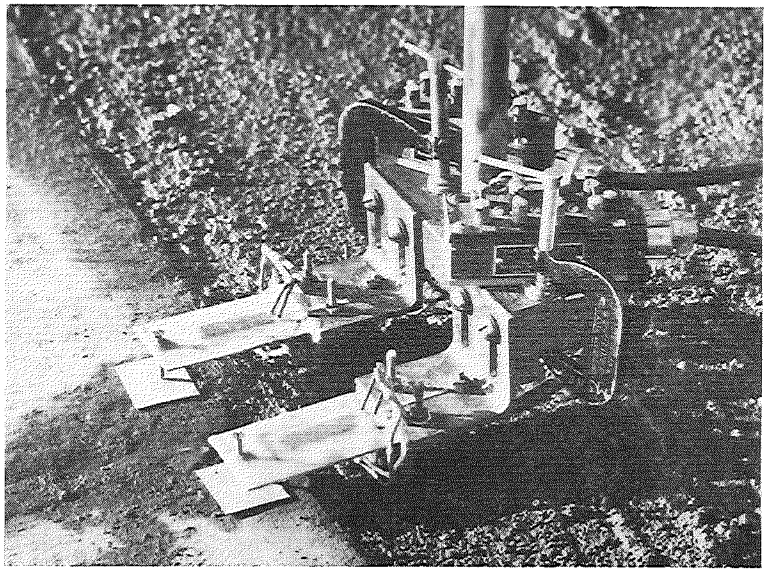


FIGURE 3. DEFLECTOMETER USED IN MEASURING PAVEMENT DEFLECTION.

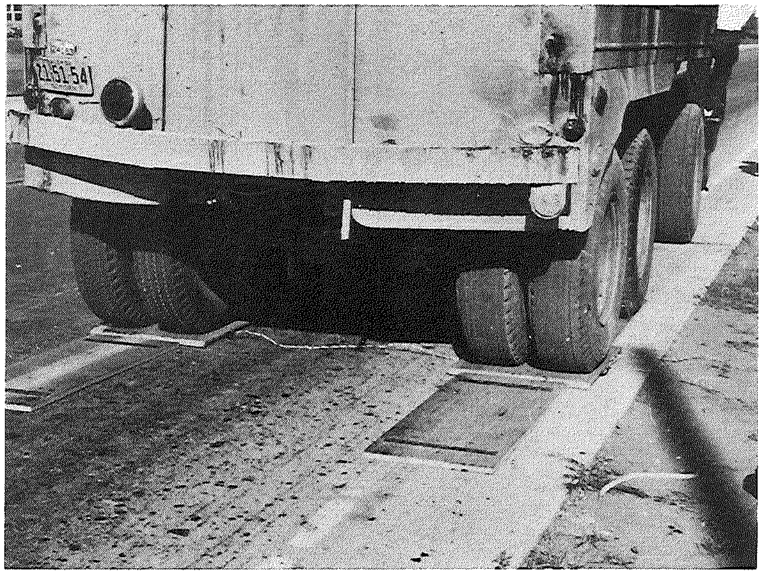


FIGURE 4. LOADOMETER PLATES USED FOR WEIGHING TEST TRUCKS.

Instrumentation

The pavement deflection due to the passage of these trucks was measured by deflectometers built in the laboratory. These deflectometers were essentially aluminum cantilever beams with lengths of 2-7/8 inches and widths of 1-1/2 inches. Each cantilever was fastened rigidly to a steel stake driven into the ground adjacent to the free edge of the pavement (See Figure 3). SR-4 strain gages fastened on the top and bottom surfaces of the aluminum cantilever measured the bending strain in the beam. A threaded screw at the free end of the cantilever was adjusted to bear on a small aluminum plate glued to the top surface of the pavement and adjacent to the edge of the pavement. This screw was adjusted until the bending strain in the aluminum cantilever was approximately fifty (50) micro-inches per inch.

With deflection of the pavement due to an axle load, the initial strain in the aluminum cantilever beam was reduced, causing a change in resistance of the electric strain gage and a resulting deflection of a light trace on a photosensitive paper strip in a Hathaway twelve-channel recording oscillograph. The relationship between the change in resistance of the electrical strain gage and the magnitude of vertical movement of the end of the cantilever beam had been determined prior to this study. The calibration of the trace deflection with strain was obtained immediately before testing by means of the Hathaway calibrating unit, which was adjusted to give a definite amount of strain. Thus, the deviation of the trace had a known relationship to the pavement deflection. The pavement deflection at the eight points shown in Figure 1 was obtained simultaneously.

By means of two traffic-counter cables, one adjacent to each end of the test area, it was possible to locate the position of the truck in the test area at any given time. This was accomplished by connecting the traffic-counter cables to the recording oscillograph in such a way that pips were introduced on the previously mentioned trace as the wheels passed over the traffic cables.

The major portion of the test program was carried out during the night (midnight to 8:00 AM) of August 27, 1952. During the night, the slab ends have a tendency to warp upward due to temperature variation and the resulting pavement deflection due to load is several times greater than it is during daytime testing.

Trucks taking part in this study were first weighed by means of electronic loadometer plates, which are shown in Figure 4. Electric strain gages attached to the bottom surface of these plates measured the strain in the plates as a single axle of a truck was centered over the plates. In order to weigh tandem axles with only two plates, it was necessary to use wooden ramps in conjunction with the plates so that the two tandem axles would be more nearly at the same level of support (see Figure 4).

This expedient did introduce some error, and more accurate readings could be obtained on tandem axles by the use of four plates. The electronic plates were calibrated in the laboratory and then again under field conditions before they were used in this study. Appendix I contains a more detailed description of these plates, the wiring diagram, and the method of calibration.

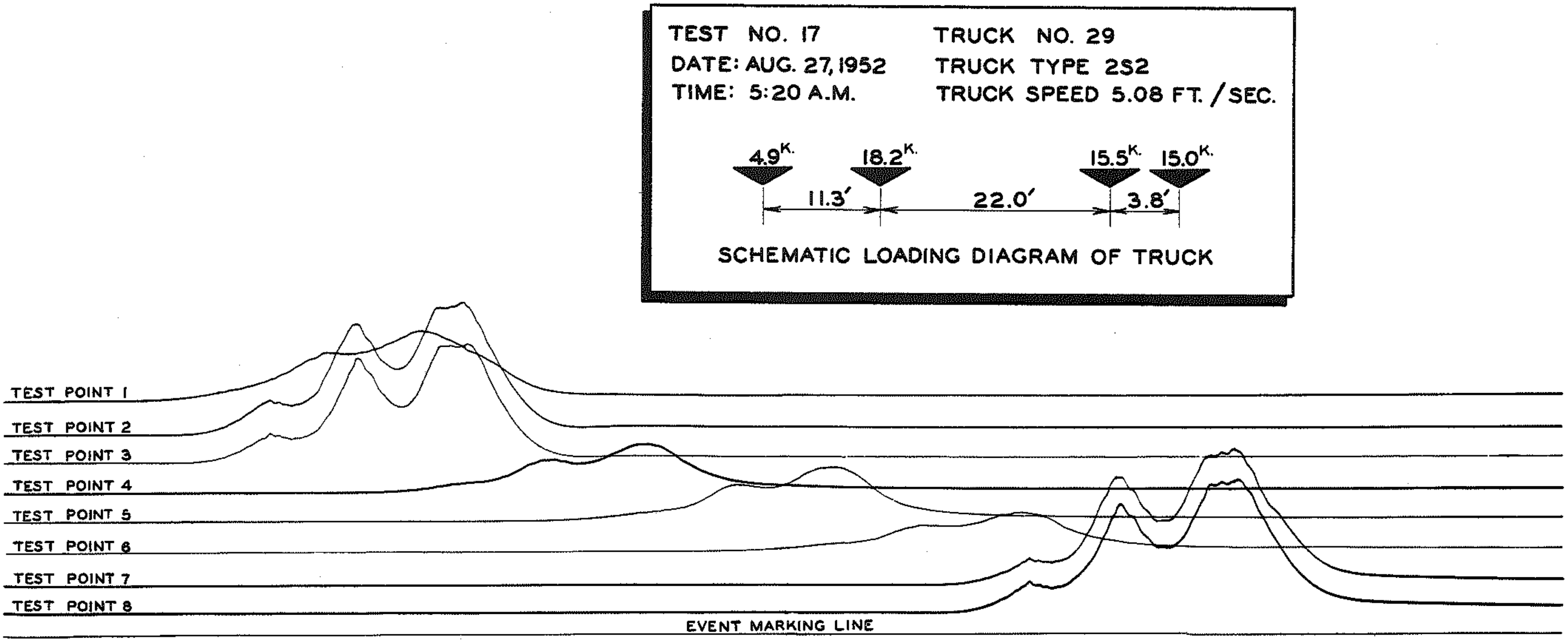
After the trucks were weighed, they were driven across the test area at a creep speed with the right front tire on a position stripe which was placed 2'- 0" from the longitudinal free edge of the pavement. The lateral position of the truck in the lane was stringently enforced. This placed the outside edge of the heavily loaded wheels approximately one foot from the free edge and within approximately 10 inches of the points where deflection measurements of the pavement were obtained. The recording oscillograph obtained a permanent record of the pavement deflection at the eight test points. A typical record of pavement deflection is illustrated in Figure 5.

Load-Deflection Data

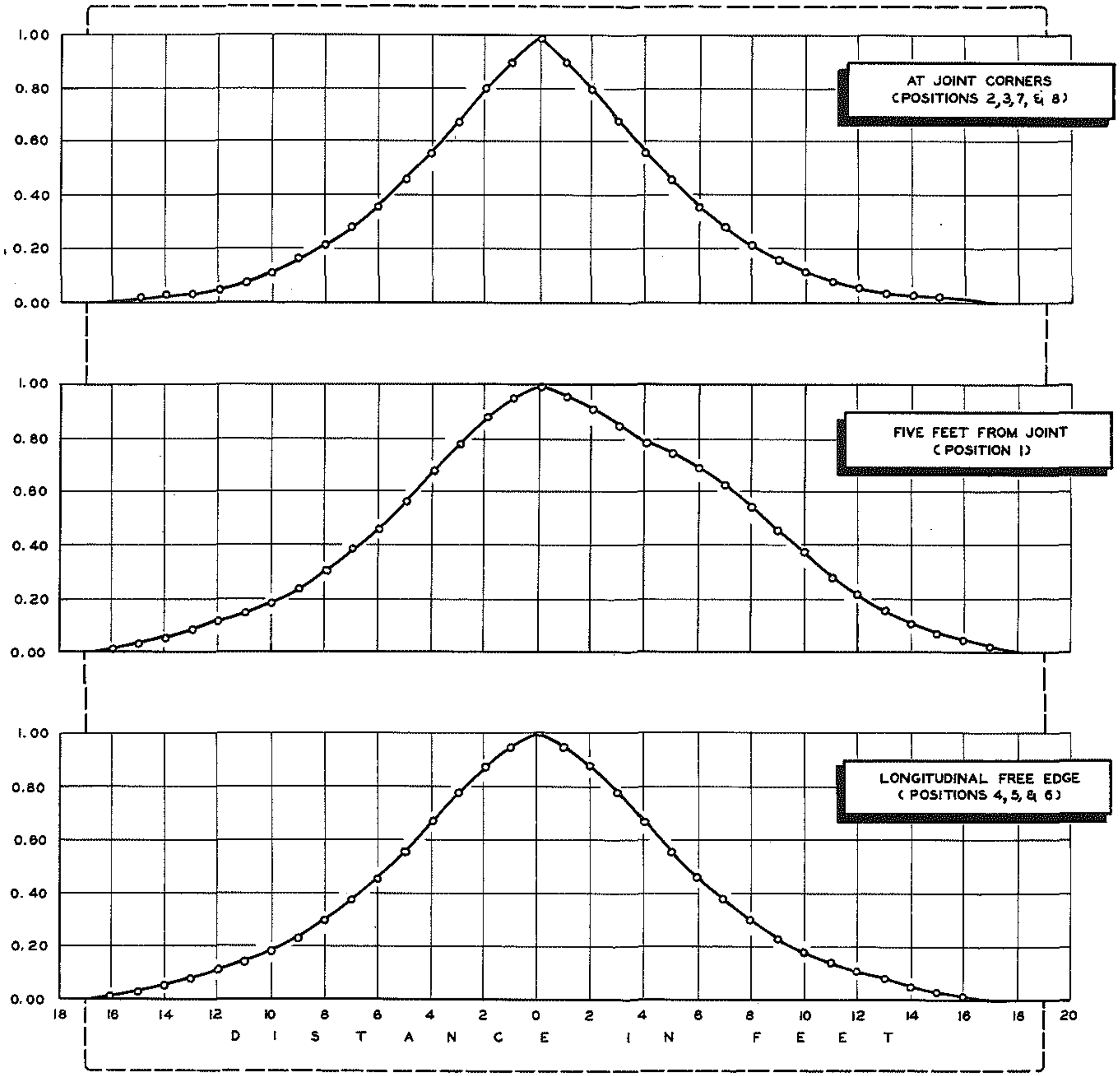
Before an attempt was made to evaluate deflections due to loads at the various gage positions, it was necessary to find the influence lines for deflection at at these positions. Only the deflection under the rear wheels of the four trucks with rear axle spacings greater than 12 feet were studied for this purpose. One-foot intervals were marked off on the trace from the point of maximum deflection and the deflection at each of the points was recorded as a percentage of the maximum deflection. It was found that the influence lines for deflection at the four gage positions 2, 3, 7, and 8 (joint corners) were very similar and the influence lines for deflection at positions 4, 5, and 6 (the longitudinal free edge) were also similar. Influence lines for deflection were constructed for the three distinct locations: (1) at the joint corner; (2) five feet from the joint (position 1); and (3) positions 24 or more feet from the joint (see Figure 6). The experimental points used in the determination of the influence line for deflection at each location had a maximum deviation from the influence line for locations 1, 2, and 3 of 0.07, 0.09, and 0.10 respectively.

No appreciable difference was found between the influence lines for deflection at the corner on the approach slab and the leaving slab. This is probably due to the fact that the two joints tested were contraction joints and the testing was carried out during August when the slab ends on each side of the joint were in relatively close contact.

Although accurate influence lines for deflection were not obtainable for front wheels, because of the large effect of the wheels of the drive axle, the data indicated that the influence of the front wheel did extend to distances of approximately 9 feet and 12 feet at the corner and free edge respectively. Based on that knowledge and the influence lines for wheels on other single axles, deflection influence lines for the front wheels were constructed similar to the influence lines in Figure 6.



TYPICAL OSCILLOGRAPH RECORD OF PAVEMENT DEFLECTION
FIGURE 5



INFLUENCE LINES FOR PAVEMENT DEFLECTION

FIGURE 6

The influence line for deflection at a point five feet from the first joint (Test Point No. 1) is quite different from the other two influence lines. There is a definite break in the curve as the wheel load passes over the joint. It appears that the rate of decrease in deflection at position 1 was interrupted as the wheel passed from the approach side of the joint to the leaving side. Unfortunately, no other similar positions were studied so that it is not known whether this characteristic is peculiar to that particular position or if all similar positions would exhibit the same characteristic. The influence line for deflection at Test Point No. 1 does not decrease to zero until the load is 18 feet from that point. At the other two locations the influence lines for deflection decrease to 0 at 16 feet.

Due to the fact that the deflection under each wheel load was affected by adjacent wheel loads, so-called "effective wheel loads" were computed and used in the study of the relationship between wheel loads and deflections. The effective wheel load equals the load at the point where maximum deflection occurs plus percentages of each adjacent load; the percentages depend upon the axle spacings and the influence lines for deflection at that point. Consider the deflection at a joint during the passage of a vehicle having two axles spaced 12 feet apart, with the front wheel load equal to four kips and the rear wheel load equal to 10 kips. The influence line for deflection at the corner due to a front wheel load indicates that the deflection 12 feet from the front wheel is zero. However, the deflection 12 feet from the rear wheel is 5 percent of the maximum deflection which occurs under the rear wheel. It follows that the effective front wheel load is equal to four kips, plus 5 percent of 10 kips, which equals 4.5 kips. The effective rear wheel load would be only 10 kips (10 + 4 x 0% = 10).

The effective wheel loads of all single axles other than front axles were tabulated with the corresponding deflection under each load. Based on the assumptions that deflection is proportional to load, and zero deflection exists under a load of zero, the line of regression was found for deflection versus load for each gage position, using the method of least squares. Table 2 lists the slope "a" of each regression line. The deflection in inches to be expected under a load is the product of "a" and the effective wheel load in kips. For effective wheel loads of 10 to 15 kips, actual deflections can be expected to vary less than ± 17 percent from the calculated deflection in approximately 68 cases out of 100, and less than ± 34 percent from the calculated deflection in approximately 95 cases out of 100.

The scatter diagrams in Figure 7 indicate the relatively large dispersion of points which represent individual load-deflection relations. This dispersion was probably caused to some extent by variations in slab warping during the test period of midnight to 8:00 AM. There seemed to be a noticeable trend for slab deflections to increase for a given load during this period. Three vehicles made two runs with identical loads over the test area with intervals of 1 hr. 3. min. to 3 hrs. 32 min. between the first and second run. The average percent increase in pavement deflection at the second run was 12 percent at the corner and 13 percent at the longitudinal free edge. Additional causes for this variation may have been, (1) slight errors in lateral placement of the wheels in the lane and (2) slight inaccuracies in the method of weighing loads.

TABLE 2

LOAD-DEFLECTION REGRESSION LINE SLOPES FOR SINGLE AXLES

Test Position	Slope "a" (inches/kip)	
1	1.37×10^{-3}	
2	3.50×10^{-3}	Average 3.44×10^{-3} for corners.
3	3.25×10^{-3}	
7	3.59×10^{-3}	
8	3.42×10^{-3}	
4	0.94×10^{-3}	Average 1.04×10^{-3} for longitudinal free edge.
5	1.21×10^{-3}	
6	0.98×10^{-3}	

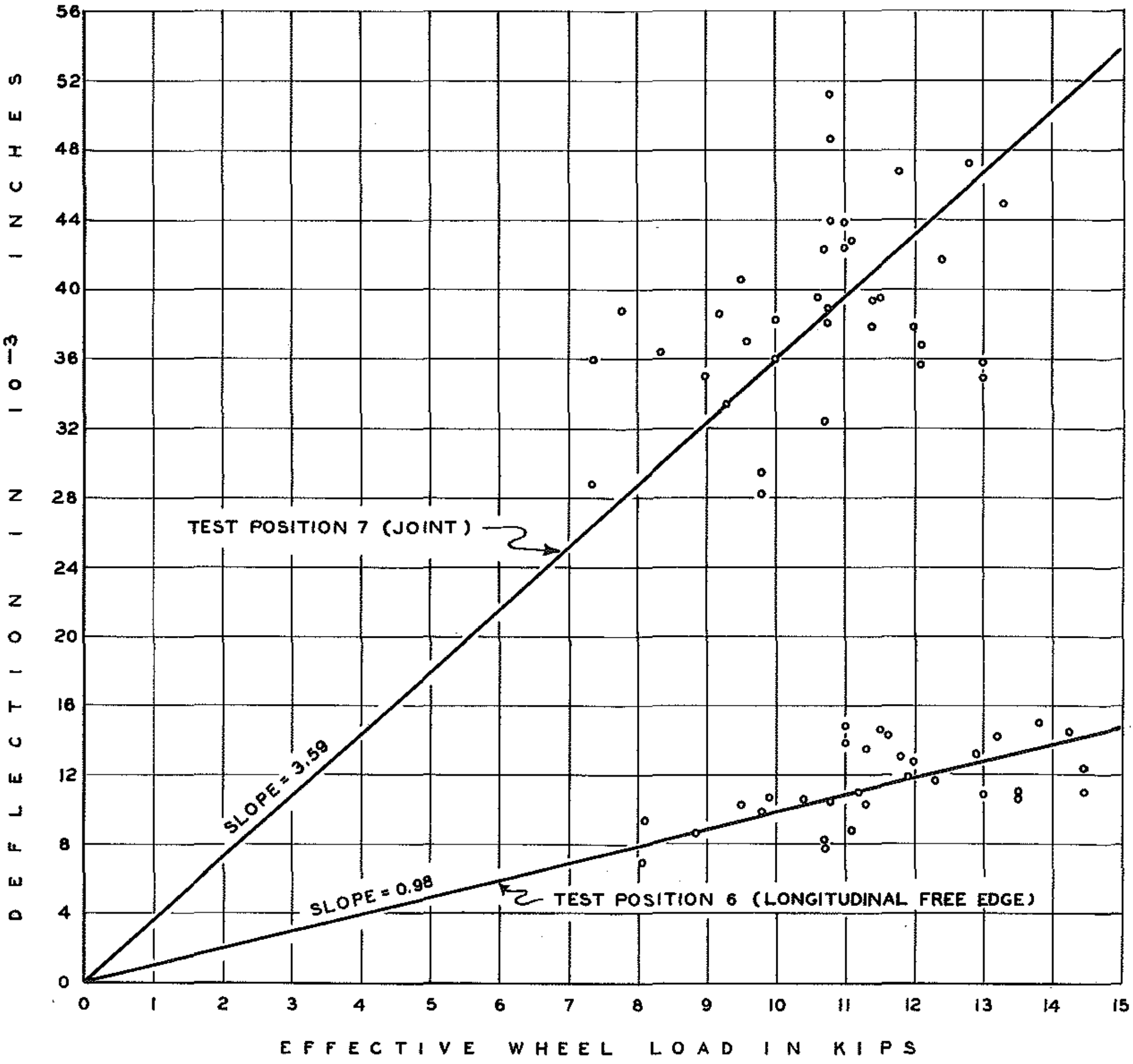
Where:

$y = aP$ (Formula 1)

y = deflection in inches

a = regression line slope in inches/kip

P = effective wheel load in kips



TYPICAL REGRESSION LINES FOR PAVEMENT DEFLECTION INDUCED BY EFFECTIVE WHEEL LOADS ON SINGLE AXLES

FIGURE 7.

The effective wheel loads for four-foot tandems were tabulated with the corresponding deflections under each load for each gage position. According to the influence lines for deflection at the corner, the percentage of a wheel load in effect four feet from the wheel load is 56 percent, and therefore the effective wheel loads are 56 percent greater than the actual wheel loads for 4-foot tandems at a corner. The maximum deflection at the longitudinal free edge due to a four foot tandem axle occurs midway between the axles and is 76 percent greater than the deflection for a single axle having the same load as each tandem axle. Thus the effective wheel load is 76 percent greater than the actual wheel load for a 4-foot tandem at the longitudinal free edge. According to our assumptions, the slope of the regression line obtained from the tandem-load data for a particular gage position should have been equal to the slope obtained from the single wheel load data. In general, the slope "a" for the four foot tandems was less than the slope "a" for the single loads.

Table 3 lists the slopes of the lines of regression for the four-foot tandems. The table also contains the ratio:

$$\frac{\text{"a" for tandem load}}{\text{"a" for single load}}$$

In general it is thought that the reason for the difference in values of the slope, "a" for single and tandem axles at the corner, may be due to variation from a linear relationship between load and deflection, which appears to be more apparent with larger effective wheel loads.

An interesting comparison can be made between the tandem-axle load which caused the same deflection as that caused by a single 18,000-pound axle. Table 4 gives this comparison with substantiating data from the Maryland Test Road.[1]

Theory of Destructivity

The term "destructivity" as used in this report refers to the comparative destructive tendency of a vehicle with respect to other vehicles. Any method of determination of destructivity of vehicles must be a logical one which yields results consistent with existing knowledge. The method to be described herein satisfies these requirements. However, it should be remembered that the method presented here is only a theory, and further test road data on destructivity could invalidate, or substantiate, this theory. When this theory is compared to the data obtained from the Maryland Test Road the agreement is as close, or closer than could be expected. A comparison of the results of this theory and the data from the Maryland Test Road will be shown later in this report.

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[1] Road Test One-MD, Highway Research Board Final Report, Special Report No. 4, Washington, D. C., 1952, p. 115.

TABLE 3

REGRESSION-LINE SLOPES FOR 4' TANDEM AXLES

	Test Position	Slope "a" (inches/kip)	Tandem - "a" / Single - "a"	
Corners	2	3.268×10^{-3}	0.933	Average 0.94
	3	3.060×10^{-3}	0.942	
	7	3.392×10^{-3}	0.944	
	8	3.236×10^{-3}	0.947	
Longitudinal Free Edge	4	1.000×10^{-3}	1.05	Average 1.00
	5	1.168×10^{-3}	0.967	
	6	0.956×10^{-3}	0.983	

TABLE 4

TANDEM-AXLE LOADINGS WHICH GIVE DEFLECTIONS EQUAL TO THOSE CAUSED BY AN 18,000-POUND SINGLE AXLE LOADING

Source of Data	Tandem-Axle Loading Equivalent to that of an 18,000# Single-Axle Loading Based on:	
	Corner Deflection	Free-Edge Deflection
Michigan State Highway Department field data	24,500 #	20,500 #
Road Test One-MD for fine grained soil - pumping	25,425#	19,150 #

Note: These data are based on the pavement deflection under trucks travelling at creep speed.

It is felt by the authors that this theory would be more applicable to concrete pavements supported by fine-grained soils than it would for pavements supported by granular soil. Also the reader must bear in mind that this method is an attempt to measure the destructive tendency of vehicles only to the extent that loading affects the deterioration of a concrete pavement.

A single wheel load, which causes a deflection of the concrete pavement under it, constitutes a force acting through a distance equal to the deflection. Assume that the deflection is proportional to the magnitude of the wheel load. Then the work done by the wheel on the supporting medium, namely the concrete pavement and the subgrade, is equal to the area of a right triangle with altitude P (P = wheel load) and a base y (y = slab deflection under wheel P) (See Figure 8). If destructivity can be measured by the magnitude of the work done on the supporting medium, then the destructivity of a wheel load P is proportional to P y. It then follows that the destructivity of one wheel load P_1 as compared to a second wheel load P_2 is:

$$\frac{P_1 \; y_1}{P_2 \; y_2}$$

Pavt & Foundation Stiffness, resilient modulus, is a function of the applied load. ∴ def can't be proportional to load. Refer back to page 5.

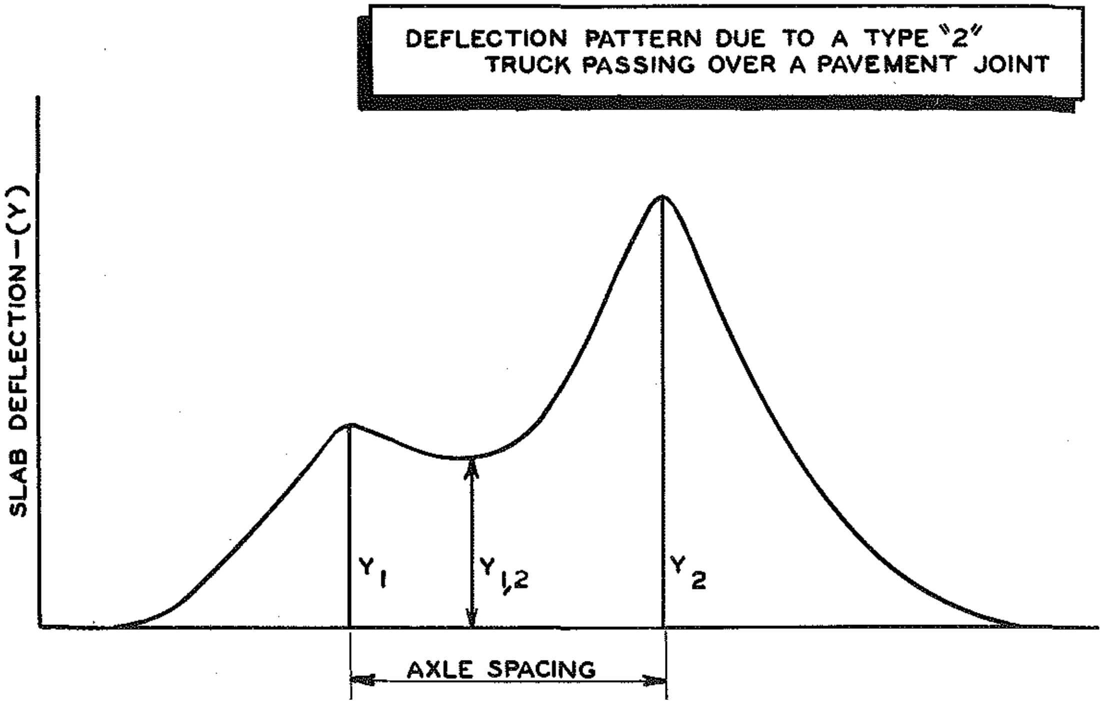
Suppose that $P_1 = 2P_2$. Then $y_1 = 2y_2$, since it has been assumed that deflection is proportional to load. The destructivity of P_1 as compared to P_2 is:

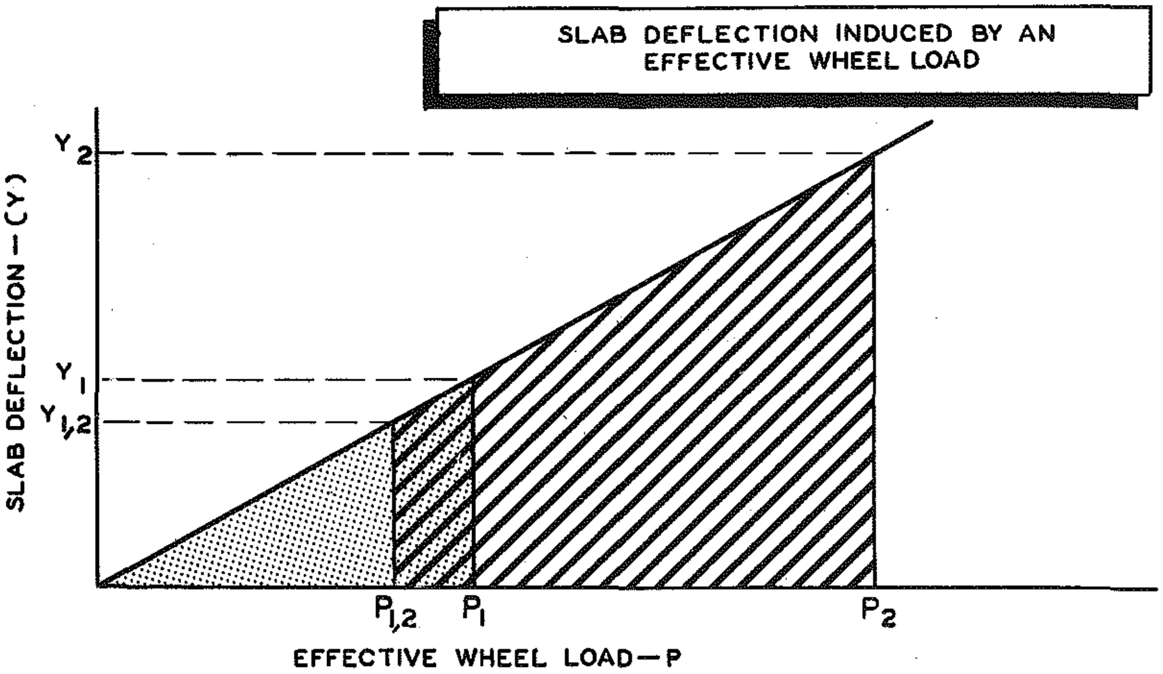
$$\frac{P_1 y_1}{P_2 y_2} = \frac{(2P_2)}{P_2}\frac{(2y_2)}{y_2} = \frac{4}{1}.$$

That is, P_1, which is twice as large as P_2, according to this method is four times as destructive. It is of interest to note that the product Py has the energy units, lb.-inches, while the ratios of destructivity have no units.

In the extension of this study to the inclusion of a number of wheel loads within a fairly short distance, effective wheel loads are used instead of actual wheel loads. This is necessary because of the overlapping effect of closely spaced wheel loads. The distance through which an effective wheel load moves is not necessarily the maximum deflection of the concrete pavement under it, but may be some lesser distance, due to the fact that the deflection of the slab may not return to zero after the passage of the preceding wheel load.

The work done on the supporting medium by a vehicle composed of a number of wheel loads is the sum of the work done by the individual wheels. However, the work done by an individual wheel is 1/2 Py, only if it is: (1) the first wheel of a vehicle, or (2) any other wheel of a vehicle which is removed from the preceding wheel by a sufficient distance that the pavement returns to its initial undeflected position after the application of the preceding wheel.


DEFLECTION PATTERN DUE TO A TYPE "2" TRUCK PASSING OVER A PAVEMENT JOINT


SLAB DEFLECTION INDUCED BY AN EFFECTIVE WHEEL LOAD

GRAPHICAL INTERPRETATION OF DESTRUCTIVITY THEORY

FIGURE 8

Figure 8 illustrates the deflection pattern at the corner of a pavement slab due to the passage of a type "2" truck. The maximum deflections induced by the front and rear effective wheel loads, P_1 and P_2 are y_1 and y_2, respectively.

The minimum deflection which occurs between the wheels is $y_{1,2}$ and $P_{1,2}$ is the corresponding effective wheel load. In Figure 8, the work done by P_1, $1/2\ P_1 y_1$ is indicated by the dotted area. The cross-hatched area in Figure 8, with sides $y_{1,2}$ and y_2 and base $(P_2 - P_{1,2})$ represents the work done by P_2. This trapezoidal area is:

$$\frac{(P_2 - P_{1,2})\,(y_2 + y_{1,2})}{2}.$$

Since y = aP, the work done by wheel 1 is:

$$\frac{P_1 y_1}{2} = \frac{a}{2}\,(P_1)^2 \qquad \text{(Formula 2)}$$

the work done by wheel 2 is:

$$\frac{(P_2 - P_{1,2})\ (y_2 + y_{1,2})}{2} = \frac{a}{2}\,(P_2 - P_{1,2})\ (P_2 + P_{1,2}) = \frac{a}{2}\,(P_2^2 - P_{1,2}^2) \qquad \text{(Formula 3)}$$

Total work done on the road by the vehicle, in lb.-inches:

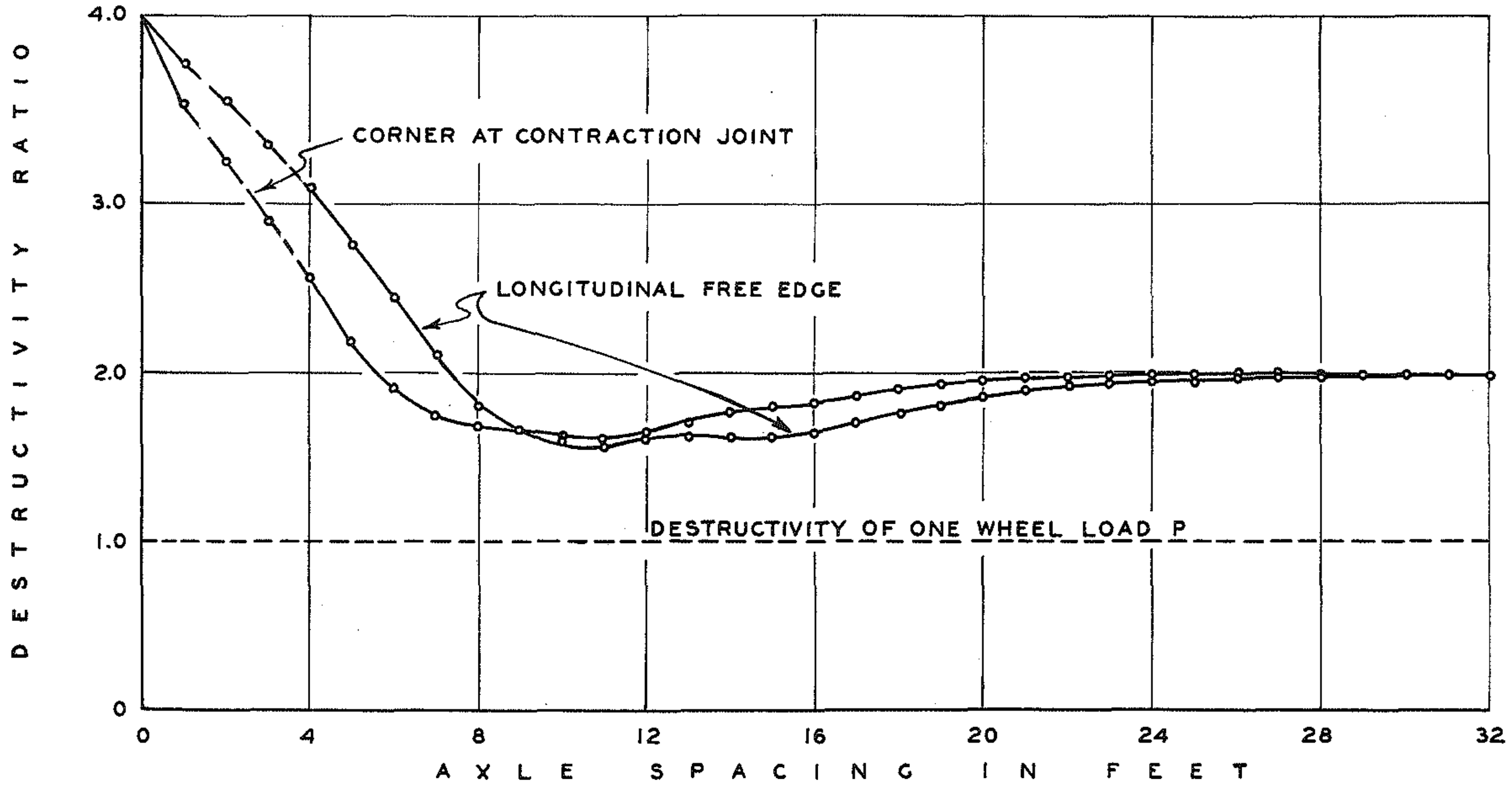
$$\frac{a}{2}\,(P_1)^2 + \frac{a}{2}\,(P_2^2 - P_{1,2}^2) = \frac{a}{2}\,(P_1^2 - P_{1,2}^2 + P_2^2) \qquad \text{(Formula 4)}$$

In general the total work done on the road by any vehicle is:

$$\frac{a}{2}\,(P_1^2 - P_{1,2}^2 + P_2^2 - P_{2,3}^2 + P_3^2 - \ldots\ldots\ldots - P_{(n-1),\,n}^2 + P_n^2)$$

Figure 9 illustrates the variation in destructivity of two equal wheel loads "P" as the axle spacing between them varies. In this case, the destructivity of a single wheel load P is assigned the value 1.0. The reason for the smaller values for a 20-foot spacing, as compared to a spacing of 32 feet, is that the minimum deflection between the passage of the front and rear axle is zero in the latter case while it is a value greater than zero in the former case. Algebraically speaking, $P_{1,2} = 0$ for the 32 foot axle spacing and the destructivity is:

$$\frac{a}{2}\,(P_1^2 - P_{1,2}^2 + P_2^2) = \frac{a}{2}\,(2P_1^2) = aP_1^2.$$



DESTRUCTIVITY OF TWO WHEEL LOADS "P"
AS THE AXLE SPACING BETWEEN THEM VARIES

FIGURE 9.

For an axle spacing of 20 feet, $P_{1,2} > 0$ and the destructivity is:

$$\frac{a}{2}\left(P_1^2 - P_{1,2}^2 + P_2^2\right) = \frac{a}{2}\left(2P_1^2 - P_{1,2}^2\right) = aP_1^2 - a\ P_{1,2}^2$$

which is less than aP_1^2.

The reliability and validity of the results obtained by means of this method may very well be in doubt until the results can be compared with sufficient experimental data on the destructive effect of various vehicles.

The Highway Research Board report on the Maryland Test Road offers some valuable information on the subject.[2] Four different axle loadings on two vehicle types were repeatedly applied to four separate test sections. The number of repetitions to cause first cracking and first pumping under each axle loading was tabulated. The values obtained from the Maryland Test for a concrete pavement on the fine-grained soil prior to pumping are reported in Table 5 along with the actual destructivity ratios, as well as the theoretical destructivity ratios. Averages of the two actual destructivity ratios and the two theoretical destructivity ratios were computed for each vehicle type, in order to facilitate the comparison of actual to theoretical values. A fair amount of agreement exists between the actual and theoretical destructivity ratios. More data such as this should be collected and studied before this theory of destructivity can be finally substantiated or invalidated.

In Table 6 are listed the destructivity ratios for many common types of vehicles in comparison to a type "2" truck. The axle loads assigned to each vehicle are as follows:

Front Axle - 8 kips

Single and 9 foot tandem axles - 18 kips per axle.

Four-foot tandem axles - 16 kips per axle for one tandem and 13.0 kips per axle for other 4-foot tandem axle combinations.

Each axle of a 9-foot tandem is assigned a weight of 18 kips, although according to law the tandem axle spacing must be greater than 9 feet in order to carry a load of that magnitude. Most so-called 9-foot tandems are actually spaced 9.1 or 9.2 feet apart. In general, deflection is assumed to be proportional to load. However in the case of 4-foot tandems at the slab corner, deflection was reduced an amount in accordance with findings in Table 3.

The 1952 loadometer survey was used as a guide in assigning logical axle spacings to the various types of trucks. Three distinctly different axle spacings were encountered for type 2S2 vehicles. The destructivity ratios for the type 2S2 truck with an 11.5 foot axle spacing were less than those associated with the truck

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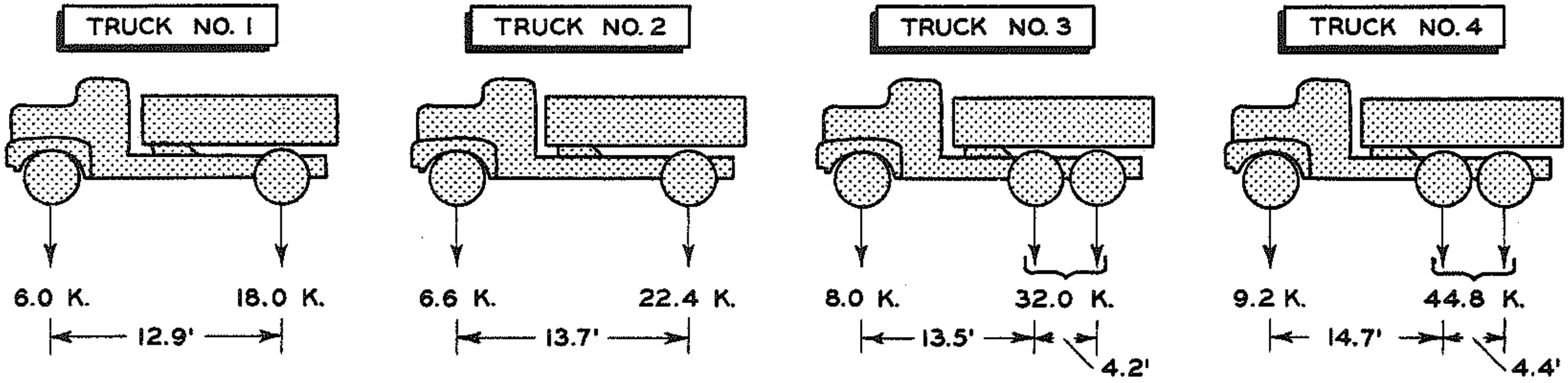
[2] ibid, p. 8

TABLE 5

COMPARISON OF ACTUAL AND THEORETICAL DESTRUCTIVITY

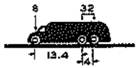
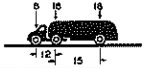
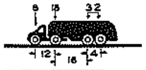
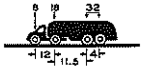
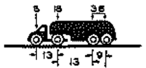
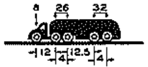
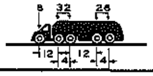
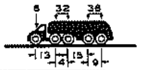
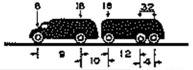
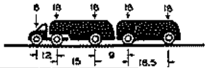
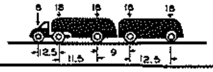
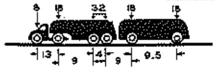
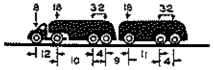
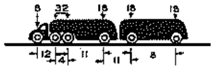
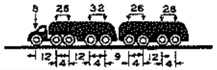
Maryland Test Road Data						Computed Theoretical Destructivity		
Truck No.	No. of Repetitions Before:		Actual Destructivity					
	First Cracking	First Pumping	Cracking	Pumping	Ave.	Corner	Free Edge	Ave.
1	210,000	126,000	1.00	1.00	1.00	1.00	1.00	1.00
2	144,000	85,000	1.46	1.49	1.47	1.57	1.56	1.56
3	106,000	44,000	1.98	2.86	2.42	1.98	2.40	2.19
4	50,000	31,000	4.20	4.07	4.13	3.92	4.63	4.27

SCHEMATIC OF MARYLAND TEST ROAD TRUCKS



The values of wheel loads and axle spacings for each truck number are actually the average of the values recorded for two similar trucks used on each test section.

THE DESTRUCTIVE TENDENCIES OF VARIOUS TYPES OF TRUCKS
TABLE 6

TRUCK TYPE	TRUCK AXLE LOAD AND SPACING	TRUCK WEIGHT IN KIPS			DESTRUCTIVITY RATIO		DESTRUCTIVITY RATIO PER UNIT PAY LOAD	
		GROSS	EMPTY	PAY LOAD	CORNER	FREE EDGE	CORNER	FREE EDGE
2		26	8.2	17.8	1.0	1.0	1.00	1.00
3		40	15	25	1.84	2.36	1.31	1.68
2S1		44	17	27	1.68	1.65	1.11	1.09
2S2		58	23	35	2.63	3.04	1.34	1.55
2S2		58	22	36	2.30	2.77	1.14	1.37
2S2 LONG TANDEM		62	24	38	2.21	2.17	1.03	1.02
3S2		66	33	33	2.60	3.16	1.40	1.70
3S2		66	33	33	2.53	3.21	1.36	1.73
3S2 LONG TANDEM		76	35	41	3.13	3.50	1.36	1.52
2-3		76	29	47	2.92	3.42	1.11	1.30
2S1-2		80	29	51	3.08	2.91	1.08	1.02
2S1-2		80	29	51	2.84	2.60	0.99	0.91
2S2-2		94	35	59	3.0	3.51	0.91	1.06
2S2-3		108	38	70	4.0	4.77	1.02	1.21
3S1-2		94	35	59	3.74	4.0	1.13	1.21
3S2-4		118	42	76	4.1	4.75	0.96	1.11

with the 16-foot axle spacing. This is consistent with the graph in Figure 9. The third type 2S2 vehicle with a 9-foot tandem instead of a 4-foot tandem has a gross weight greater than that on the other two type 2S2 vehicles but the destructivity ratios associated with it are less than the destructivity ratios for the other two type 2S2 vehicles. According to this method, a 36 kip, 9-foot tandem, is less destructive than a 32 kip, 4-foot tandem.

The type 3S2 truck, having 2 sets of 4-foot tandems, was listed twice. In the first instance a 32 kip load was assigned to the rear tandem and a 26 kip load was assigned to the foremost tandem. In the second instance the two loads were interchanged. The interchanging of the tandem loads caused no appreciable change in the destructivity ratios.

Table 6 also lists the destructivity of each vehicle divided by its pay load which was assigned on the basis of the 1952 Michigan loadometer survey. This ratio was set equal to 1.0 for the type "2" vehicle in order to aid in the comparison of the various vehicles. The existence of a small value for a particular truck indicates that the use of this truck will minimize the destructive effect of transporting a given load. These ratios are naturally dependent upon the pay load assigned to each vehicle, and are valid for only these pay loads.

Summary

A rational method of evaluating the destructive tendency of different types of vehicles on the basis of pavement deflection has been proposed. On the basis of this theory the following conclusions may be drawn:

1. The spacing of axles at approximately 11 feet gives the least destructive effect.

2. A four-foot tandem with a total load of 32 kips is more destructive than a nine-foot tandem with a total load of 36 kips.

3. A four-foot tandem would have to be limited to approximately 28 kips, considering destructivity at the slab corner, and approximately 26 kips, considering destructivity at the longitudinal free edge, in order to have the same destructivity per unit load as that of a single axle loaded to 18 kips.

Additional load-deflection data should be obtained and compared to that which was obtained and reported here. Furthermore, other data pertaining to the comparative destructivity of vehicles should be collected and studied before this theory is finally accepted or rejected. This can be accomplished by means of a full scale test program conducted in such a way that each vehicle to be analyzed, travels repeatedly over a separate test section until failure occurs. If all of the test sections have identical properties, a comparison of the number of repetitions of each truck to induce failure will provide a measure of the comparative destructive tendency of each.

The purpose of this report is to propose a rational theory for evaluating the destructive tendencies of various types of commercial trucks on a concrete pavement. It is expected that any destructivity theory on a controversial subject such as this will be severely criticized. Constructive criticism may be helpful in developing a new theory or modifying the present one. The present theory compares well with recent research data on this subject, such as obtained by the Maryland Test Road, and therefore it is presented as a basis for further argument and criticism.

APPENDIX I

ELECTRIC LOADOMETER PLATES

The loadometer plate is composed of a sheet of armour plate steel 30-1/8 inches by 24-3/16 inches by 1/2 inch thick. A strip of one-inch channel iron is welded underneath each of the short sides at the edge, and a strip of rubber (24-3/16 inches by 9/16 inch by 5/8 inch) of 60-68 Durometer hardness is cemented into the groove of the channel to give the plate a base which will seat itself upon a rough surface such as concrete.

Ten A-7, SR-4 strain gages (120 ohm) are mounted on the under or concave side of the plate at the points indicated in Figure 1A. Gages 1, 2, 7, and 8 are wired in series, and gages 3, 4, 5, and 6 are wired in series. These two series circuits are then wired in parallel, giving a resultant resistance of 240 ohms. The two temperature compensating gages are mounted upon unstrained cantilevers and wired in series, thus giving 240 ohms also.

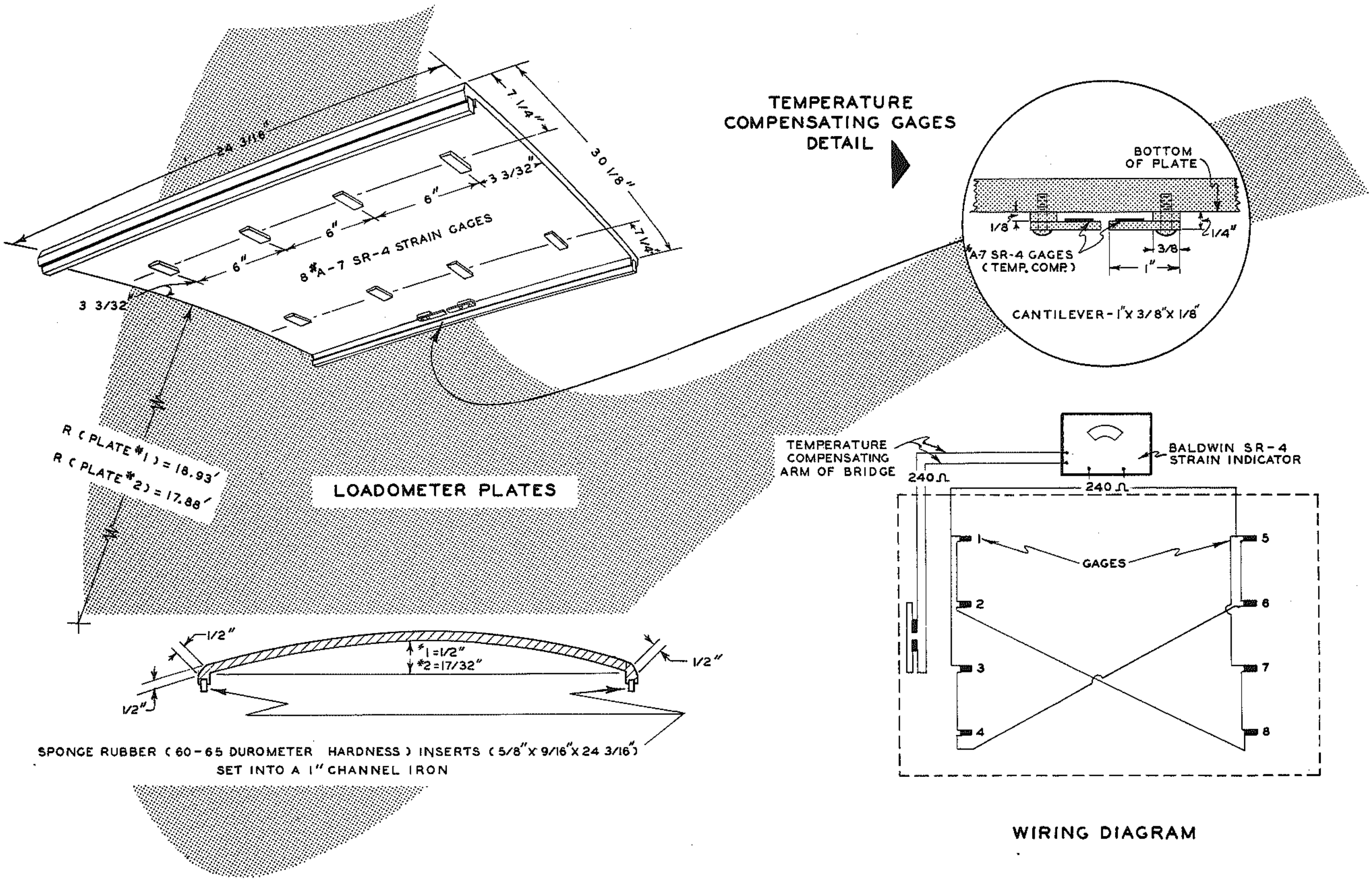
The plates were calibrated in the laboratory and at the weigh station near Fowlerville on US-16. In the laboratory, the loads were applied by a hydraulic press with the load distributed over an area of approximately 40 square inches. It was necessary to also calibrate at the weigh station because of the possibility of differences in the area of load application, which in the case of dual truck tires may be as much as 150 square inches. In the laboratory the loads were applied from 0 to 14,000 lbs. in 1000 lb. increments in the four positions, as follows:

1. At junction of transverse and longitudinal centerline.
2. On transverse centerline and 4 inches off longitudinal centerline.
3. On longitudinal centerline and 4 inches off transverse centerline.
4. At a point 4 inches off transverse centerline and 4 inches off longitudinal centerline.

It was found that for any of the above positions the results were very nearly linear and very good repetition could be obtained.

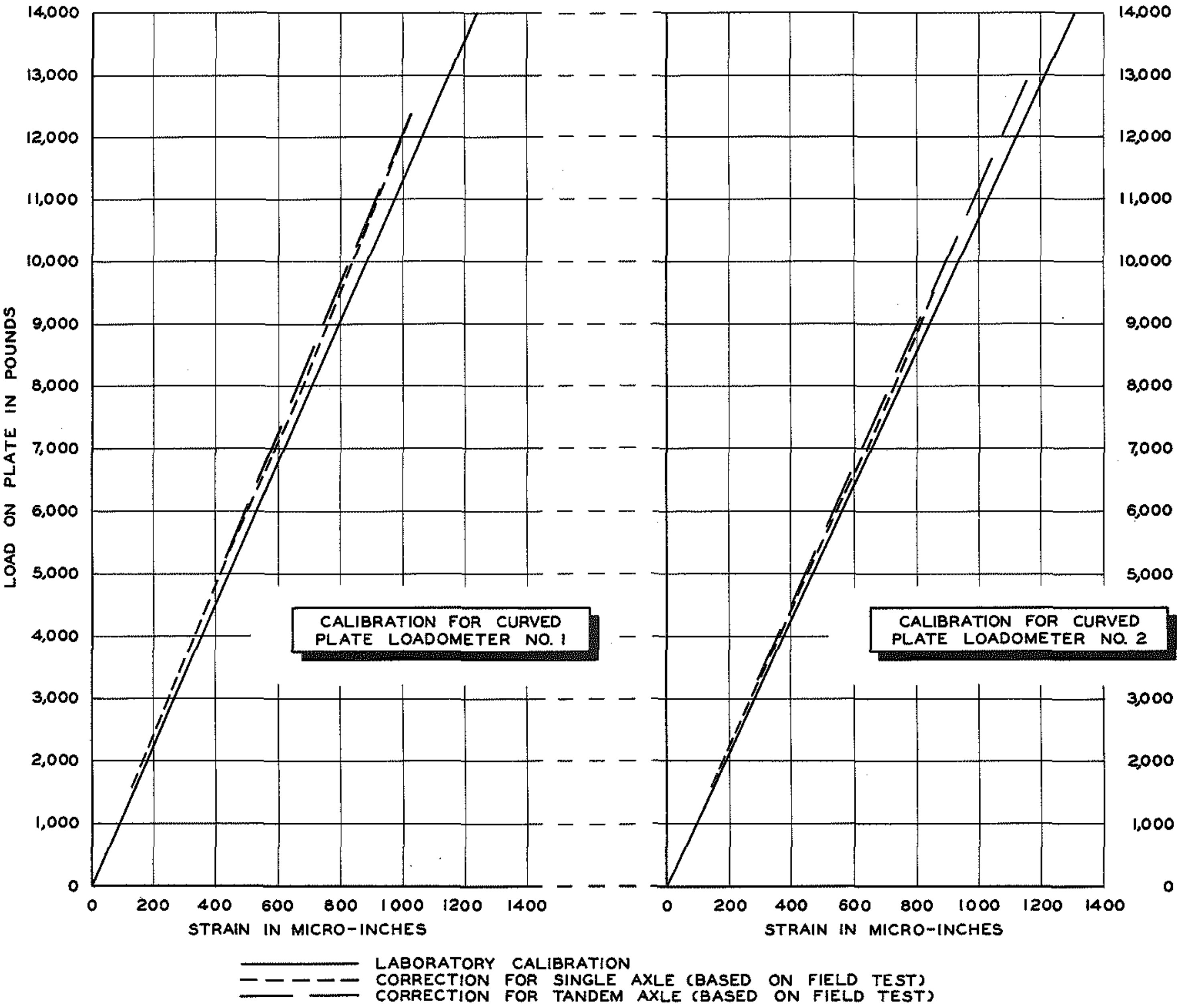
The maximum range of deviation over the four positions was approximately seven percent. It was found that in practice it is quite easy to center the wheel loads on the transverse centerline and, in the case of dual tires, symmetrically with respect to the longitudinal centerlines. Therefore, it was concluded that this centering of the loads would eliminate the deviation due to calibration positions

3 and 4 and consequently reduce the range of deviation to approximately 2.2 percent. However, the readings obtained from the weigh station indicated that a correction curve for single axles and another for tandem axles was necessary. This correction was necessitated by the elevating effect of the plates. This elevating effect was partially compensated for in the case of tandem axles, by wooden plates 3/4 inch thick, which were placed under the axle adjacent to the one being weighed. A copy of the calibration curves for Plates 1 and 2 are shown in Figure 2A.



DETAILS OF ELECTRONIC LOADOMETER PLATES

FIGURE 1A.



CALIBRATION OF ELECTRONIC LOADOMETER PLATES
FIGURE 2A