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THE RELATIVE EFFECTS OF COMMERCIAL VEHICLES ON CONCRETE PAVEMENTS

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Preliminary Draft of a Progress Report on the Research Study of Dynamic Load Aspects of Truck Size and Weight

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CONTENTS

SYNOPSIS

Experimental data is presented in this report on three extensive field tests on concrete pavements in which deflections and strains were recorded for a variety of vehicles. This data has been analyzed and summarized into influence lines for pavement deflection and strain, and load-deflection and load-strain relationships for single and tandem axles. Effects of temperature and slab warping on these data are demonstrated.

A rational theory is presented for determining the relative effect of vehicles on a concrete pavement. This theory is rational in that its principle is based on energy absorption of the pavement due to the passage of a vehicle. Influence lines for deflection and load-deflection relations from the three tests are used to demonstrate the application of the theory. The theory is substantiated by comparison with the results of the relative effects of vehicles on experimental test roads. A variety of applications for the theory are demonstrated, such as in vehicle design, changing legal axle load limits, and predicting the effects of traffic load on a pavement.

RELATIVE EFFECTS OF COMMERCIAL VEHICLES ON CONCRETE PAVEMENTS

This is a progress report on the second phase of a cooperative program titled "A Study of Dynamic Load Aspects of Truck Size and Weight." This phase deals with ~~factual~~ data on pavement stresses and deflections resulting from various types of commercial vehicles. These data were gathered for the purpose of improving design of highways and bridges, as an engineering basis for solving load regulatory proglems, and as an equitable basis for allocation of motor vehicle tax responsibility among highway users.

Project Organization

A number of the agencies cooperating in this program had previously conducted individual studies on various portions of the overall problem. This study was initiated to tie together these earlier efforts and to expand the work into a more comprehensive and organized program.

A preliminary outline for the entire study including objectives, need, procedure, and work assignments, was prepared in March 1956, by the Research Laboratory Division, for review and comment by the Department's administration and the cooperating agencies. The outline was approved by the Department in December 1956, and by the cooperating agencies by April 1957. Several drafts of the outline were prepared, the final approval draft being dated December 1956.

In the approved outline, this second phase was titled "Measurement of the Relative Effects Caused by Different Types of Commercial Vehicles on Pavement Surfaces." This progress report summarizes data from three field tests conducted under this phase of the program. It consists of description of the field tests, analysis and interpretation of the data, presentation of a theory of relative effect of commercial vehicles, and application of this theory. The tests, the theory, and the discussion presented here deal with concrete pavements. This second phase of the program also includes bituminous pavements--a comparable report will be prepared, based on field tests on that pavement type, and a relative effect theory presented.

Test Objectives

Test 1's objective was to determine the pattern and magnitude of deflection under day and night conditions for a variety of commercial vehicles under identical test conditions. The Test 1 data were gathered to establish confirming factual information on vehicle-induced pavement-energy relationships, based on pavement deflections from a variety of vehicles. A basic theory for rating the relative effect of vehicles had previously been developed and reported in MSHD Research Laboratory Report 256.

The objectives of Test 2 were the same as for Test 1, as no night data were obtained during Test 1 due to inclement weather. In Test 2, both day and night data were obtained, with a different combination of test vehicles.

Test 3's objectives were to obtain data on temperature-strain and single and tandem axle load strains throughout a continuous 24-hour period, and to establish, if possible:

1. The pattern and magnitude of load strains and deflections.

2. The strains and pavement elevation changes due to slab warping.

3. Relationships between strain and deflection.

4. A relative effect theory based on pavement strain, similar to the relative effect theory based on pavement deflection, which had been developed previously.

DESCRIPTION OF THE TESTS

Site plans and instrumentation for all three field tests are presented in Fig. 1. Axle spacing and load diagrams for the test vehicles are given in Fig. 2. Photos of all vehicles are in the Appendix.

Field Test 1

The first test was conducted on November 20, 1956, on a 300-ft section of the northbound roadway of US 27 (Project 19-41, C1), about 8 miles north of Lansing. This 9-in. uniform, 22-ft concrete pavement, built in 1951, was constructed on a 15-in. granular subbase over a subgrade of Miami series soil (clay loam). This soil is an A-4 type according to Highway Research Board classification.

The test plan called for load deflection tests in the afternoon, when the pavement is in its flattest or best-supported condition, and also in the predawn early morning hours, when the slab ends are warped upward so that subgrade support is at a minimum. This latter test phase, however, was cancelled because of extremely heavy rains.

The first or afternoon portion of the test involved taking oscillographic recordings of pavement edge deflection patterns under slowly moving vehicles, at three approach joint corners and at three leaving joint corners (contraction joints), and at two mid-slab longitudinal free edge positions (Fig. 1). These tests were run between 2:00 and 4:00 p.m. on the test day. The ten vehicles for which deflection patterns were recorded included three Type 2S1 (loaded, half-loaded, empty), three Type 2S2 (loaded, half-loaded, empty), and one Type 2S2-2 (loaded), one Type 2S1-2 (loaded), one Type 2 (loaded) and a passenger car.

Each vehicle made five creep-speed test runs in numerical order according to assigned vehicle numbers at 3-minute intervals, so that five runs of each would be spaced through the entire test period. Each vehicle was positioned laterally during

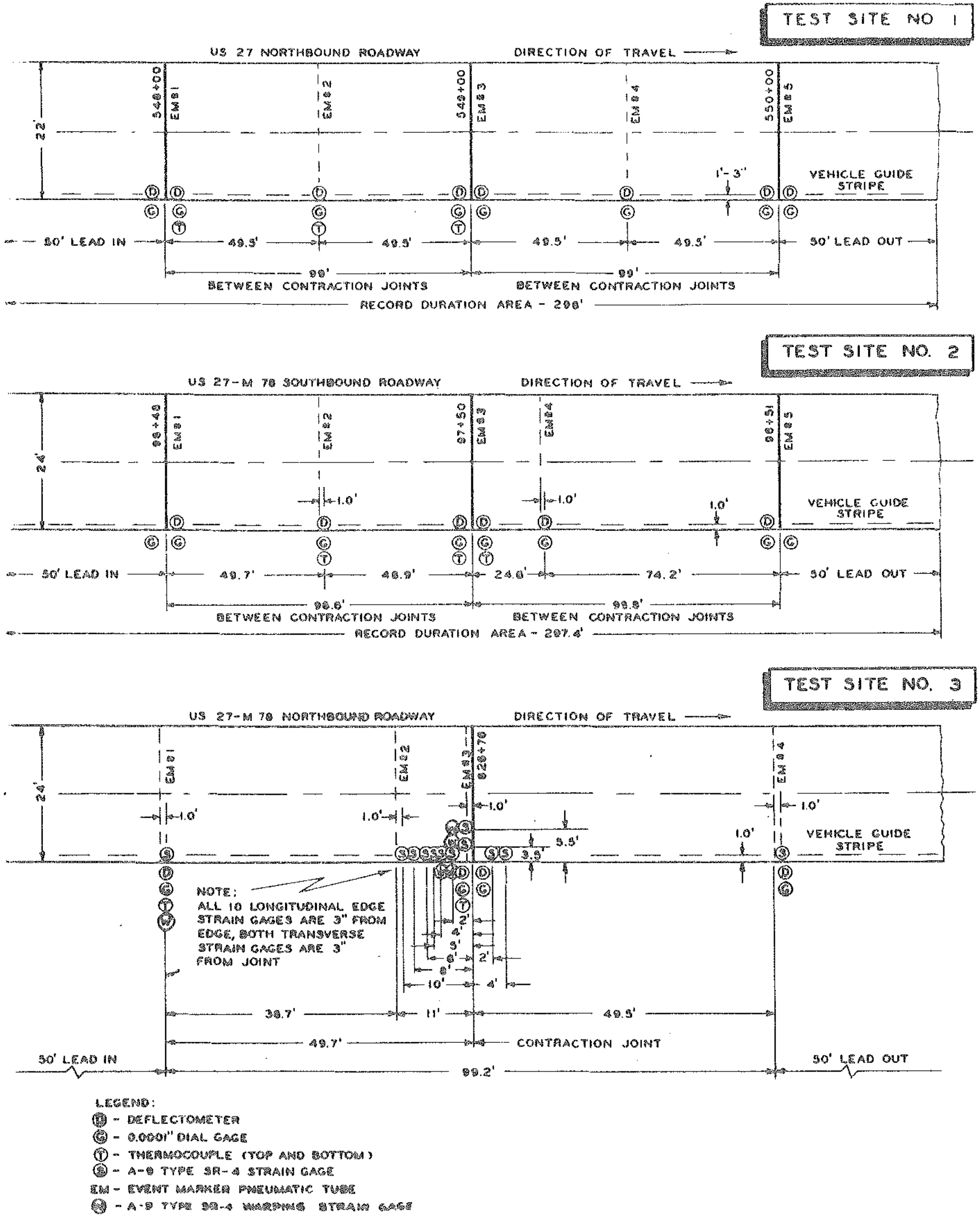

Figure 1. Site and instrumentation plans for the three field tests.

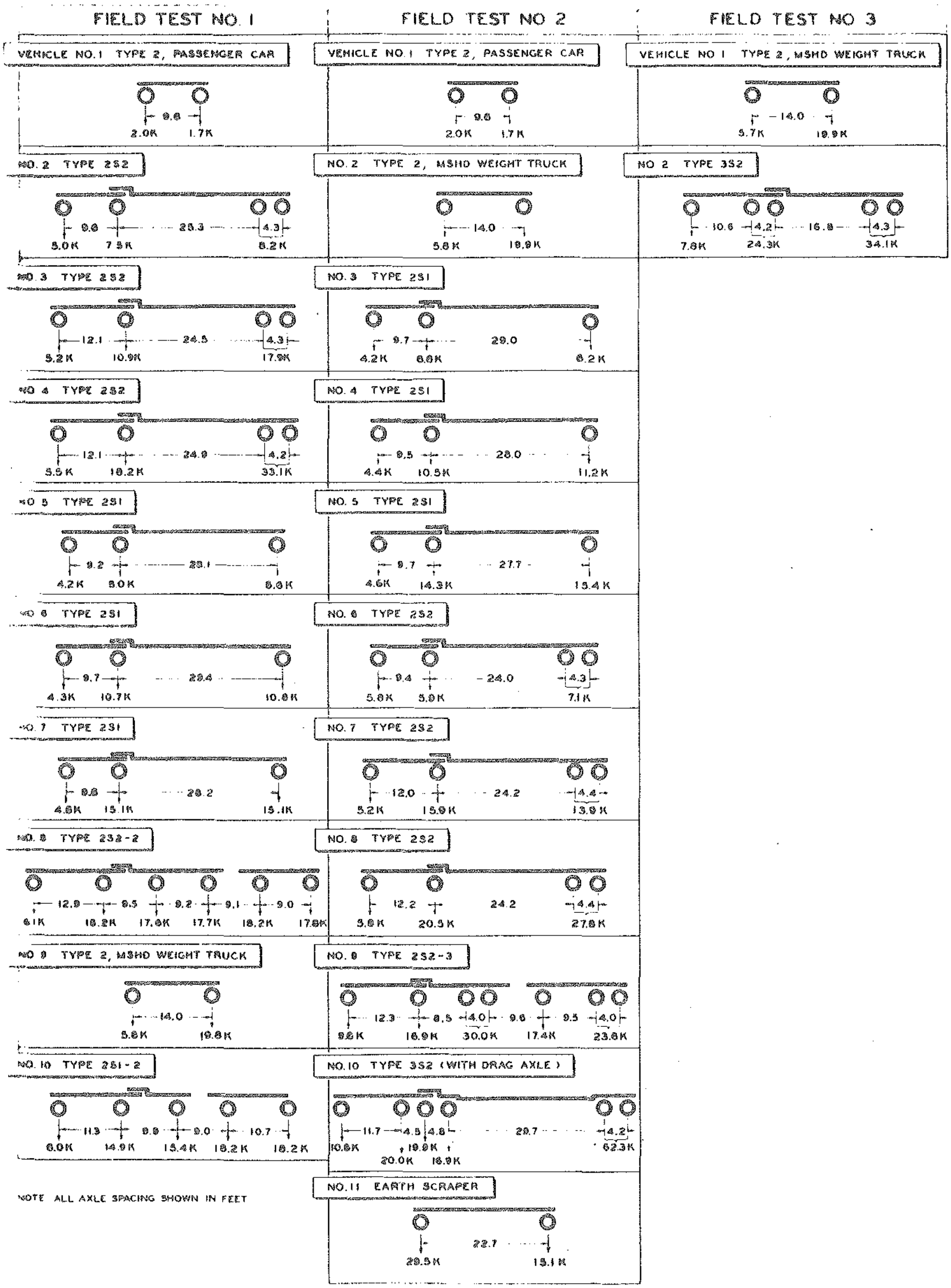

Figure 2. Vehicles for the three tests, including axle spacings and loads.

its runs so that the outer edge of the outside tire of the load axles followed an alignment stripe 1 ft 3 in. from the pavement edge.

Before and during the test period, at 30-minute intervals, recordings were made of air and pavement temperatures, and pavement elevation changes.

Any given concrete pavement slab is in almost continuous movement due to air and solar radiation temperature variations. These temperature variations cause the slab ends to warp downward when the slab top surface is warmer than the bottom (day), or upward when the surface is cooler than the bottom (night). Thus, the magnitude of deflection of a pavement joint corner under a given fixed load obviously varies throughout the day, as the slab ends move toward or away from their support, the subbase. Because of this phenomenon and because it is impossible to run many dynamic pavement deflection tests in any short period, separate tests with a given vehicle over a 2-hour period will yield varying deflection data. Thus, deflection data have to be corrected to one time.

In this test series, all data were corrected to 2:00 p.m., the series starting time, using the following procedure:

The MSHD weight truck made three pre-test runs at 2:00 p.m., and three post-test runs at 4:15 p.m. Both of the three-run series were completed in 8 minutes or less, so the change in pavement load-deflection relationship would be negligible.

The average deflection of the three pre-test runs was then subtracted from the average for the post-test runs, and the difference used in connection with straight-line interpolation to correct the deflection of all test vehicles to the standard 2:00 p.m. Separate correction factors were used for each of the eight test points.

Field Test 2

The second test was performed June 20 and 21, 1957, on a 300-ft section of the southbound roadway of US 27 - M 78, about 2 miles southwest of Lansing (Project 23-17, C11)

This concrete pavement, built in 1952, was of a 9-in. uniform thickness, 24-ft wide, on a 15-in. subbase over Miami series soil meeting the Highway Research Board A-4 classification.*

The test objective was to duplicate the Test 1 afternoon data, and also to complete the early morning runs that rain had prevented during Test 1. The site and instrumentation are shown in Fig. 3. The afternoon and the predawn tests were both successful--the first between 1:50 and 6:00 p.m. on June 20 and the second between 12:40 and 4:30 a.m. on June 21.

The procedures were identical with those of Test 1, with these minor differences:

1. The test site was changed to a more satisfactory location.

2. Each vehicle made only three runs instead of five during each test series.

3. Vehicle load axles were positioned 1 ft from the pavement edge rather than 1 ft 3 in.

4. Pavement and air temperatures and pavement elevation changes were recorded at 30-minute intervals from 11:00 a.m. on the first test day through 11:00 a.m. of the second day.

5. Fig. 2 shows variations in vehicle axle loads and spacings between the two tests.

The MSHD weight truck again was used as a control vehicle, for the same purpose and in the same manner as in Test 1. All deflection data were corrected to mid-test times--3:16 p.m. and 2:10 a.m. for day and night, respectively.

<u>Field Test 3</u>

The third test took place August 31 and September 1, 1957, on a 100-ft section of a short spur of the northbound roadway of US 27 - M 78 about 2 miles northeast of

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* In connection with this field investigation, tests were also run on a flexible pavement on M 79 near Charlotte. However, due to various troubles encountered in instrumentation and testing, the resulting data were considered too erratic and unreliable to be included in this report.

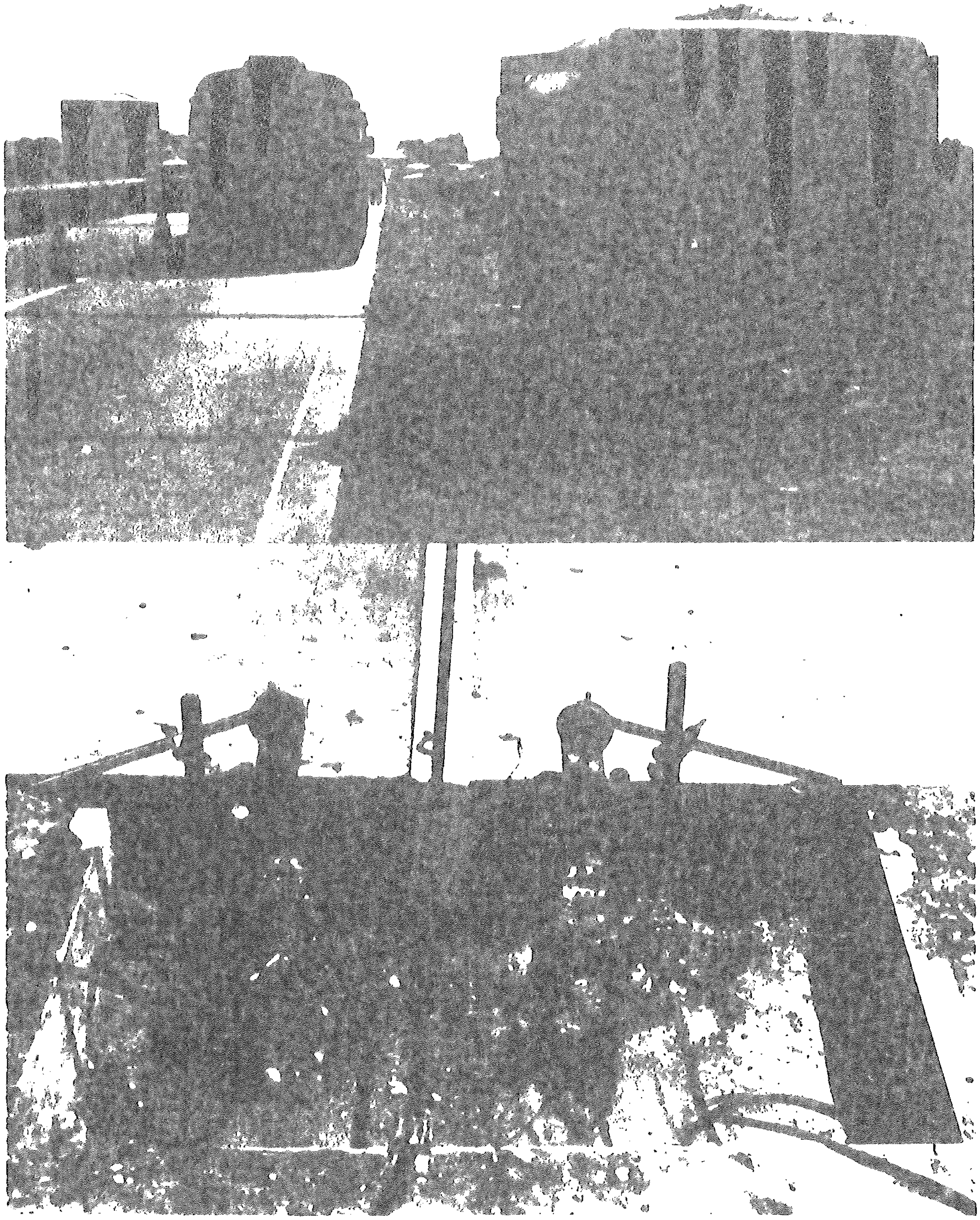


Figure 3. Field Test 2 site, and instrumentation at joint.

Charlotte (Project 32-17, C14). This spur section had been built in 1956, but was not yet open to traffic. The 24-ft, 9-in. uniform pavement was constructed on a 12-in. subbase, over subgrade soil of the Conover series falling in the A-4 and A-6 classifications of the Highway Research Board.

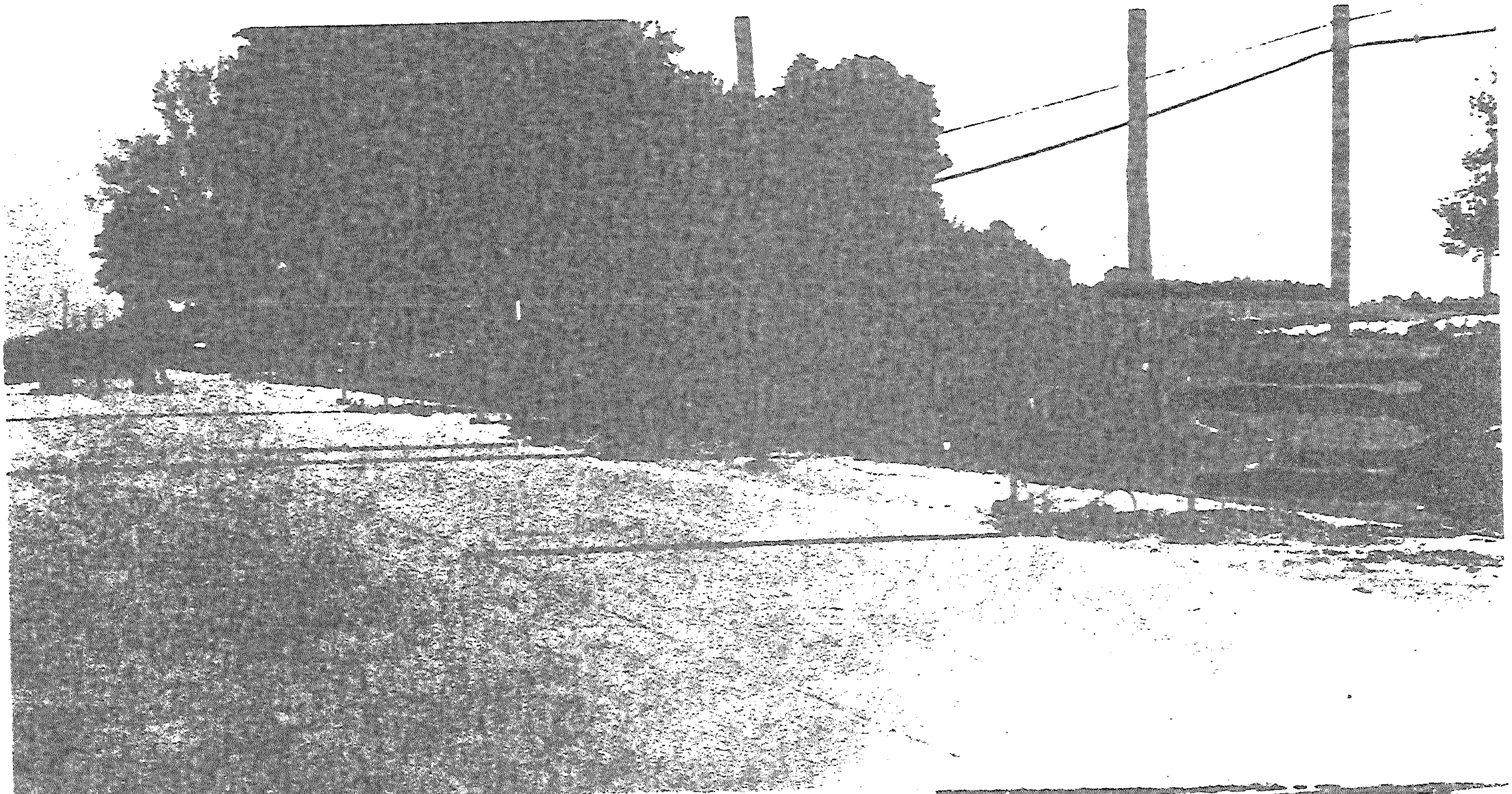
The test instrumentation and procedures were considerably different than for either of the first two field tests, since the test objectives were different. The site and instrumentation are shown in Fig. 4.

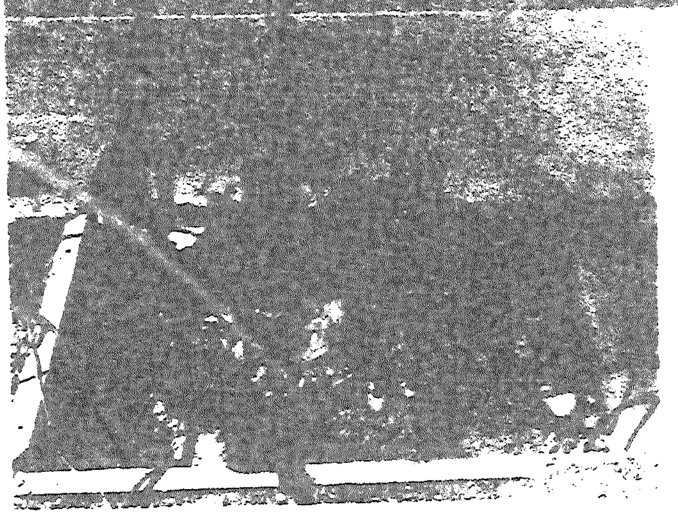
The 100-ft pavement area under study included 50 ft at either side of a contraction joint. In addition to being instrumented with deflection transducers, this region had a number of electrical resistance type strain gages mounted on the slab and positioned so as to determine the magnitude and distribution of slab surface stresses under dynamic loads (Fig. 1).

The test procedure consisted of six creep-speed runs--three by each of the two test vehicles--every hour for a 24-hour period starting at 1:50 p. m. on August 31, and continuing until 1:30 p. m. on September 1. The two test vehicles were the MSHD weight truck with a single rear axle loaded to 19.9 kips, and a Type 3S2 truck with a tandem rear axle loaded to 34.1 kips (Fig. 2).

During each set of hourly runs, oscillographic recordings were made of pavement deflections and strains. Each run was made with the vehicle positioned laterally so that the outside edge of the outside tire of the load axle was 1 ft from the pavement edge.

Immediately preceding each hourly test, readings were taken and recorded for the pavement and air temperatures, the pavement elevation changes, and the pavement surface warping strains.





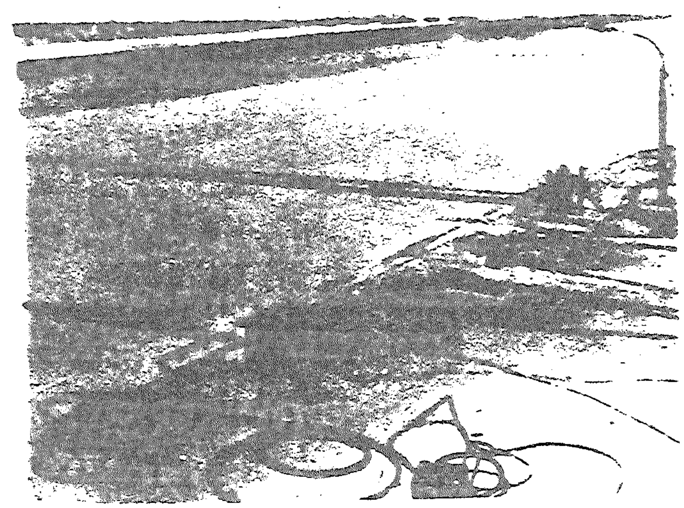


Figure 4. Field Test 3 site (above), with views of deflectometer (left) and strain gage instrumentation (right).

DATA ANALYSIS

A fundamental objective of Tests 1 and 2 was to establish data on two relationships:

1. The influence line for pavement deflection as an axle load approaches, passes over, and travels away from a given point on the pavement, and

2. The axle load-to-pavement deflection relationship at a given point on the pavement.

While these two relatively simple relationships form the crux of the theory which will be discussed later, actually applying these relationships to the problem of vehicular effects on pavement is complicated by a multiplicity of factors which may affect these relationships. These factors include:

1. The location of the point on the pavement under consideration--whether along the longitudinal free edge, along the edge but adjacent to a transverse joint, or at an interior point on the pavement slab (only the first two of these types were considered in the tests or analyses).

2. The stiffness of the subgrade, or more specifically the modulus of subgrade reaction.

3. The stiffness of the pavement slab, which is influenced by thickness.

4. Climatic conditions--the moisture content of the subgrade which influences the second factor, subgrade stiffness, and the warping of the slab which depends upon temperature differential throughout the depth of the slab. Slab warping influences the amount of support the slab receives from the subgrade.

5. The magnitude of the axle load under consideration.

These factors have been considered in the analysis either directly by grouping the data so that the effect of these factors is apparent, or indirectly by controlling or adjusting them so as to eliminate their effect.

Influence Lines for Pavement Deflection (Tests 1 and 2)

In both Field Tests 1 and 2, test vehicles were selected to obtain maximum distances between the last axle and the preceding axle. This was done to isolate the pavement deflection resulting from the last axle as much as possible from that resulting from the preceding axle, thus obtaining the influence of only a single axle. A typical oscillograph trace of pavement deflection is shown in Fig. 5.

To determine the effect of the magnitude of axle load on the influence line, a wide range of axle loads were used on the test vehicles. Single axle loads varied from 6.6 to 15.1 kips in Test 1, and 6.2 to 15.4 kips in Test 2. Tandem axle loads varied from 8.2 to 33.1 kips and 7.1 to 27.8 kips for Tests 1 and 2 respectively. Test points were grouped at the longitudinal free edge as follows: at the slab center, at the approach side of a transverse joint, and at the leaving side of a transverse joint.

Further subdivision was made with regard to single or tandem axle types, and time of day, which had a marked influence on deflection, and all test runs were properly adjusted to a common time. However, day and night tests were separated because of the great difference between magnitudes of deflection in these two periods. The influence of axle weight was also considered, but it was found that for the range of loads used on the commercial vehicles, the magnitude of the axle load did not significantly affect the influence line.

In Fig. 6, the influence lines for pavement deflection due to a single axle load are given for Test 1 at the three pavement points mentioned previously. It should be noted that in Fig. 6, the influence line for the approach side of the joint corner was nearly identical to that for the leaving side, and subsequently in this report, the approach and leaving side test points are combined as joint corner without further designation.

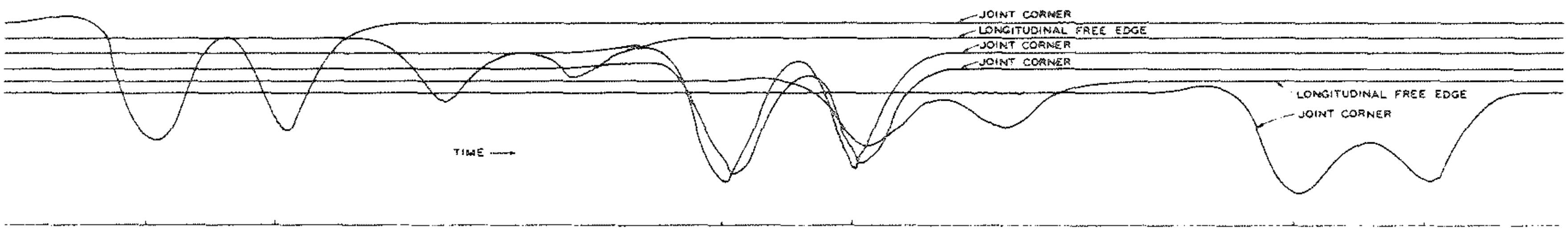


Figure 5. Typical oscillograph trace--deflection caused by passage of two-axle truck.

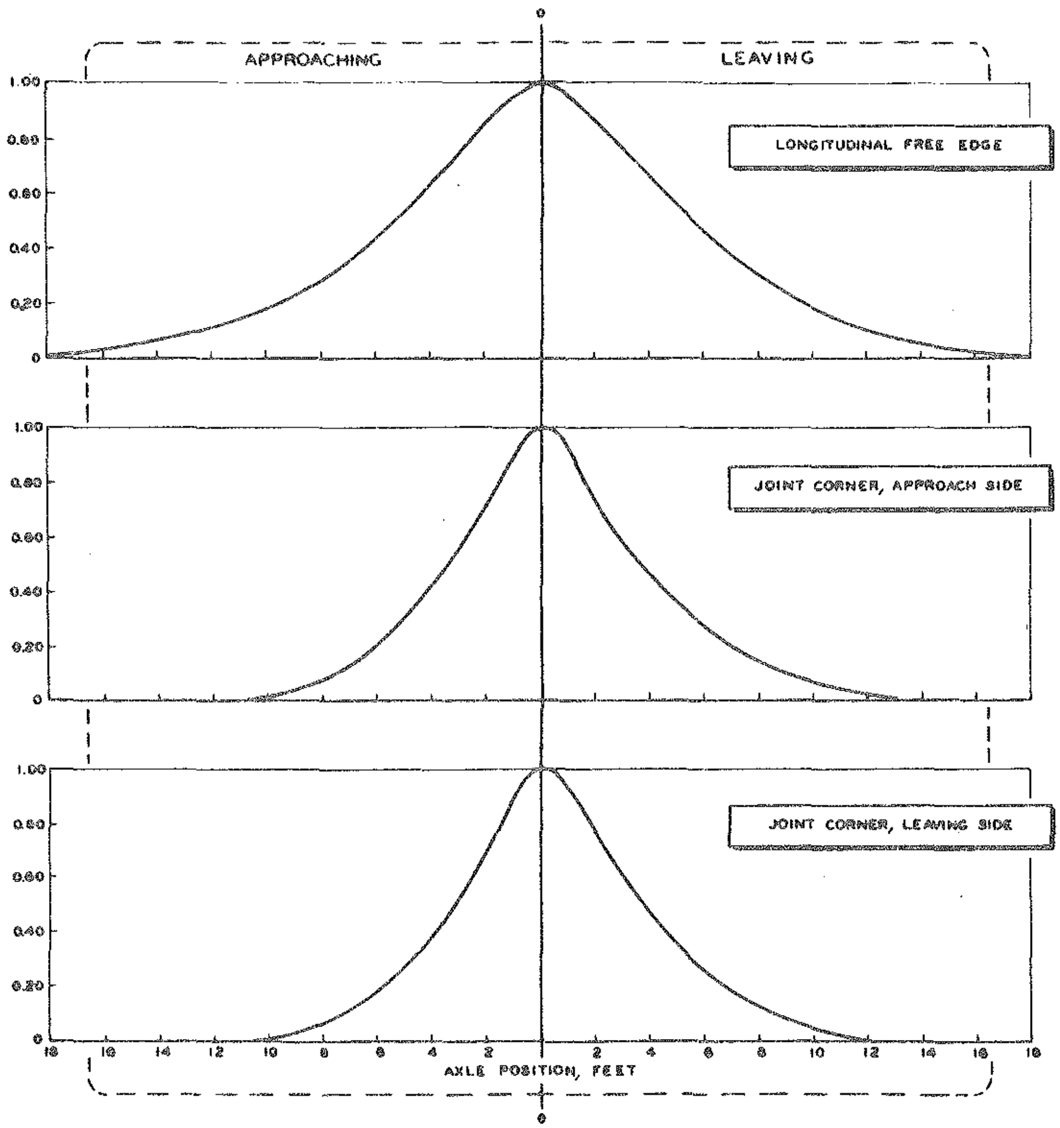


Figure 6. Influence lines for pavement deflection: Test 1 (day), single axle.

Fig. 7 gives the influence lines for pavement deflection for single axles at the longitudinal free edge and at the joint corner for Test 2 under day and night conditions. The greater distance over which an axle load affects deflection at night is very apparent. The reason for this, however, is best discussed in connection with load-deflection relationships. Although day and night influence lines differ considerably, Fig. 8 shows that those for pavement deflection at night at two different locations are very similar. The influence line designated "Alma" is from data obtained in 1952 on US 27 just east of Alma, Michigan (8-in. pavement) and reported in 1956 in Research Report 256. Influence lines for pavement deflection due to tandem axles are given for Tests 1 and 2 in Figs. 9 and 10. The type of pavement position--longitudinal free edge or joint corner--and the concrete pavement warping determine whether these influence lines will have single or double peaks. The zero location represents the time the tandem axle is straddling the pavement point where deflection is being measured.

Load-Deflection (Tests 1 and 2)

Load-deflection relationships for single and tandem axles at longitudinal free edge and joint corner positions are shown under day and night conditions for Tests 1 and 2 in Fig. 11. When comparing daytime deflections in Tests 1 and 2, it should be remembered that Test 1 was conducted in November under moist subgrade conditions and Test 2 in June under much drier subgrade conditions--one reason for the much greater deflections in the first case.

Load-deflection relationships in Fig. 11 also compare the effects of single and tandem axle loads. As shown in Table 1, the tandem axle load equivalent to an 18-kip single-axle load for deflection depends on pavement position, amount of warping (i. e., day or night conditions), and may be influenced by other factors not investigated in this

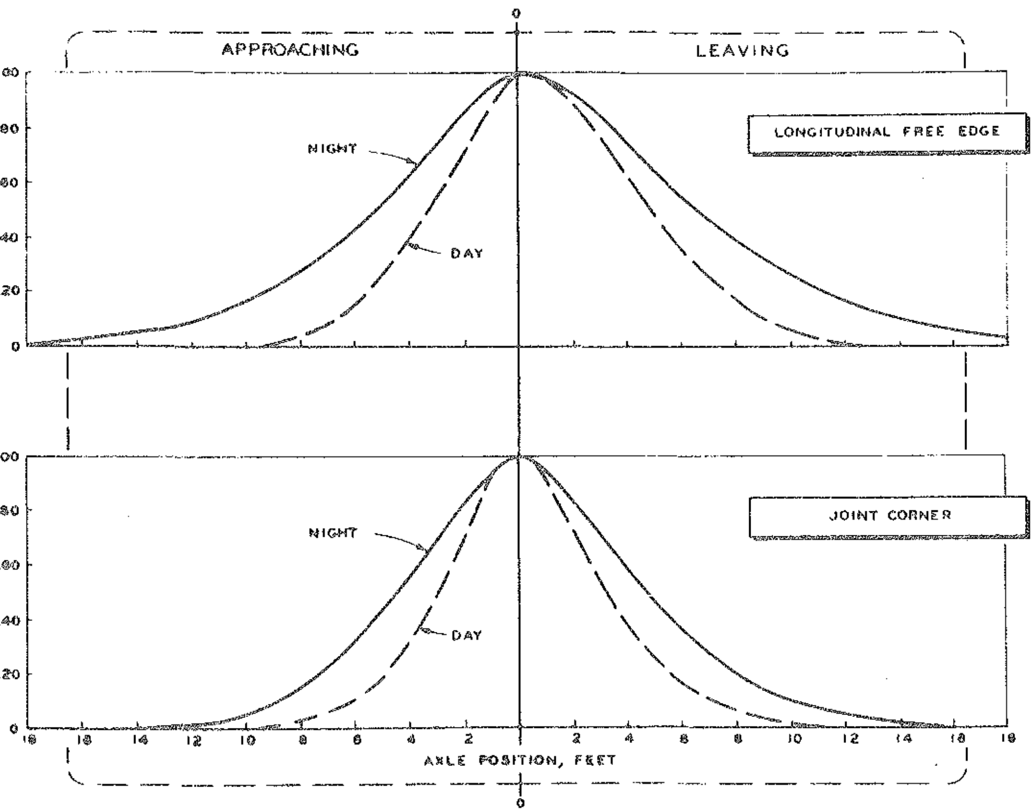


Figure 7. Influence lines for pavement deflection: Test 2, single axle.

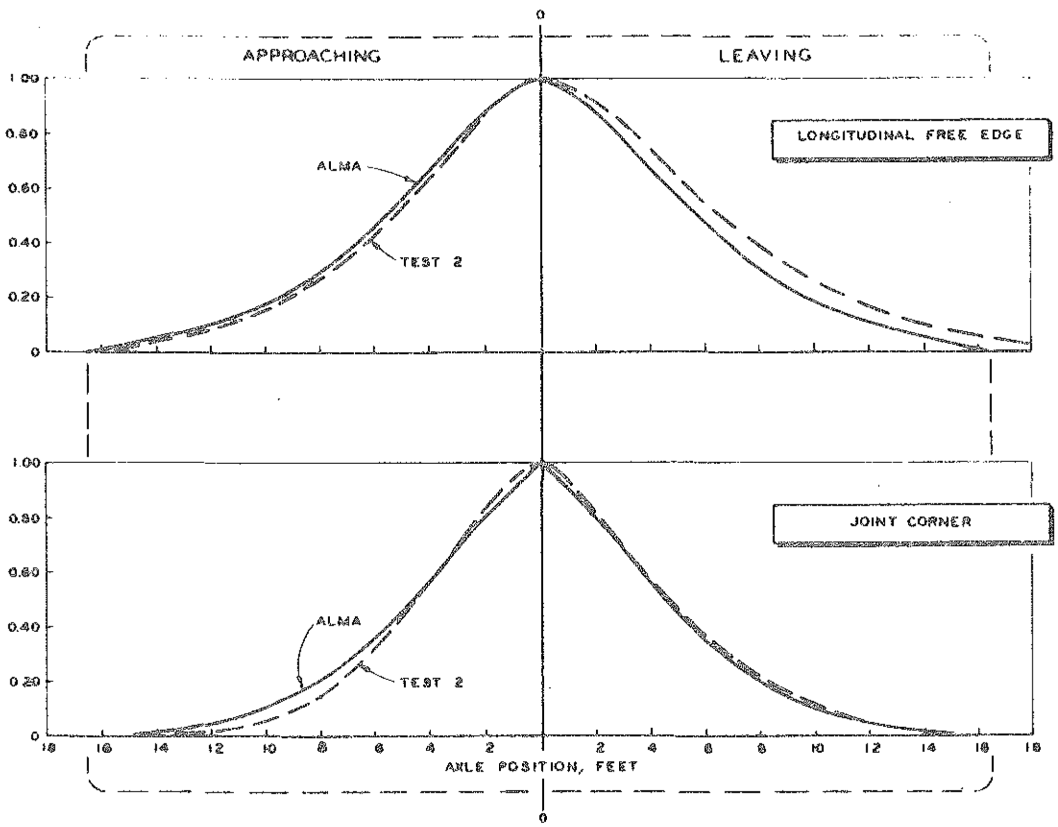


Figure 8. Influence lines for night pavement deflection: comparison of Test 2 and Alma Test.

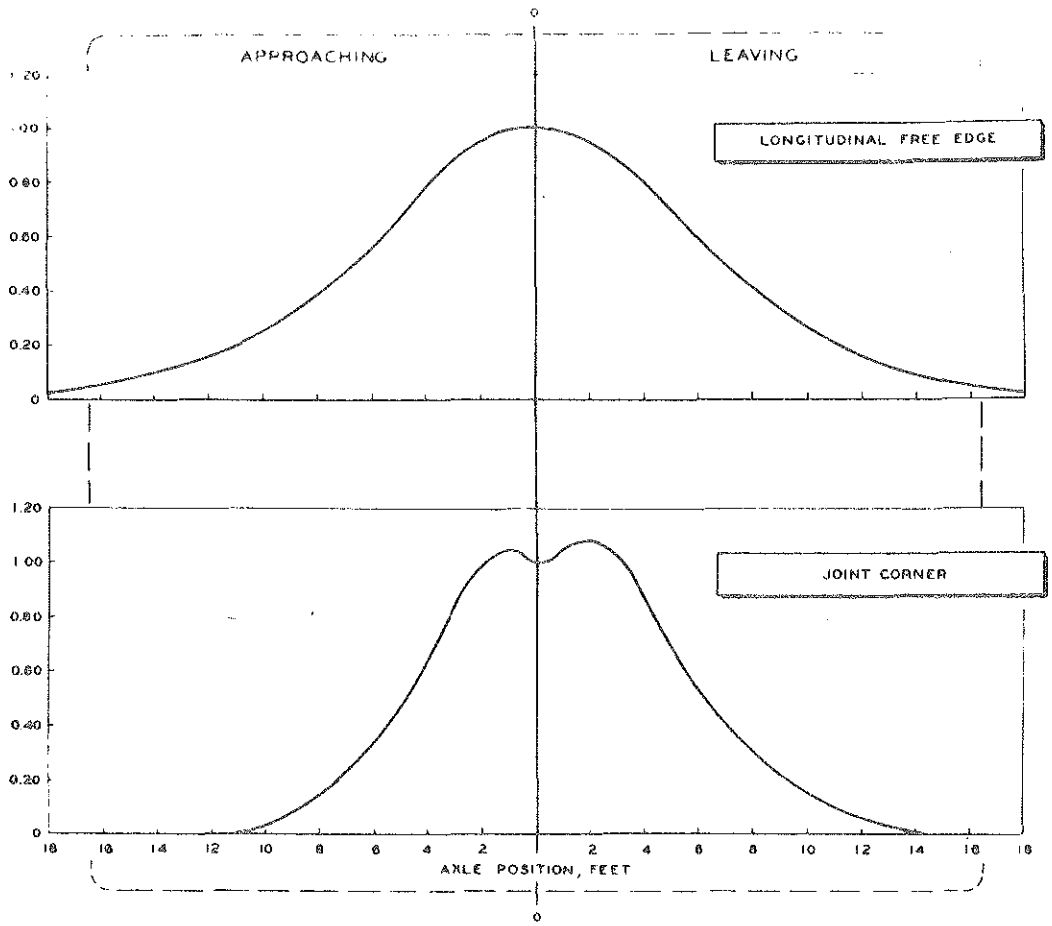


Figure 9. Influence lines for pavement deflection: Test 1 (day), tandem axles.

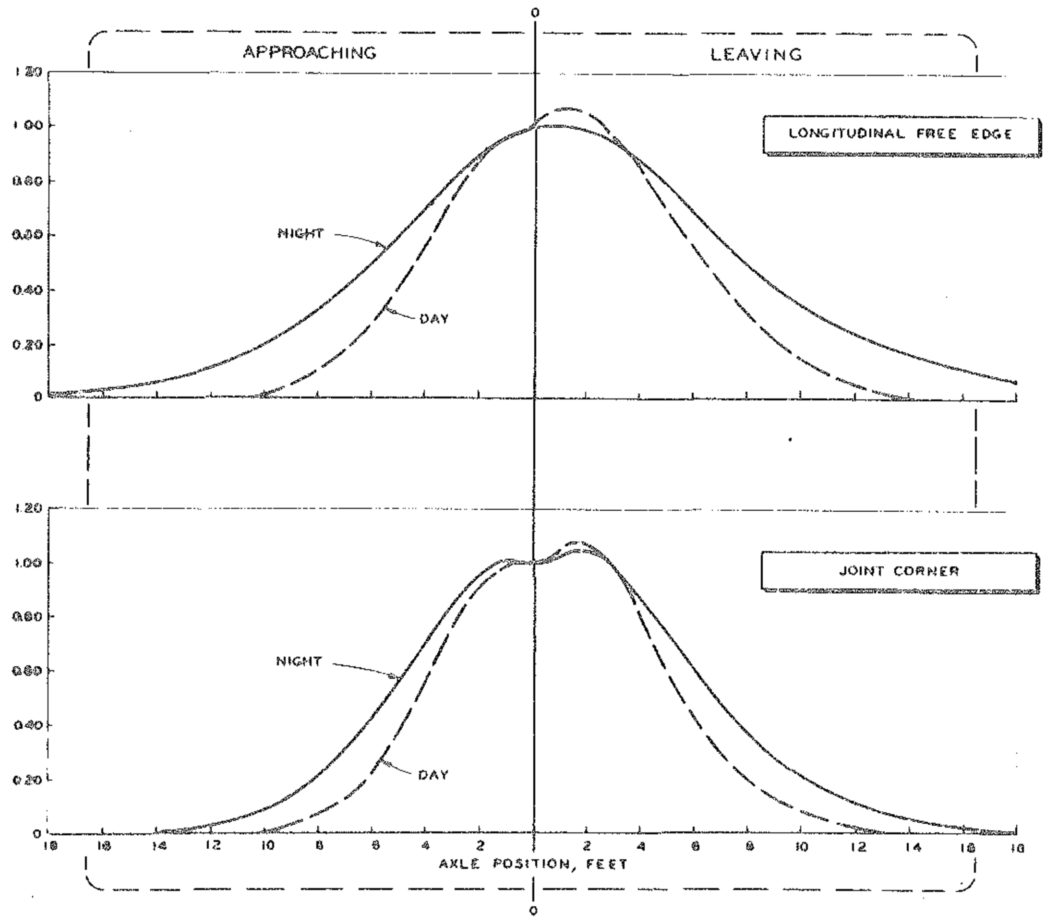


Figure 10. Influence lines for pavement deflection: Test 2, tandem axles.

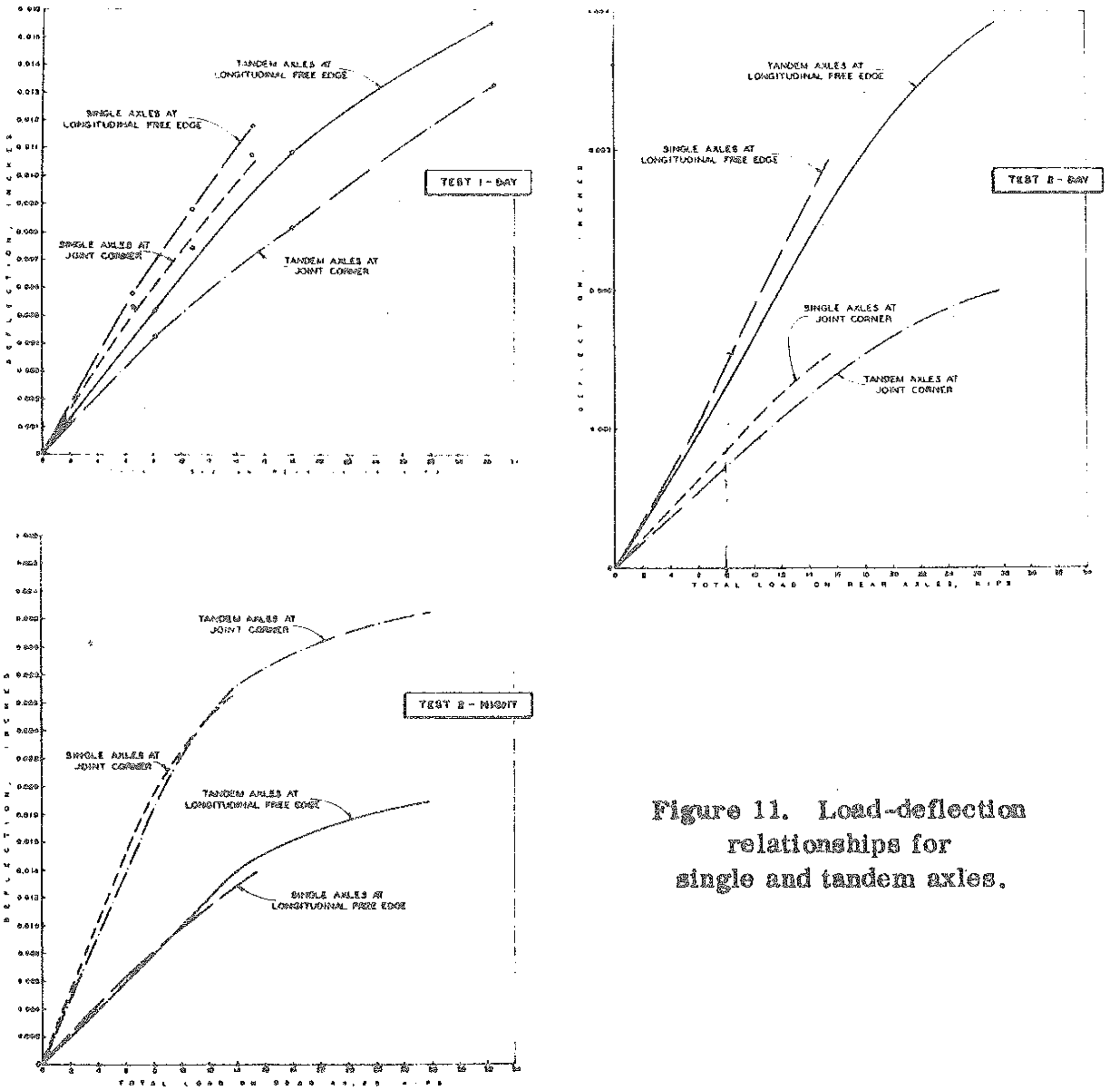


Figure 11. Load-deflection relationships for single and tandem axles.

TABLE 1
TANDEM AXLE LOAD EQUIVALENT TO 18-KIP SINGLE AXLE LOAD
BASED ON PAVEMENT DEFLECTION

Data Source	Tandem Axle Load Equivalent, kips	
	Day	Night
Test 1		
Longitudinal Free Edge	25.8	----
Joint Corner	29.0	----
Test 2		
Longitudinal Free Edge	21.7	16.5
Joint Corner	21.0	17.2
Alma, 1952		
Longitudinal Free Edge	----	20.5
Joint Corner	----	25.4
AVERAGE	24.4	19.9

program, such as pavement thickness or modulus of subgrade reaction. Individual values for this relationship for a single test may have very little value, but averaging values from several may give an approximate ratio between these two axle types. Averaging the joint corner and the longitudinal free edge positions, results in a tandem axle load of 24.4 kips during the day and 19.9 kips at night as equivalent to an 18-kip single axle load.

In Fig. 12, day and night deflections are shown at a common scale to illustrate the significance of the effect of slab warping on pavement deflection. In general, during the day the top surface is warmer than the bottom, tending to cause the slab to warp downward. Differences in moisture content also influence slab warping so that even during the day the slab may not warp downward but instead may be less severely warped upward or more nearly flat. During the night, the top surface is generally cooler than the bottom, causing the slab to warp upward and thus lose effective subgrade support, especially at joint corners.

As a result of this warping, pavement deflections for a given axle load become much greater at night than during the day, this increase being most marked at the joint corner. As Fig. 12 shows, night deflections were approximately 18 times greater at the joint corner, and 5 times greater at the longitudinal free edge, than were day deflections for a given load. Although this appears high compared to most published data on night-to-day deflections, the ratios were 10.7 to 1 and 8.1 to 1 for the joint corner and longitudinal free edge, respectively, for Test 3, discussed later in this report.

~~Also, a~~ A limited test program was conducted by the Department in August 1954, on 9-in. concrete pavement, which also gave ratios similar to these. For an air

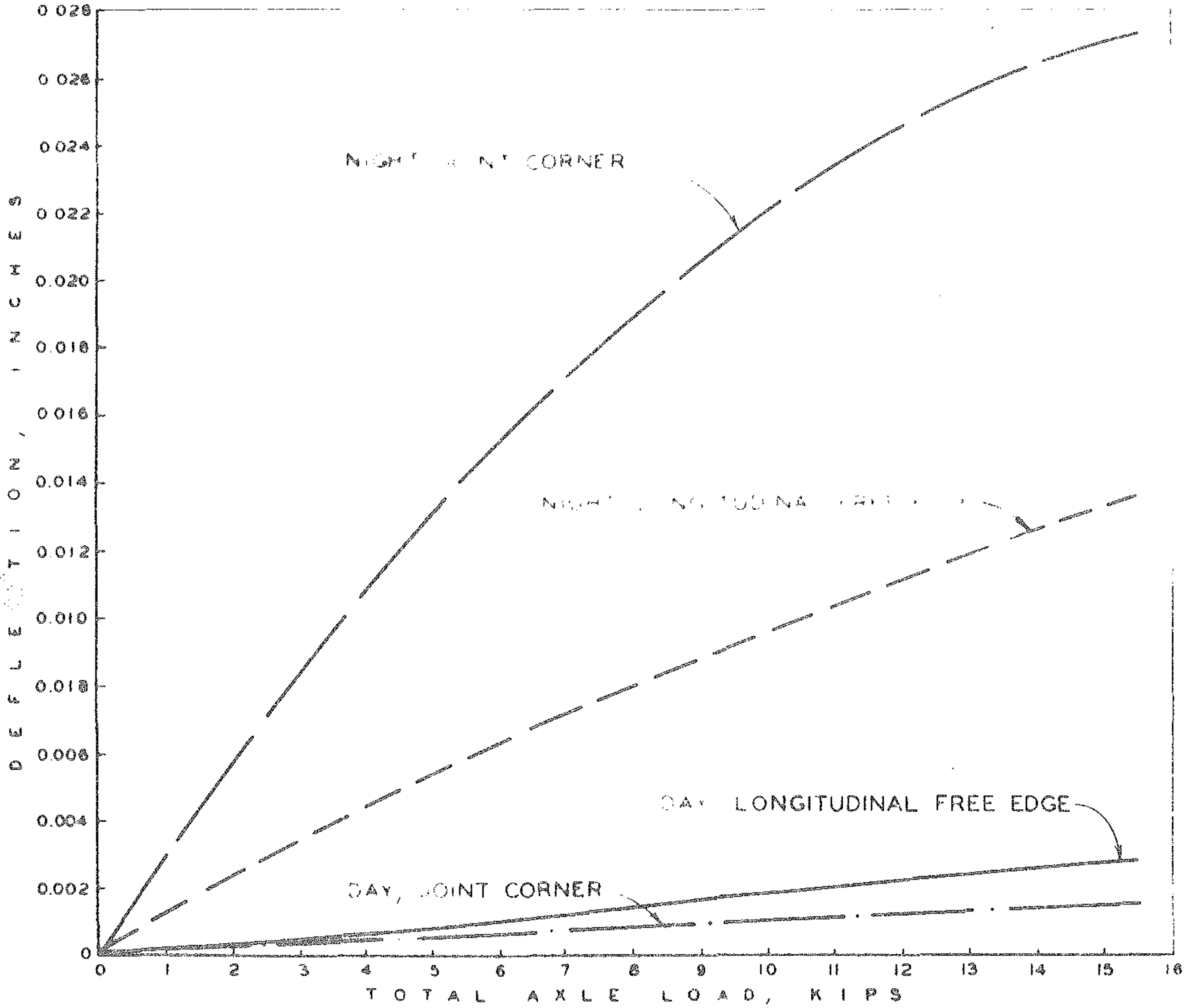


Figure 12. Load-deflection relationships: Test 2, single axle.

temperature range of 46 to 83 F from night to day, the maximum ratio of night-to-day deflections at the joint corner for a given load was 12.2 to 1. The effect of slab warping on pavement deflections and pavement stresses will be discussed more completely in connection with Test 3, where observations were made approximately hourly throughout a 24-hour period.

Use of Data

In the first two tests, the recorded vehicle patterns represented vertical deflection of the pavement slab. These deflections will be used later in this report to develop a theory for determining the relative effect of vehicles on a concrete pavement. Repeated pavement deflection may cause a gradual loss of subgrade support due to displacement of subgrade material, and thus may be used as a measure for determining the gradual deterioration of the pavement structure.

Another type of pavement deterioration, which may not be caused by gradual loss of subgrade support, but suddenly by the application of one load exceeding the tensile strength of the concrete pavement, is pavement cracking. Cracking is caused by excessive tensile strain. Therefore, to complete the picture of the effect of vehicles on concrete pavements, it is necessary to determine not only the pavement deflections but also the pavement strains. Consequently, an experimental study of the relationship between pavement load-deflection and load-strain was considered necessary to reinforce or to modify any relative effect theory based on pavement deflection. For this purpose, Test 3 was organized and performed.

This phase of the report presents data obtained from that test, discusses the factors which affect pavement deflection and strain, and correlates these two measures of vehicle relative effect.

Influence Lines for Pavement Strain and Deflection (Test 3)

Fig. 13 shows influence lines for pavement strain and deflection for a single axle load under day and night conditions at the longitudinal free edge and the joint corner. One feature which is very apparent in this comparison is the much shorter influence of axle loads on strain, together with the fact that there are both tension and compression strains in the top surface of the pavement. It may be seen that tensile strains at the longitudinal free edge top surface relative to the compressive strains are larger during the day than at night. This is also true at the joint corner. Maximum tensile strains with the axle load at the joint, exceed the compressive strains when the wheel is over the strain gage 5 ft from the joint, both in day and night tests.

Typical magnitudes of deflection and strain are shown in Figs. 14 and 15, for the two test vehicles under day and night conditions. Deflection and strain shown for the longitudinal free edge represent measurements made at that precise location. However, in the case of the joint corner, the maximum strains which occurred simultaneously with a maximum corner deflection were at a point 5 ft ahead of the joint.

In comparing day and night deflections under the single axle load (Fig. 14), the ratios are 1 to 10.7 at the joint corner and 1 to 8.1 at the longitudinal free edge. The ratios of day to night strains, however, are much smaller. Near the joint corner, day to night compressive strain ratios are 1 to 1.7 and tensile strain ratios are 1 to 2.8. At the longitudinal free edge, compressive strain ratios day to night are 1 to 1.2. Somewhat similar relationships are shown for tandem axle loads in Fig. 15.

Daily Deflection and Strain Variations

The third test program was designed specifically to obtain more detailed information on the influence of temperature and pavement temperature differentials on pavement warping, load-deflection, and load-strain during a 24-hour period. From

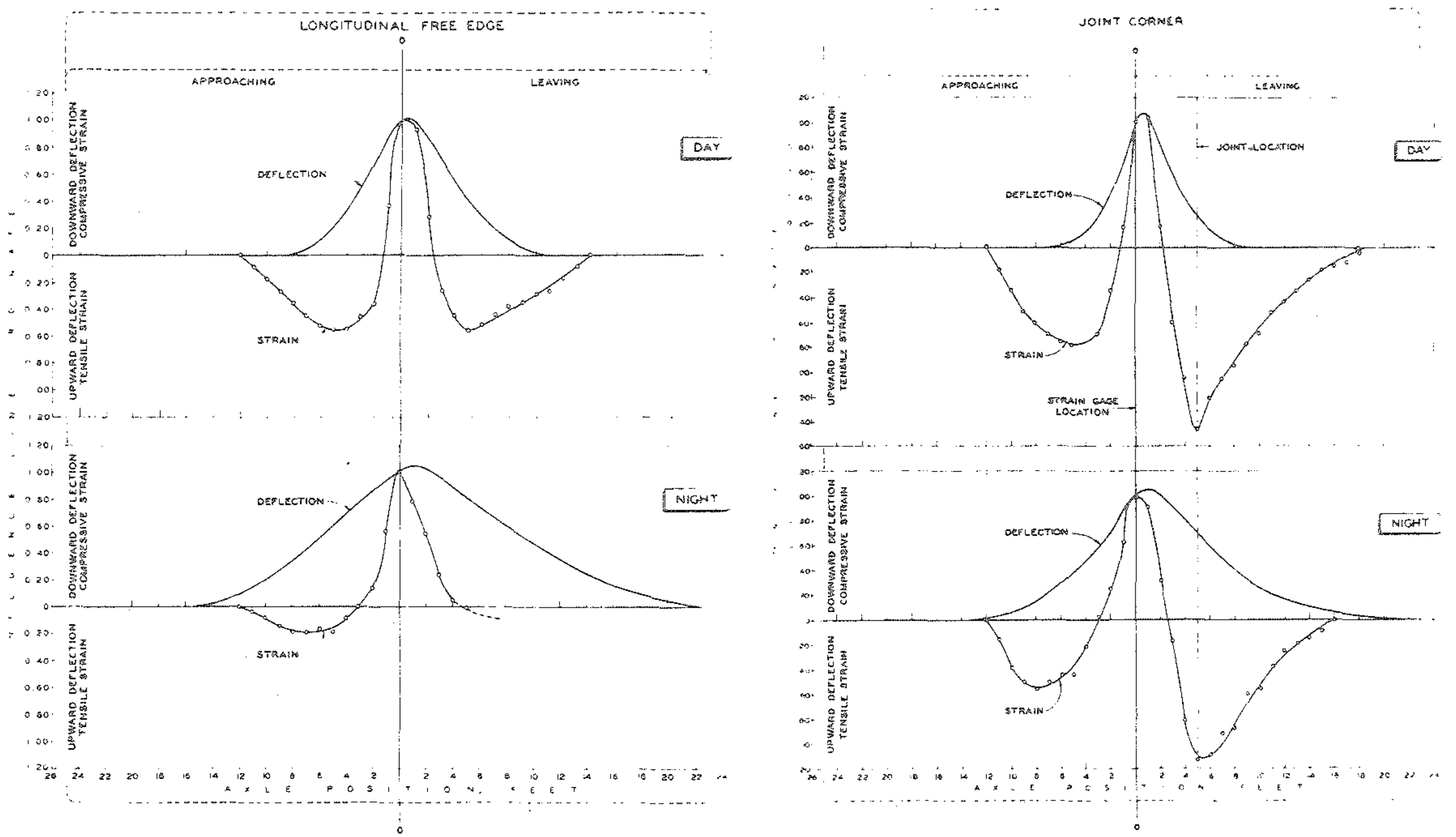


Figure 13. Influence lines for deflection and strain: single axle.

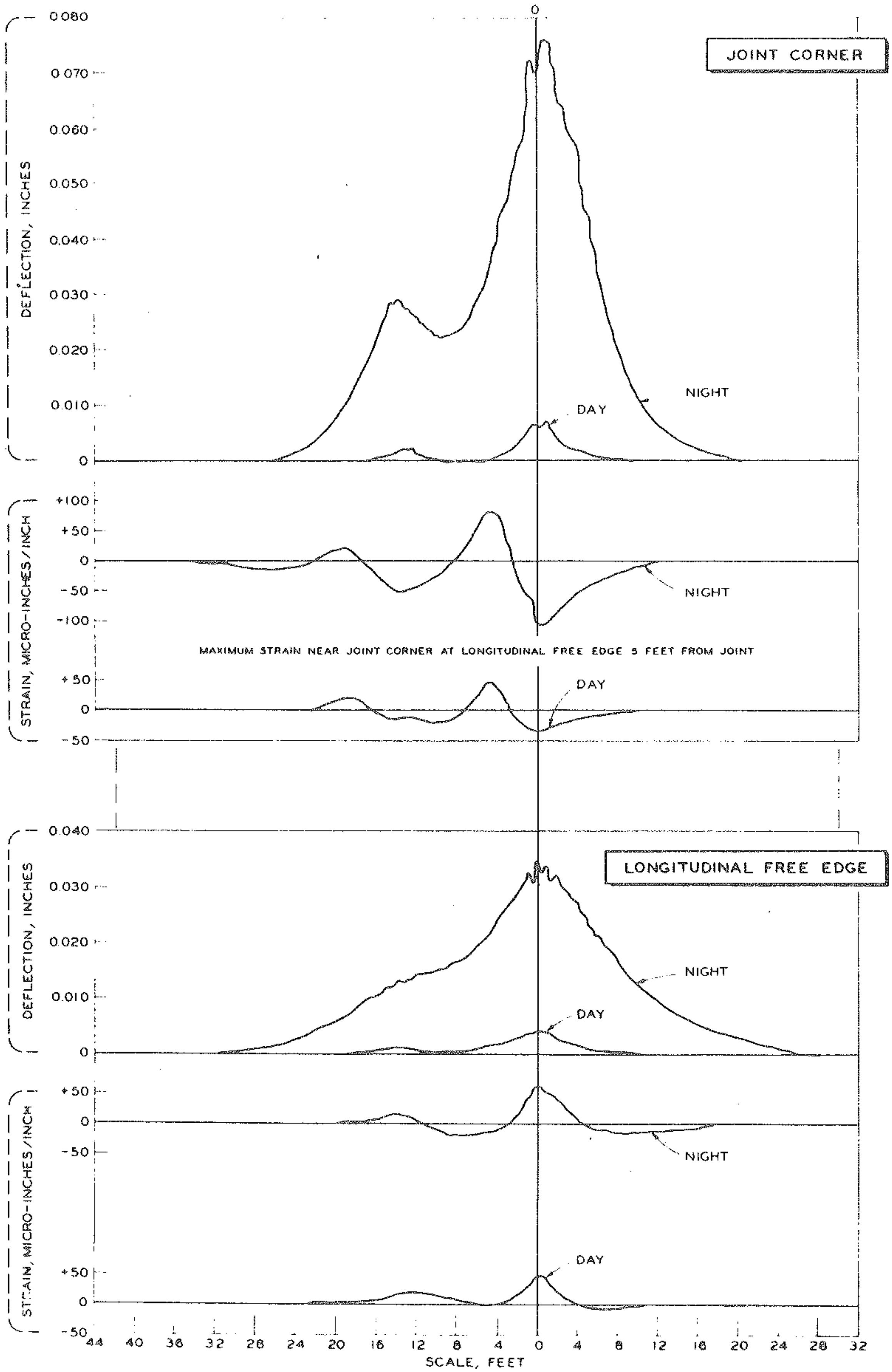


Figure 14. Deflection and strain patterns resulting from passage of Vehicle 1 Test 3 (single axle load--19.9 kips).

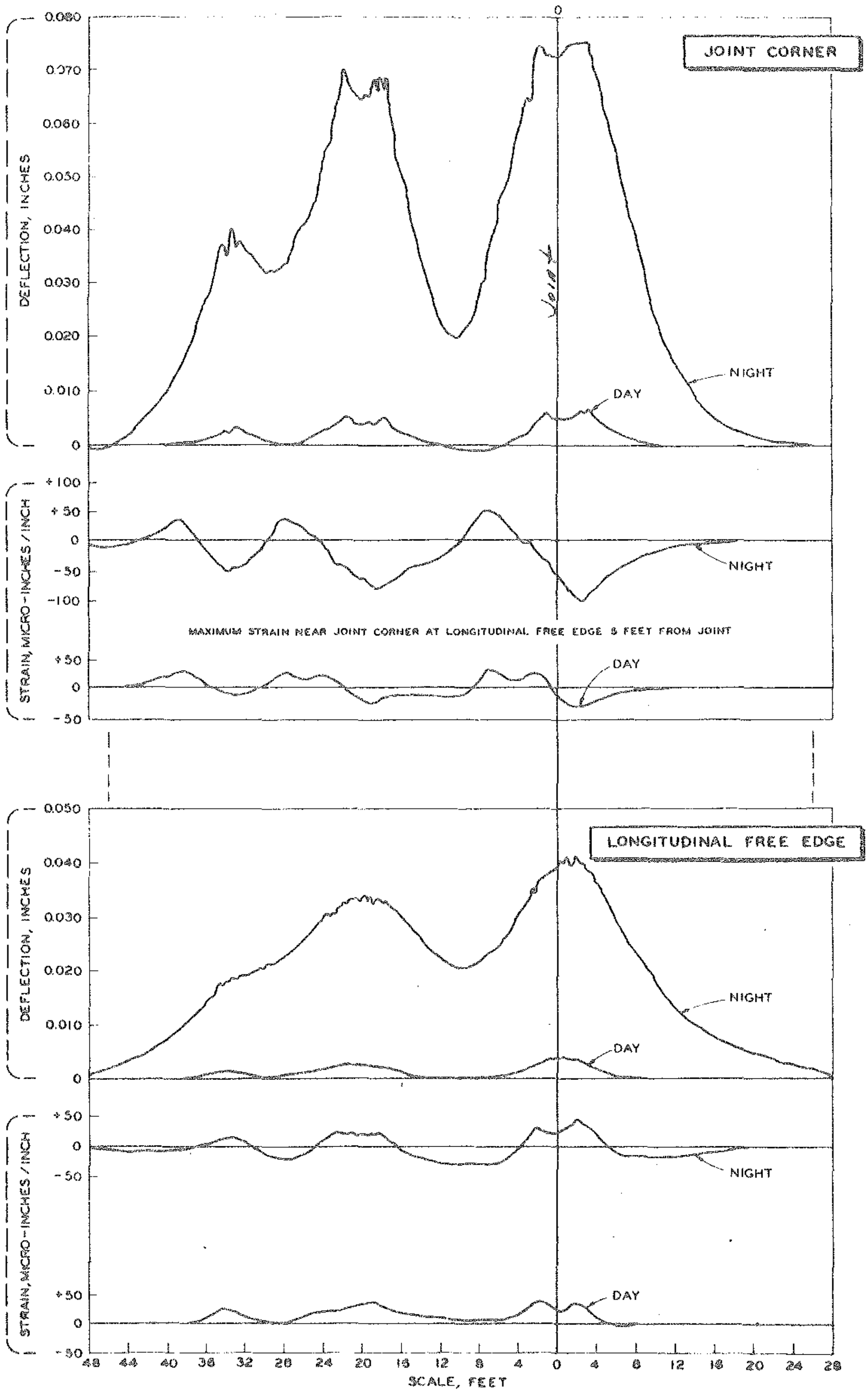


Figure 15. Deflection and strain patterns resulting from passage of Vehicle 2 Test 3 (tandem axle load--34.1 kips).

previous testing it was realized that temperature changes from hour to hour had a marked effect on these factors, and, therefore, air temperature and pavement slab temperature at the top and bottom of the slab were recorded approximately every hour. In addition, vertical movements of the pavement were also recorded.

In Figs. 16, 17, and 18 the air temperature and slab temperature differentials are shown to indicate their effect on pavement warping, and on deflection and strain near the corner and at the free edge due to a single axle load of 19.9 kips. The air temperature range for the 24-hour period was from a minimum of 64 F to a maximum of 92 F. This rather wide range in temperature resulted in a maximum total pavement temperature different between top and bottom of slab of 31F, or 3.45 F per in. with the top surface warmer than the bottom, and 16 F or 1/8 F per in. with the bottom surface warmer than the top. The pavement temperature differences resulted in a total warping movement of 0.150 in. at the joint corner and 0.065 in. at the longitudinal free edge.

The reference point, zero, for these warping movements was arbitrarily taken as the first reading, for it was not possible to establish any absolute reference point. Since the first readings occurred at approximately 1:30 p.m., with nearly a maximum positive temperature differential, the pavement edges were near their minimum relative elevation. The pavement deflection at the joint corner (Figs. 16 and 17) and at the free edge (Fig. 18), are also shown for an axle load of 19.9 kips for the 24-hour period. Pavement strains along the longitudinal free edge at various distances from the transverse joint are also given. The peak-to-peak strain variations, and the maximum compressive strains for the various test times are shown, the differences between these being the maximum tensile strains. At all pavement locations the maximum compressive strains occurred with the axle over the strain gage, while the maximum tensile strains generally occurred

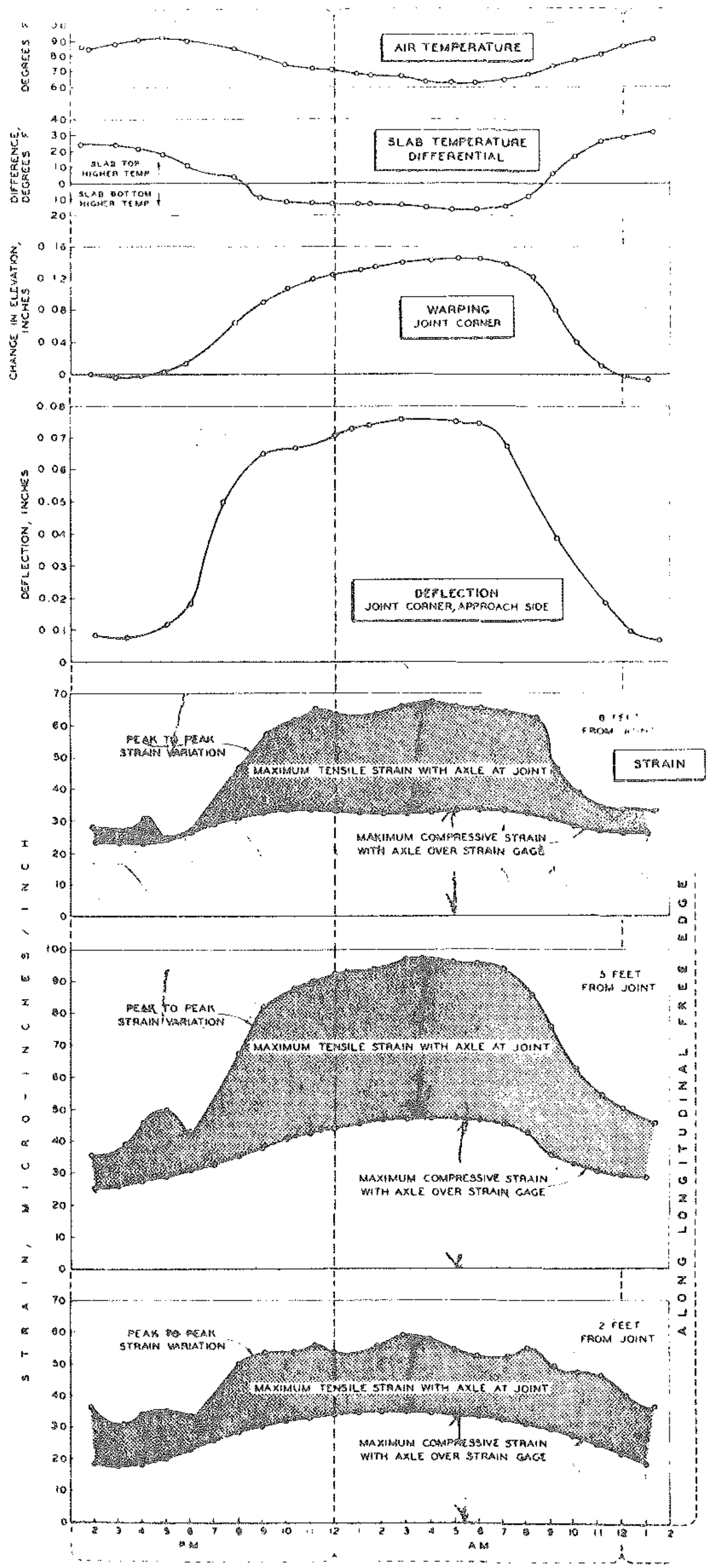


Figure 16. Temperature effects at joint corner, approach side, on pavement warping, load deflection, and load strains (single axle load--19.9 kips).

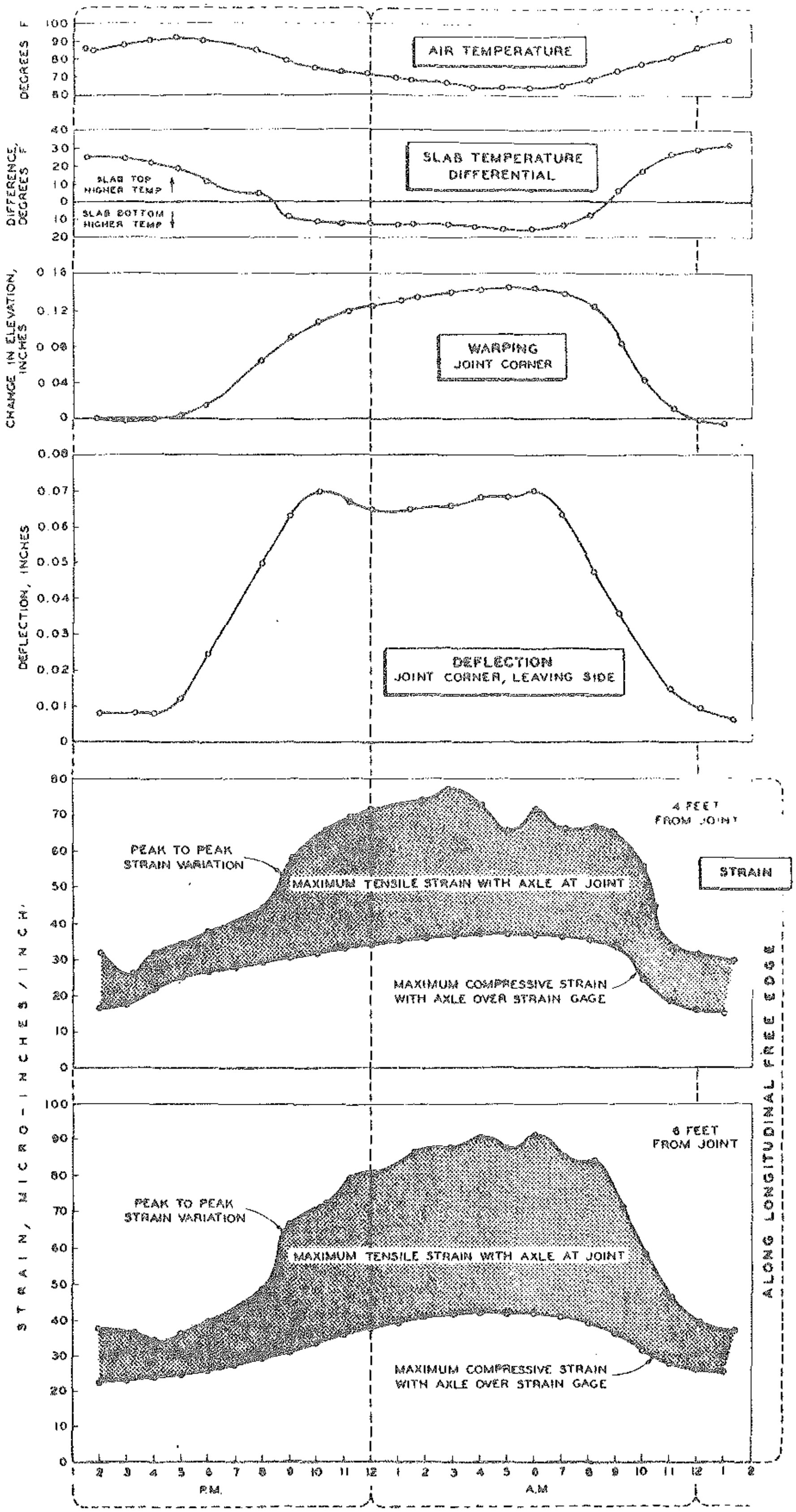


Figure 17. Temperature effects at joint corner, leaving side, on pavement warping, load deflection, and load strains (single axle load--19.9 kips).

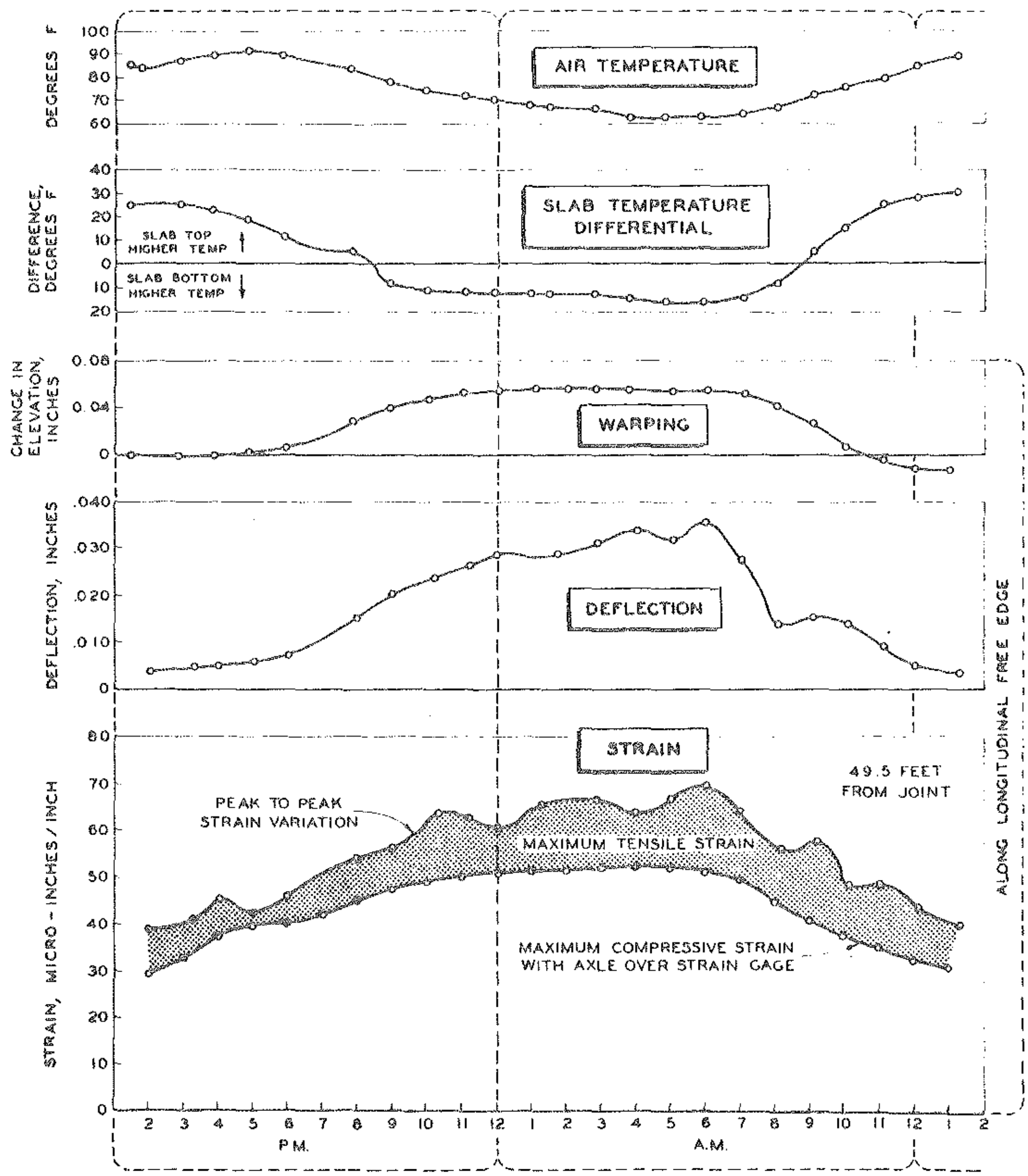
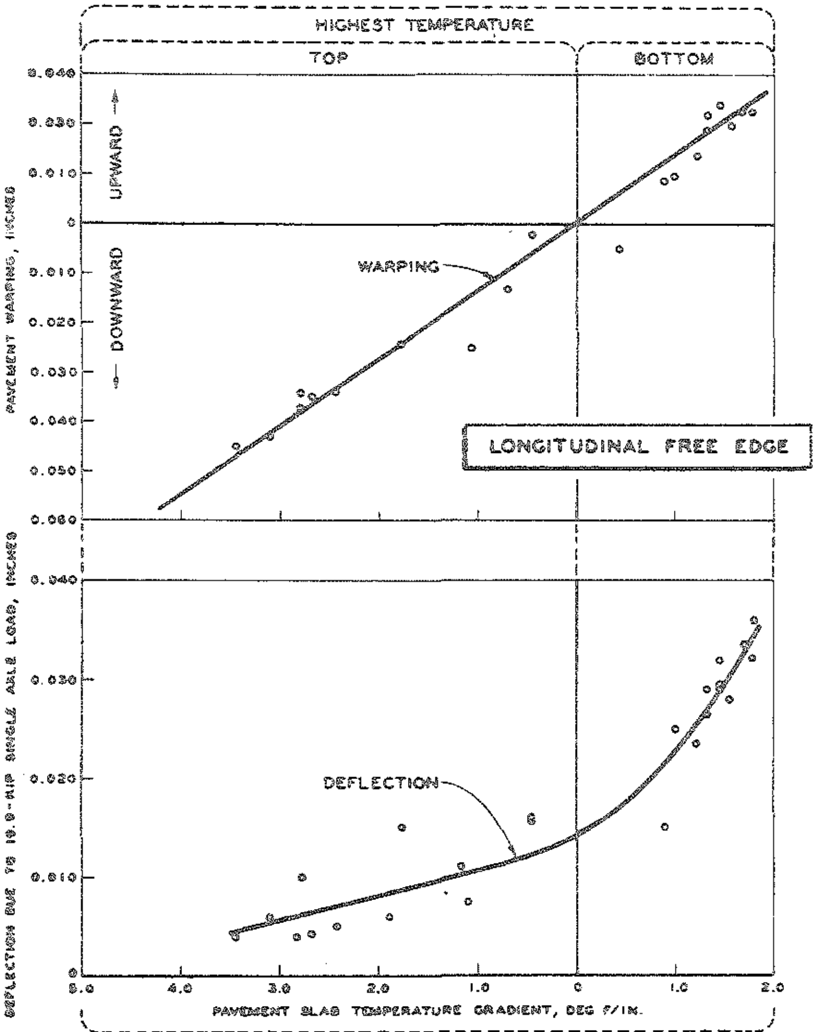


Figure 18. Temperature effects along longitudinal free edge on pavement warping, load deflection, and load strains (single axle load--19.9 kips).

for locations near the joint when the axle load was at or near that joint. The strain gage location 5 ft from the joint generally had the largest tensile strains regardless of the amount of pavement warping during the 24-hour period.

Collectively, Figs. 16, 17, and 18 indicate the close correlation between slab temperature differential, the resulting pavement warping, and the increased deflections and stresses at the joint corner or the longitudinal free edge due to this warping, with resulting poor subgrade support condition. The extreme ratios of day to night load deflection are approximately 1 to 10.5 at the joint corner and 1 to 9 at the longitudinal free edge. Extreme day to night strain ratios at 5 ft from the joint are 35 to 87 micro-inches, peak to peak, or a ratio of 1 to 2.5, and at the longitudinal free edge at mid-slab, 39 to 70 micro-inches, or a ratio of 1 to 1.8. In the cases of both deflection and strain the increased warping near the joint results in larger ratios of deflection or strain between day and night conditions, although for any location the strain ratios are much smaller than the deflection ratios.

Another method of indicating the relationships between pavement temperature differential, warping, and the effect on load-deflection is indicated in Fig. 19, for both the longitudinal free edge and the joint corner. For pavement warping elevation the zero point is taken as the point where the temperature differential between top and bottom of the slab is zero. For both pavement locations the relationship between pavement warping and temperature differential appears to be linear, with maximum upward warping under the maximum temperature difference where the bottom pavement surface is the warmer. This condition also results in the maximum deflection for both locations for the given load. At the joint corner, the temperature gradient and the deflection relationship appear to be linear, but for the longitudinal free edge the relationship curves upward ~~in a concave line~~ with a progressively steeper slope.



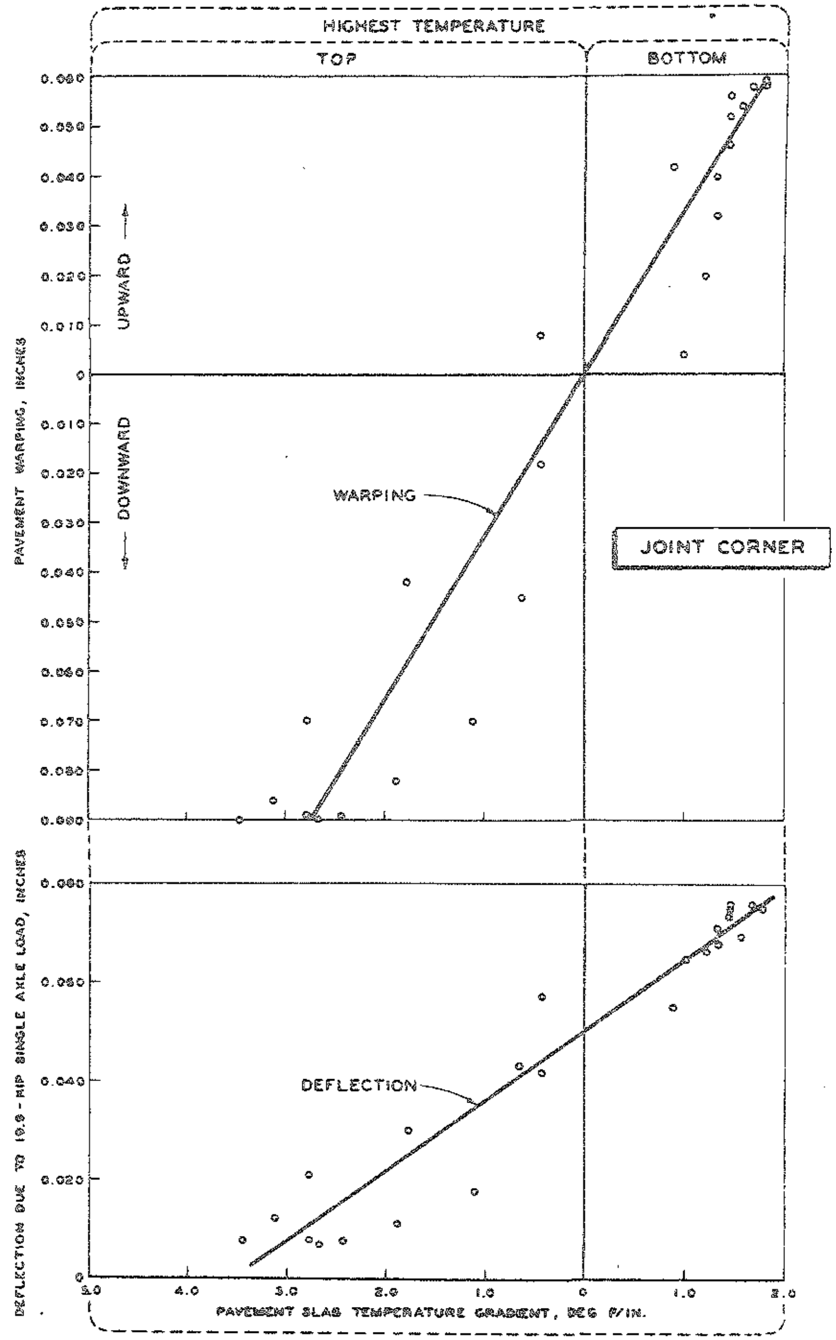


Figure 19. Effect of pavement temperature gradient on warping and load deflection.

In a similar MSHD study in August 1954, the maximum temperature differentials between the slab top and bottom were 28 F or 3.11 F per in. during the day with the top warmer than the bottom, and 17 F or 1.89 F per in. during the night with the bottom warmer than the top. This resulted in an average corner elevation change of 0.068 in., compared to 0.150 in. for Test 3. The maximum day to night deflection ratio at the joint corner for the 1954 test was 1 to 12.2. This compares to 1 to 10.7 for Test 3.

Pavement Stresses

While there may be some error in converting strains to stresses, depending on the reliability of the estimate for the modulus of elasticity of the concrete, pavement stresses are more readily interpreted for design purposes, and therefore this extension of the data is made, based on an assumed modulus of elasticity of 5 x 10^6 psi. The maximum load stresses resulting from the passage of a 19.9-kip single axle load are shown in Table 2. The maximum tensile stresses of the top surface are 255 and 250 psi, at 5 and 6 ft from the joint, and the maximum compressive stress, 262 psi at mid-slab along the longitudinal free edge. The tensile stress near the joint corner, 255 psi, is somewhat greater than predicted by the formula for protected corners* which is generally used:

$$S = \frac{3.36\,P}{d^2}\left[1 - \frac{\sqrt{\frac{a}{l}}}{0.925 + 0.22\frac{a}{l}}\right]$$

For a modulus of subgrade reaction, K = 200 psi per in., and a modulus of elasticity of concrete of 5 x 10^6 psi, both of which appear to be reasonable assumptions, the formula gives a stress of 211 psi compared with the maximum tensile stress of 255 psi measured near the joint corner.

* The notation used in this formula is that usually employed in pavement design, and may be found in many reference sources, such as "Concrete Pavement Design," Portland Cement Assn.: Chicago (1951), p. 17.

TABLE 2

MAXIMUM AND MINIMUM LOAD STRESSES
DUE TO A 19.9-KIP SINGLE AXLE LOAD
(Modulus of Elasticity assumed 5 x 10^6 psi)

Longitudinal Free Edge Position	Tensile Stress, psi		Compressive Stress, psi	
	Maximum (Night)	Minimum (Day)	Maximum (Night)	Minimum (Day)
8 ft from transverse joint	175	5	168	115
6 ft	250	55	210	110
5 ft	255	55	210	125
4 ft	205	45	185	75
2 ft	120	65	175	90
Midslab point	88	15	262	145

All pavement strains measured on top surface.

Single-Tandem Axle Relationships

Practical limitations prevented determination of deflection and strain for the 24-hour period for more than one single and one tandem axle load. However, it is interesting to observe the relationship between these two loads throughout the period as shown in Fig. 20. In this comparison of tandem to single axle loads, the ratio of effect is noted for the 34.1-kip tandem load as compared to the 19.9-kip single axle load. During the test period the effect ratios varied slightly, but for deflection the average ratio was 1.15 at the joint corner and 0.93 at the longitudinal free edge. The average strain ratio of tandem to single axle load was 0.79 at the joint corner and 0.83 at the longitudinal free edge. For deflection at the joint corner only, the effect of the tandem was greater than the single axle load. However, a study of published experimental data on the relationship between the effect of tandem and single axle loads shows a variety of ratios between the two for both deflections and strains. Also laboratory studies under more controlled conditions may give results that do not agree with field studies. However, as shown previously, since both deflection and strain are so greatly affected by pavement warping, the slab condition at the time of the test may have a marked effect on the relationship between tandem and single axle loads for comparable deflection and strain. At night in the upward warped condition of the pavement slab, the deflection effect of the tandem axle load appears to be generally more severe than during the day, relative to the single axle load. This is best shown in Table 1, which presents tandem axle loads equivalent in deflection to 18-kip single axle loads.

Deflection and Strain Relationships

Since deflection or strain are the most logical bases for evaluating the relative effect of various vehicles, it is of interest to determine whether there is a definite relationship between these two. The relationship is established statistically for the longitudinal free

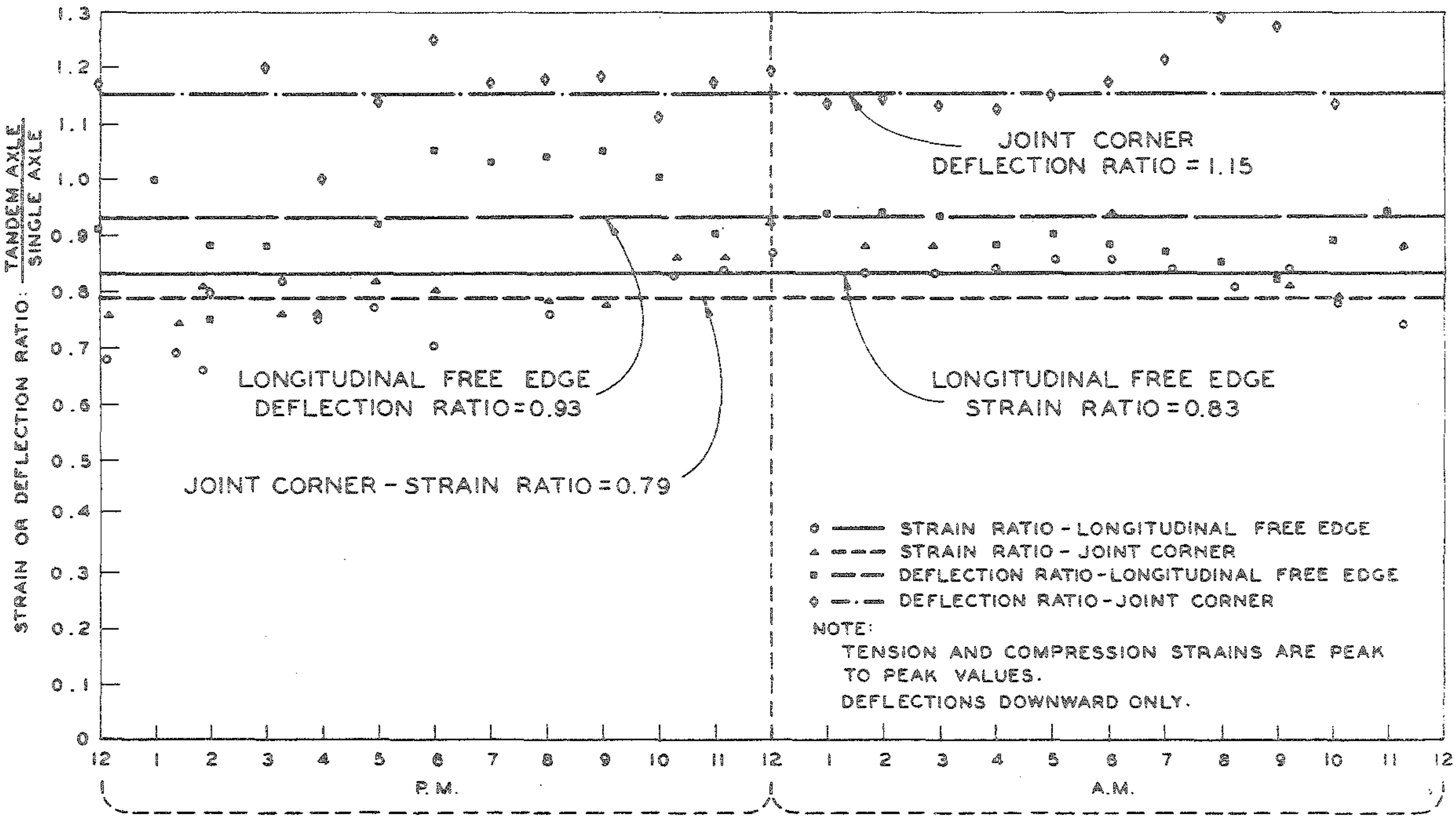


Figure 20. Pavement strains and deflections: ratios of tandem to single axles.

edge and the joint corner in Fig. 21. The correlation coefficient is 0.97 for the tandem axle and 0.93 for the single axle load, with standard errors of estimate of ± 1.9 and ± 2.5 micro-inches per in. of strain, respectively, for the longitudinal free edge data. For the joint corner the correlation coefficient is 0.92 for tandem axle loads and 0.96 for single axle loads with standard errors of estimate of ± 8.1 and ± 6.0 micro-inches per in. of strain. The correlation between deflection and strain in all four cases is statistically highly significant--probability of no correlation being less than 1 in 1000--but the standard errors of estimate are a good deal smaller for the longitudinal free edge. The relationship between deflection and strain is significantly different for tandem and single axles, this being most apparent at the longitudinal free edge. In comparing the Fig. 21 lines, it may be noted that the slopes for the regression lines for the longitudinal free edge are significantly flatter than for the joint corner; or, in other words, at the longitudinal free edge the ~~stress~~ strain increases less rapidly with increased deflection.

In order better to visualize the effect of pavement strains due to warping and due to load, the pavement strains have been transformed to pavement stresses in Fig. 22 by assuming the modulus of elasticity of the concrete to be 5 million psi. The point of reference, zero strain due to warping, is taken arbitrarily as the strain at the time the temperature gradient through the pavement slab is zero. Temperature compensation was obtained by strain gages on small concrete blocks of the same thickness as the pavement and buried alongside the pavement. The strains in two arms of the electrical bridge thus had automatic temperature compensation and the strains read were due to strain differences from restraint of the pavement slab. During the day, restrained temperature warping caused maximum tensions at the slab bottom as shown, and during the night at the slab top. These strains are converted to stresses and then combined with maximum compression or tension stresses due to the 19.9-kip single axle load for

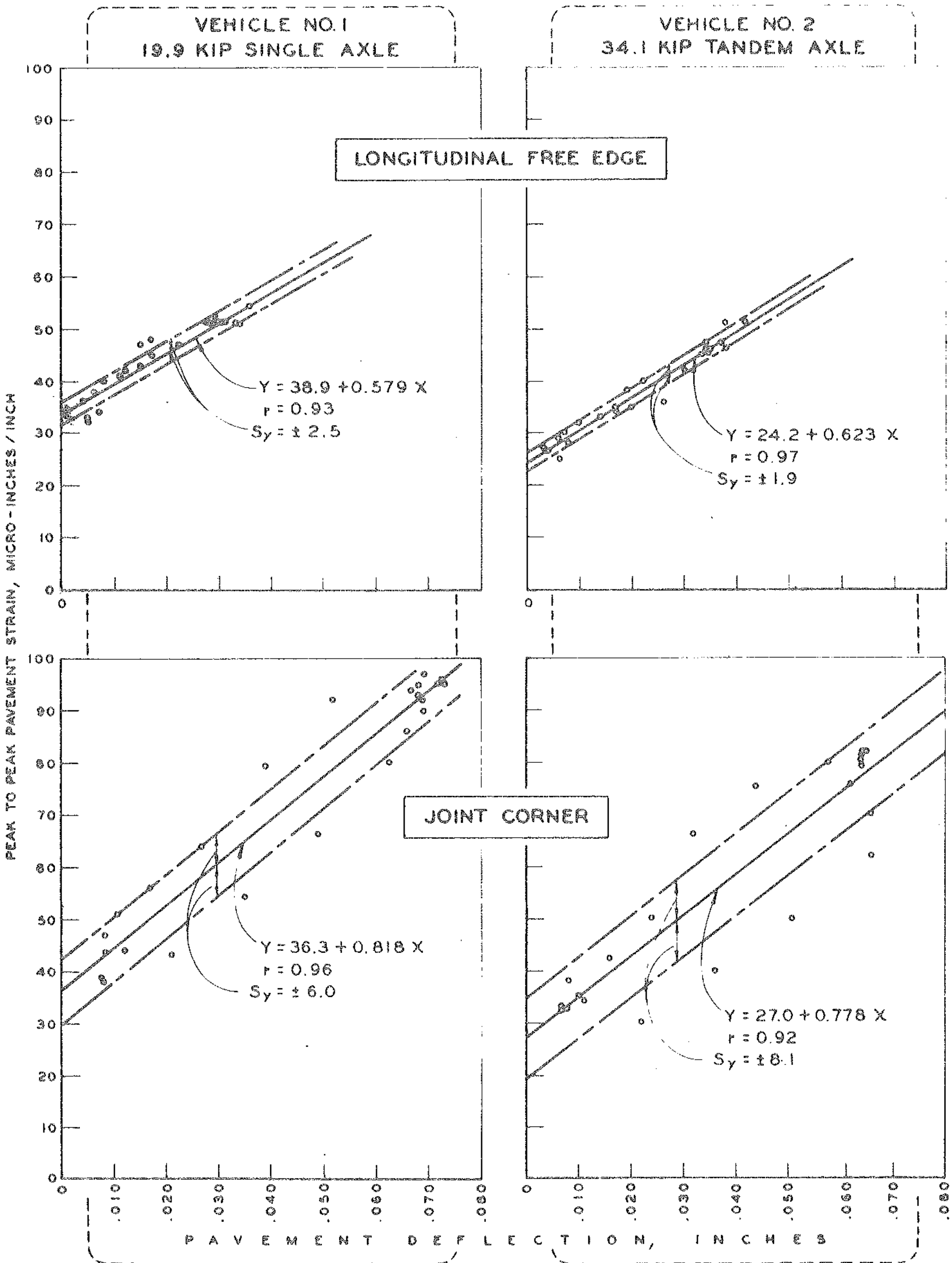


Figure 21. Pavement deflection-strain relationships (24-hour period).

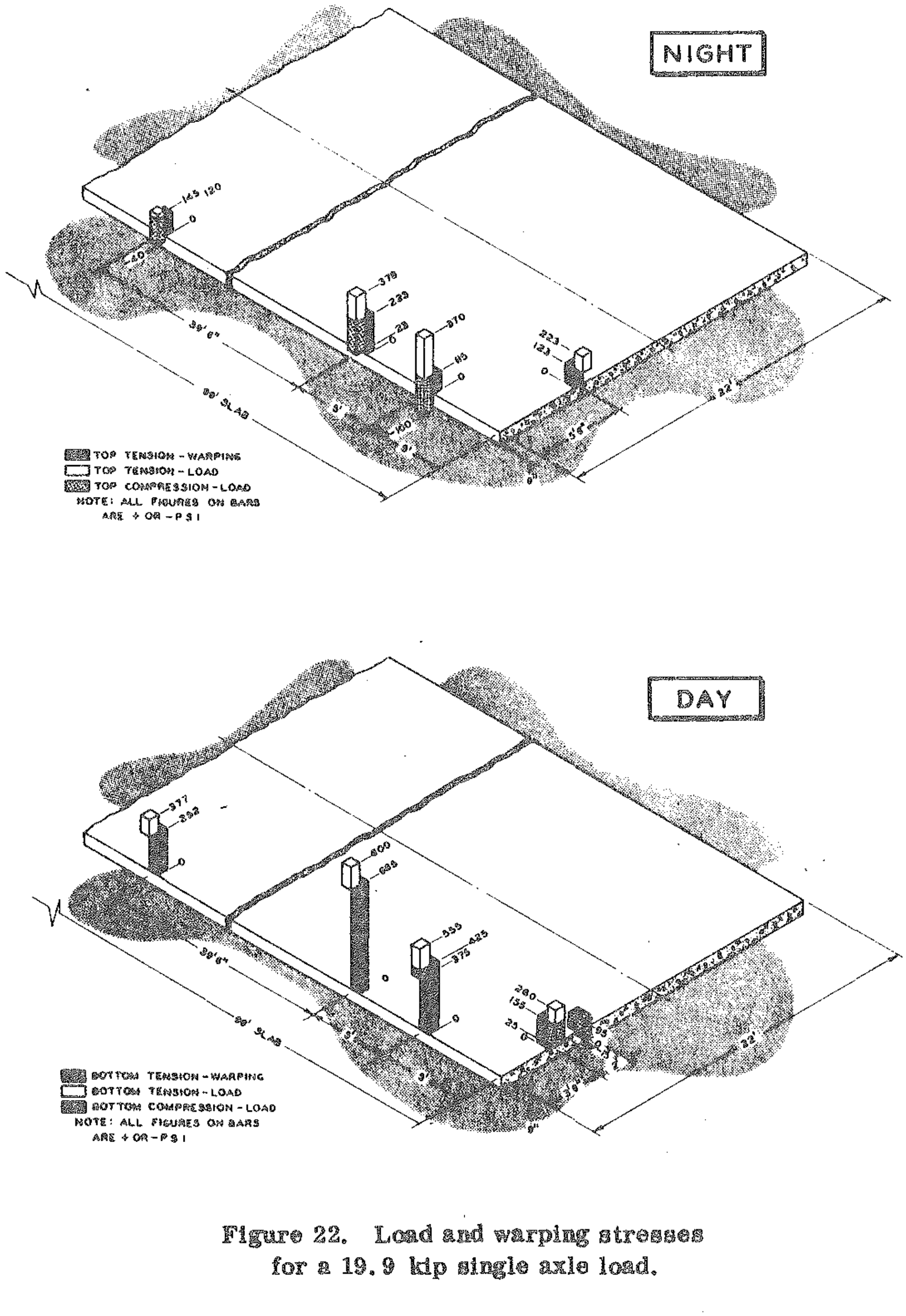
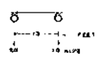
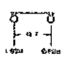
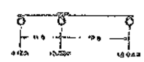
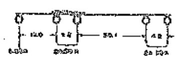
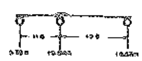
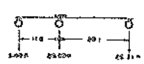
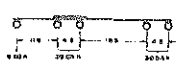
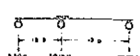
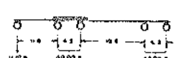


Figure 22. Load and warping stresses for a 19.9 kip single axle load.

TABLE 11
SUMMARY OF THE RELATIVE EFFECT RATIOS
AASHO TEST VEHICLES COMPARED TO A TYPE 2 TRUCK
(Based on Data from Test 2)

Truck Type	Vehicle Load and Spacing	Relative Effect Ratio						
		Day			Night			Overall Avg
		Joint Corner	Free Edge	Avg	Joint Corner	Free Edge	Avg	
Type 2		1.00	1.00	1.00	1.00	1.00	1.00	1.00
AASHO 1		0.02	0.01	0.01	0.02	0.02	0.02	0.02
AASHO 2		0.10	0.10	0.10	0.11	0.12	0.12	0.11
AASHO 3		0.84	0.93	0.88	1.07	0.86	0.96	0.92
AASHO 4		1.67	2.11	1.89	1.82	2.49	2.16	2.14
AASHO 5		1.55	1.75	1.65	1.76	1.78	1.77	1.71
AASHO 6		2.88	3.79	3.34	2.60	3.33	2.96	3.15
AASHO 7		2.58	2.78	2.68	1.94	1.98	1.96	2.32
AASHO 8		3.85	5.02	4.44	3.30	5.04	4.17	4.30
AASHO 9		4.50	4.78	4.64	3.53	4.24	3.88	4.26
AASHO 10		5.38	7.11	6.24	4.60	6.67	5.64	5.94

At present, it would appear to be necessary to have a reasonably good estimate of the following traffic information, to get a reliable estimate of the relative effects of traffic load on the performance of specific pavement sections:

1. Total volume of traffic.
2. Percent commercial traffic in the total volume.
3. Percent of each commercial vehicle type in the total commercial traffic volume.
4. Percent of loaded and unloaded commercial vehicles.
5. Average axle spacing for each commercial vehicle type.
6. Average axle loads for each commercial vehicle type, loaded and unloaded.

<u>Limitations of Theory</u>

It may be argued that sufficient data have not been gathered to indicate that the theory presented here is a valid measure of the relative effect of various vehicles on a concrete pavement. However, if pavement deflection is a criterion for the relative effect of vehicles, then the theory presented is logical and rational since it is based on the pavement deflection energy resulting from passage of a vehicle. Further, the deflection data gathered from three different test programs at different locations and different times of the year, while varying widely in absolute values of pavement deflection, are in very substantial agreement in indicating the relative effects of vehicles on pavements. Of course this in itself is not a guarantee of the value of the theory, for the theory is only of value if it predicts reasonably well the relative effect of repeated application of known test vehicles over different test sections which are structurally identical. Results of only one test of this type are currently available for concrete pavements---the Maryland Test Road. The theory has been applied to the vehicles used on that test road and the relationship between their relative effect according to the theory, and the known relative performance based on load repetition for "first cracking" and "first pumping," are in remarkably close agreement. Another test of the theory may be made when the AASHO Road Test is completed.

The theory at the present time is suggested as applicable only to concrete pavements. However, tests have been conducted in a similar manner for bituminous pavements and the present theory, or a comparable theory, is under study as a method for determining the relative effect of vehicles on bituminous pavement. A report on this phase of the program can be expected within a year.

CONCLUSIONS

From experimental observations in the three tests the following facts are apparent:

1. The influence of axle load on pavement deflection extends over a slightly greater distance for the longitudinal free edge than for joint corner positions.

2. The influence of axle load on pavement deflection is much broader at night than during the day, for the same pavement locations.

3. The maximum influence of axle load on pavement deflection extends over a distance of approximately 36 ft. The effect of the axle is first noted when the axle approaches the pavement point in question but is still 18 ft away. As the axle approaches the influence increases, coming to the maximum when the axle is on the point, and then decreasing as the axle moves away, with no appreciable effect when the axle is 18 ft or more past.

4. In comparing the magnitudes of the daytime deflections, the longitudinal free edge deflection is slightly greater than the joint corner deflection, but at night the deflection at the joint corner is much greater.

5. Slab warping has a very great effect on the magnitude of pavement deflection for a given load. This effect is much more pronounced at the joint corner than the longitudinal free edge.

6. The single and tandem axle load equivalents for pavement deflection depend on the period of day and the pavement position under consideration. The range in equivalent loads may vary from nearly equal values to nearly twice the load for a tandem for equal deflection. The only equitable approach to the problem is statistical, with all influencing parameters such as pavement warping recorded so that proper sampling procedures may be employed.

7. Daytime deflection testing (8:00 a. m. to 5:00 p. m.) of concrete pavements is insufficient. For useful data, 24-hour deflection studies are generally required.

8. Pavement load-strains vary throughout the day, as do pavement load-deflections, and, while deflection and strain change together, the magnitude of the variation is much smaller for strains.

9. Correlation between pavement load deflection and pavement load strains at a given location is very good. Either one may be predicted from the other with satisfactory accuracy.

In interpreting the data, and using the theory presented in this report, certain conclusions are possible on the basis of this theory:

1. It is possible to duplicate with reasonable accuracy the composite load-deflection pattern resulting from a multi-axle vehicle passing over a given point in the pavement on the basis of single-axle influence lines and load-deflection relationships. With this procedure it is possible to compare the effects of all vehicles, providing information is available only on axle loads and axle spacings.

2. The ~~results of~~ relative effects of vehicles, based on the theory, have been compared with experimental results from test roads with very good agreement.

3. It has been demonstrated that the theory has application to optimum spacing of two axles for a minimum effect on the pavement. In a similar manner, the arrangement of axle spacings and axle loads can be optimized to give a minimum pavement effect for a given total vehicle load.

4. It has been demonstrated that the theory has application in determining the relative effect for a variety of vehicles, and that it may be used for predicting test road results, effects of changing legal load limits, and in other problems where the effect of traffic loads is a consideration.

5. It has been demonstrated that the relative effect of a vehicle can be predicted by this theory, using three different and independent sources of influence-line and load-deflection data, with results from the three tests in very close agreement. While time of day, time of year, or particular region of a pavement slab extensively influence the magnitude of pavement deflection and the resulting pavement energy values, the relative effects of particular vehicles will remain substantially constant with respect to one another.

In summary, based on a reasonable amount of experimental data, a rational theory has been developed for predicting the relative effect of vehicles on a concrete pavement. This theory has been substantiated by results from previous test roads and may be tested further on the basis of results from the AASHO Road Test. While at present the theory is suggested only for concrete pavements, the application of the theory to bituminous pavements is now being analyzed, and it is expected that this theory or a similar one based on an equally rational approach, can be developed for bituminous pavements in the near future. It is expected that a similar report on bituminous pavements will be available within a year.

APPENDIX

Photographs of all test vehicles used for the three field studies are shown in Figs. 30, 31, and 32. These vehicles were made available through the cooperation of the Automobile Manufacturers Association and the Michigan Trucking Association. The specific members of these agencies who furnished vehicles are:

George F. Alger Co.
Ford Motor Co.
Fruehauf Trailer Co.
Leonard Refineries, Inc.
Liquid Transport, Inc.
N. & W. Transport, Inc.
REO Division, The White Motor Co.
Robinson Cartage Co.
Howard Sober, Inc.
Telford Equipment Co.

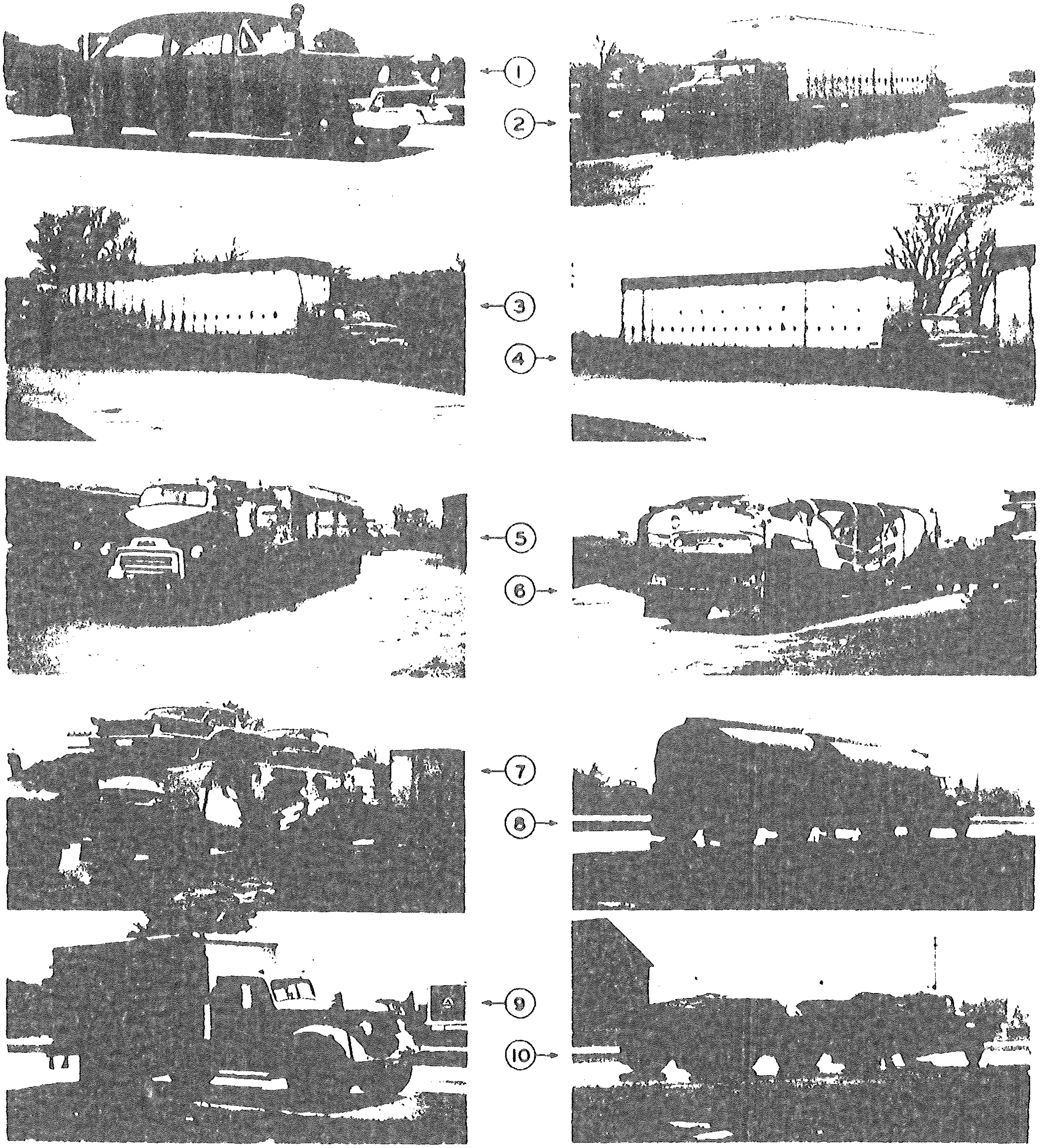
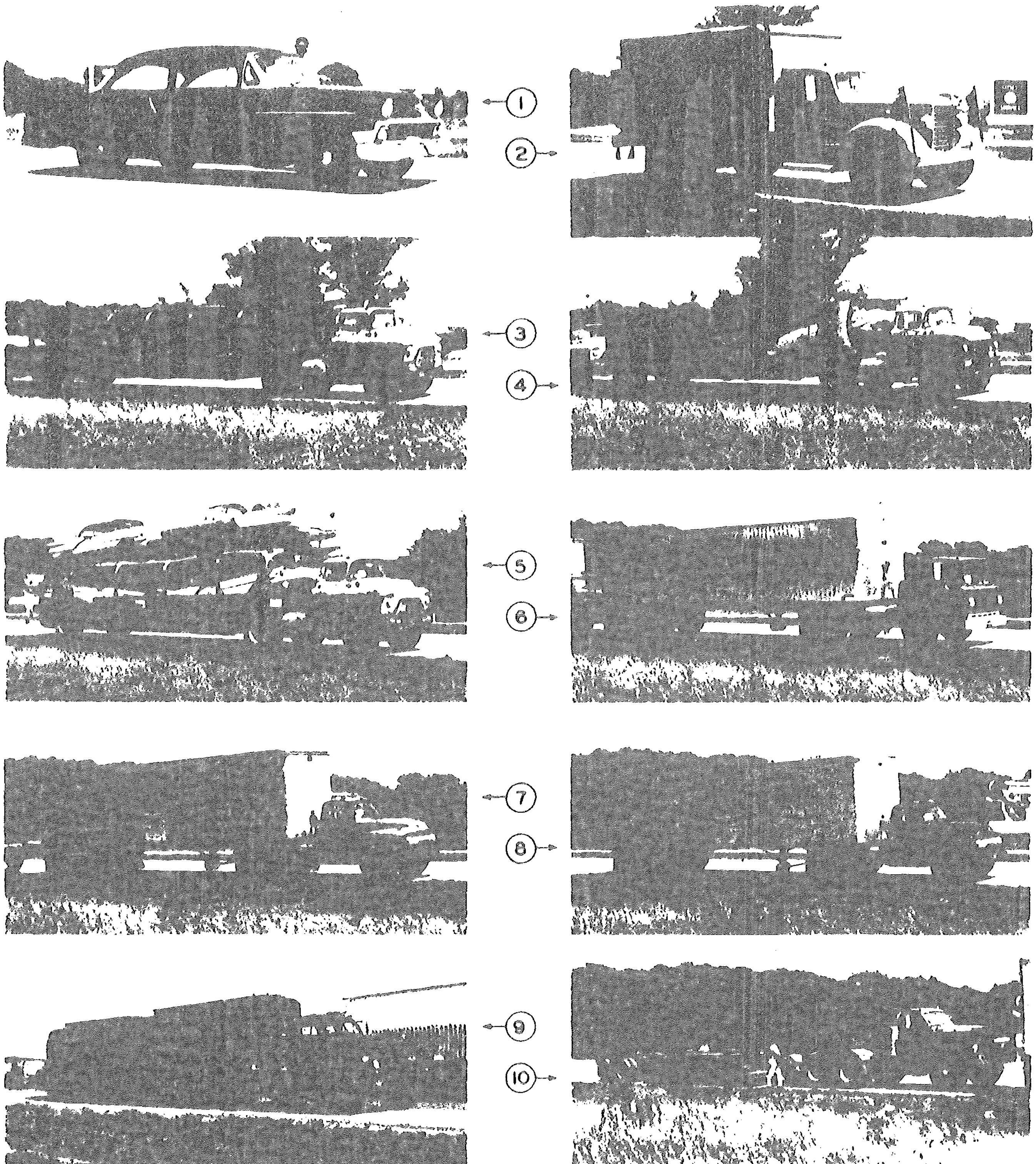


Figure 30. Vehicles for Test 1.



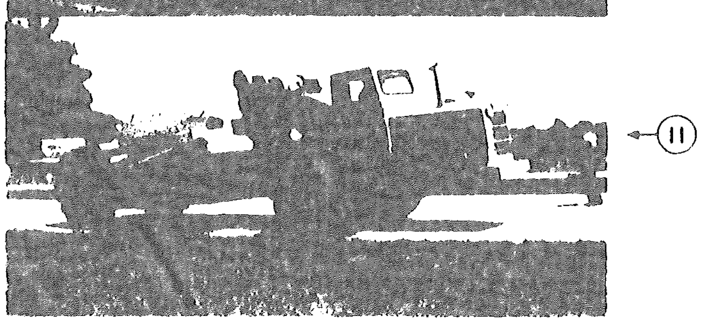


Figure 31. Vehicles for Test 2.

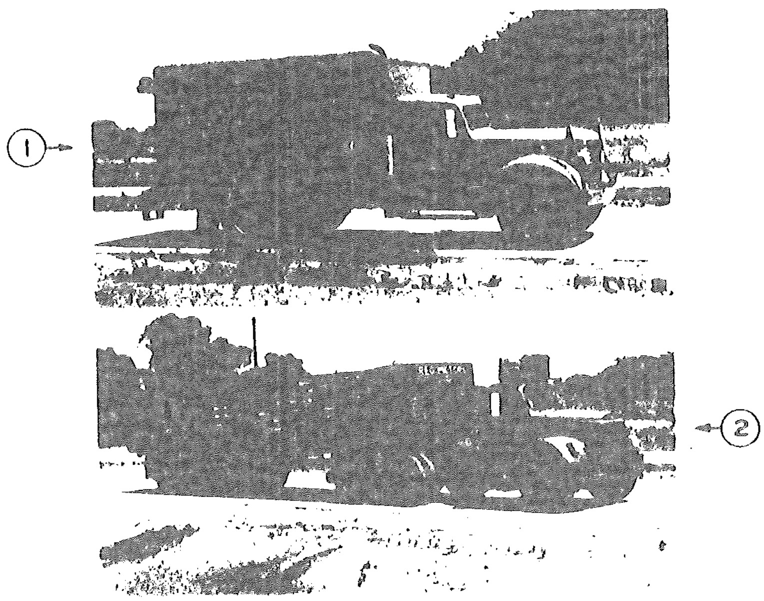


Figure 32. Vehicles for Test 3.

that time of day. In combining warping and load stresses, the maximum tension stresses were 800 psi at the bottom pavement edge at 10 ft from the transverse joint, and 378 psi at the top in the same location during the night. While the absolute tension stress values of 800 and 378 psi are questionable because of the abritrary zero stress condition assumed at the time of zero temperature gradient, the maximum stress change of 800 + 378 = 1178 psi does represent the total range in stress encountered at this point due to a combination of warping and load stresses.

DATA INTERPRETATION

So far the discussion of the analysis of data has considered only the most simple case of the effect on pavement deflection, or stress, of a single isolated load. However, in many cases axle loads on commercial trucks are spaced closer than 16 or 18 ft, and therefore, as shown by the previous influence lines, pavement deflections or stresses at certain times result from the overlapping effects of two or even more axles. The overlapping effects of single axles have already been shown in the case of tandem axles, which had influence lines and load-deflection relationships different than those of single axles.

However, to use data previously obtained for isolated axles and apply them to actual commercial vehicles, it is necessary to determine how these overlapping axle load effects can be combined. As noted previously, the load-deflection relationships are not perfectly linear, especially at larger loads, and therefore the effects of two axles influencing pavement deflection or stress at a given time cannot be added numerically.

Effective Load

To work systematically with overlapping load effects, one may use a coined term "effective load" which by definition will mean the numerical single axle load resulting from one or more load axles having the same effect on pavement deflection or stress at a given point as a single axle load of that magnitude. Thus a 32-kip 4-ft tandem axle load straddling a joint is basically two single axle loads of 16 kips, one 2 ft ahead and one 2 ft behind a joint. If the load-deflection relationship were linear, this would be equivalent to an effective load at the joint of

$$16 \text{ kips} \times 0.70 + 16 \text{ kips} \times 0.70 = 11.2 + 11.2 = 22.4 \text{ kips}$$

where 0.70 is the influence line ordinate 2 ft ahead and also 2 ft behind the joint (Fig. 7 joint corner day influence line). Actually the load-deflection relationship is not linear, but the overlapping effects of multiple axles are treated in subsequent analyses and computations as a single axle effective load giving the same deflection at the desired point under discussion as results from the overlapping effects of a combination of single axles.

Construction of Vehicle-Deflection Patterns

To show that the pavement deflection pattern of a given vehicle passing over a given point, on the basis of single axle load data, can be duplicated with reasonable accuracy, this theoretical deflection pattern has been compared here with the actual deflection patterns for certain vehicles. In Fig. 23, one of these comparisons is shown. The actual pavement deflection pattern (average of 3 runs) is given for Vehicle 9 of Test 2, Type 2S2-3, passing over Test Point 4. The theoretical deflection pattern is also shown. This was obtained by treating all axles as single axles, and then combining the influence lines and load-deflection relationships for single axles with the overlapping effects of these single axles to obtain the composite deflection pattern. It should be noted that the deflections are not added algebraically when overlapping axle load effects occur, but according to the manner in which the increased effective axle load will increase the deflection at the given test point.

A satisfactory method of predicting the composite deflection pattern of various types of commercial vehicles on the basis of single axle load data forms a step in the process of determining the relative effect of these vehicles on the pavement.

Theory of Relative Effect

One of the major objectives of this research program is the determination of a rational method of measuring the effect of commercial vehicles on the life of the pavement.

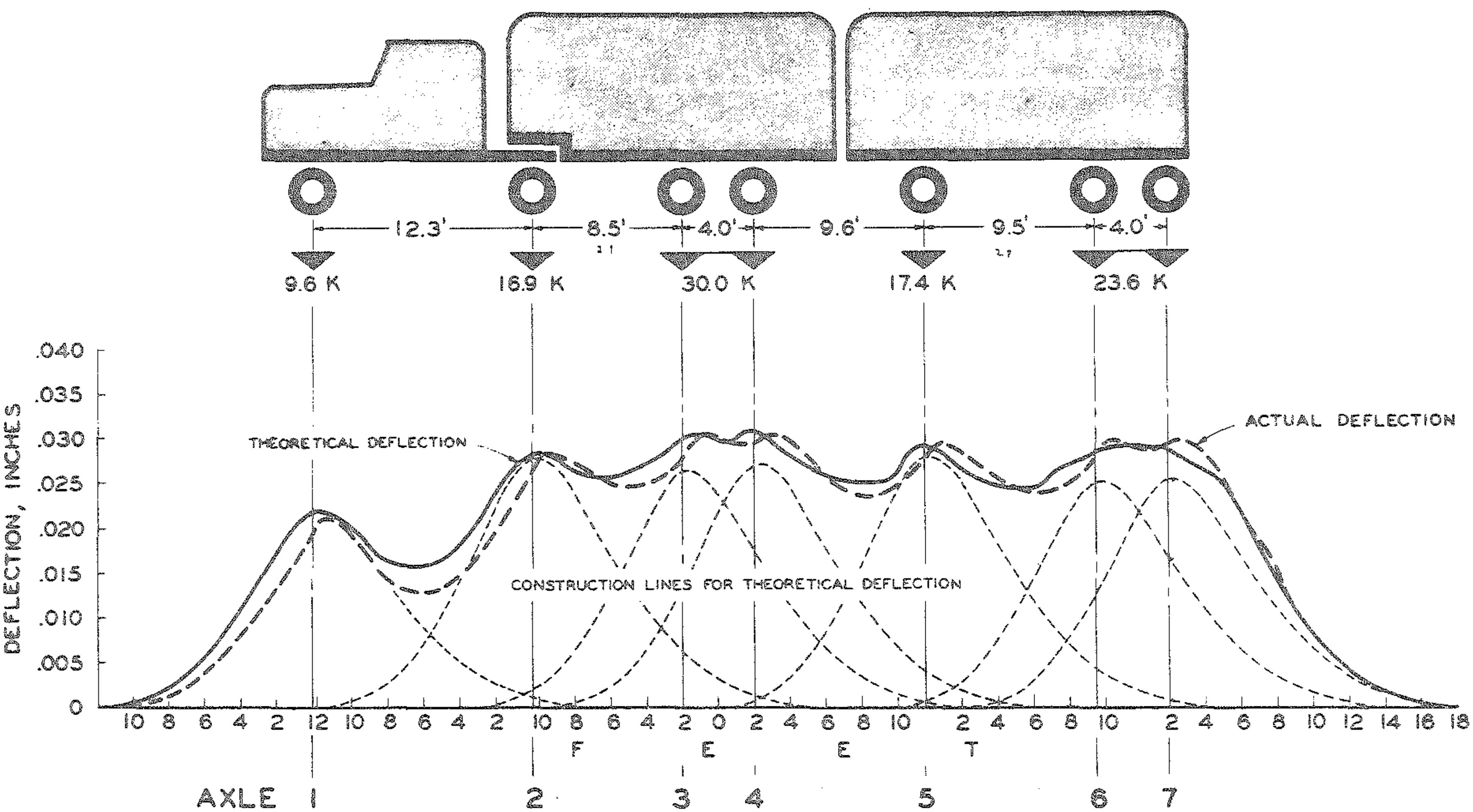


Figure 23. Comparison of actual and theoretical deflection patterns: Test 2 (night).

Any theory, no matter how sound from a theoretical point of view, must stand the test of whether it relates reasonably well to previous practical experimental test results. After explaining this theory, the results of its use will be compared with results from test road data where the relative effect of certain test vehicles was related to pavement performance. It must be kept in mind that this theory applies only to pavement performance as influenced by vehicle load effects. It does not and cannot take into account weathering and other natural causes of pavement deterioration.

Linear Load-Deflection. In the beginning, to simplify theoretical concepts it will be assumed that pavement deflection is proportional to effective axle load. This is not essential but makes the analysis simpler to explain and understand. Later this will be extended to non-linear load-deflection relationships.

A single axle load, causing a deflection of the concrete pavement beneath, constitutes a force acting through a distance equal to the pavement deflection. The work done by the axle on the supporting medium, namely the concrete pavement and the subgrade, is equal to the area of a right triangle with legs P and Y, where P equals axle load and Y equals pavement deflection under axle P (Fig. 24). For example, the positive work done by the front axle load is $\frac{P_1 Y_1}{2}$. Negative work is done as the deflection decreases between Axle Loads 1 and 2, and this negative work is the area of the trapezoid

$$P_{1,2}, P_1, Y_1, Y_{1,2} = \left(P_1 - P_{1,2}\right)\left(\frac{Y_1 + Y_{1,2}}{2}\right)$$

The positive work resulting from Axle 2 approaching and passing over the pavement joint is the area of the trapezoid

$$P_{1,2}, P_2, Y_2, Y_{1,2} = \left(P_2 - P_{1,2}\right)\left(\frac{Y_2 + Y_{1,2}}{2}\right)$$

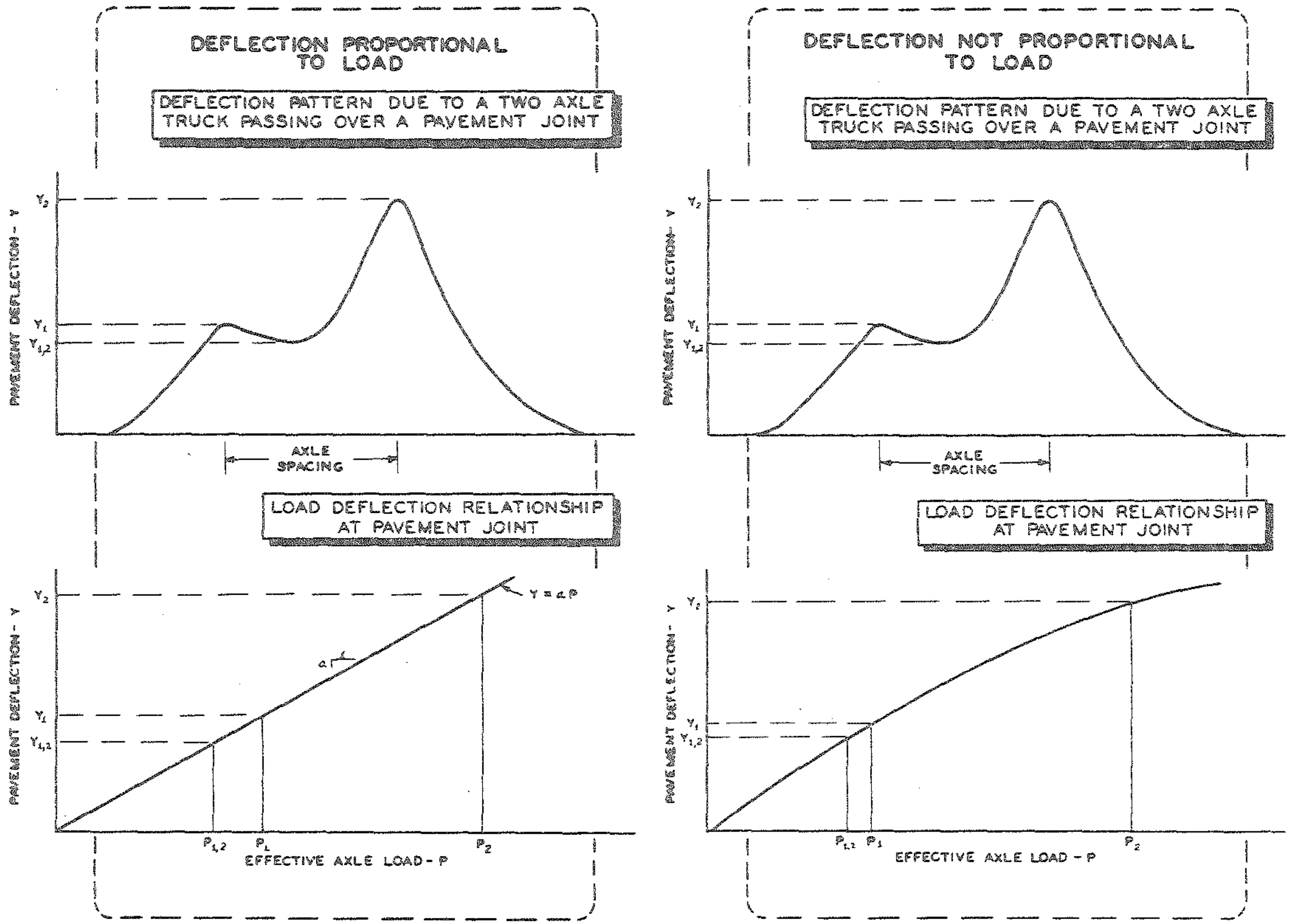


Figure 24. Graphic interpretation of relative effect theory.

Only the positive work is considered because it is obvious from the diagram that it is equal to the negative work if the pavement deflection returns to zero after passage of the truck. It should be noted that this is mathematically analogous to the work done on a spring compressed in a similar manner. This is reasonable, for the pavement is considered for purposes of mathematical analysis to be an elastic beam or plate on an elastic foundation. For this simple case, the total work done by the two-axled vehicle is

$$\frac{P_1 Y_1}{2} + \frac{(P_2 - P_{1,2})(Y_2 + Y_{1,2})}{2}$$

Since deflection has been assumed proportional to load, $Y = aP$, where "a" is the proportional constant between load and deflection, it is possible to substitute aP for Y as follows:

$$Y_1 = aP_1$$

$$Y_2 = aP_2$$

$$Y_{1,2} = aP_{1,2}$$

Then Equation 5 is:

$$\frac{P_1(aP_1)}{2} + (P_2 - P_{1,2})\frac{(aP_2 + aP_{1,2})}{2}$$

or

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

This is the total work done on the road by the two-axle vehicle. In general, the total work done on a road by a vehicle with effective axle loads P_1, P_2, P_3, P_4, P_5 .... P_n, and minimum effective loads of $P_{1,2}$, $P_{2,3}$, $P_{3,4}$, $P_{4,5}$, ... $P_{n-1,n}$, is

$$\frac{a}{2}\left[P_1^2 - P_{1,2}^2 + P_2^2 - P_{2,3}^2 + P_3^2 \dots - P_{n-1,n}^2 + P_n^2\right]$$

<u>Non-Linear Load Deflection.</u> As shown in Fig. 24 similar graphical areas are involved if deflection is not linearly proportional to load, except that mathematical

computation of the areas becomes more awkward, and it is very difficult to develop an equation mathematically for the total work done by the vehicle.

Verification of Constructed Vehicle-Deflection Patterns

Both in Tests 1 and 2 data from certain vehicles were available as checks on the validity of developing a deflection pattern from the single axle load data. For example, in Test 1 the actual deflection pattern was compared to the theoretical one based on single axle load data for Vehicle 8, a six-axle truck. However, rather than compare these deflection patterns visually, the relative effect on the pavement of the actual and theoretical deflection pattern was computed. Thus a mathematical comparison was possible.

Table 3 compares relative effects based on the actual and theoretical deflection patterns. It should be noted that a direct comparison between the relative effects based on actual and theoretical deflection patterns developed from single- and tandem-axle data, was made for joint corner data in 22 cases and for longitudinal free edge positions in 10 cases. For certain individual cases the difference is rather large, with a maximum difference of 39.2 percent. But when this comparison is made collectively, between the actual and the theoretical deflection patterns with regard to sign, the average error is +3.6 percent for the joint corner and +5.5 percent for the longitudinal free edge. The correlation between the relative effects based on actual and theoretical deflection patterns is shown in Fig. 25, for data both from joint corner positions and longitudinal free edge positions. The correlation coefficients and standard errors of estimate are 0.97 and 0.95, and ±112 in.-lb and ±57 in.-lb for joint corner and longitudinal free edge positions, respectively. In each case a statistical test of the correlation coefficient shows that the correlation between actual and theoretical deflection values is highly significant--less than 1 chance in 1000 of no correlation.

Revised Table 3
3-17-63

TABLE 3
RELATIVE PAVEMENT EFFECT
BASED ON ACTUAL AND THEORETICAL DEFLECTION PATTERNS

Test	Time	Test Position	Vehicle	Relative Pavement Effect in Inch-Pounds			
				Actual Deflection	Theoretical Deflection	Difference	Percent Difference
Joint Corner							
1	Day	1	8	535	483	-52	- 9.8
1	Day	2	8	226	269	+43	+19.1
1	Day	4	8	215	203	-12	- 5.8
1	Day	5	8	197	231	+34	+17.2
1	Day	7	8	393	383	-10	- 2.6
1	Day	8	8	265	286	+21	+ 7.8
2	Day	1	2	23	22	- 1	- 5.5
2	Day	3	2	23	20	- 3	-12.1
2	Day	4	2	19	16	- 3	-15.5
2	Day	6	2	20	20	omit - (-) 0	- 0.5
2	Day	1	9	76	54	-22	-29.2
2	Day	3	9	55	66	+11	+20.8
2	Day	4	9	44	51	+ 7	+14.7
2	Day	6	9	59	55	- 4	- 6.4
2	Night	1	2	262	321	+59	+22.4
2	Night	3	2	232	302	+70	+30.2
2	Night	4	2	177	244	+67	+37.6
2	Night	6	2	163	174	+11	+ 6.9
2	Night	1	9	597	754	+157	+26.2
2	Night	3	9	710	554	-156	-21.9
2	Night	4	9	543	479	-64	-11.8
2	Night	6	9	407	405	- 2	-0.6
					Average Error		+3.7
Longitudinal Free Edge							
1	Day	3	8	175	228	+53	+30.6
1	Day	6	8	566	598	+32	+ 5.7
2	Day	2	2	32	36	+ 4	+13.8
2	Day	5	2	31	32	+ 1	+ 3.8
2	Day	2	9	102	104	+ 2	+ 1.9
2	Day	5	9	94	86	- 8	- 8.4
2	Night	2	2	130	128	- 2	- 1.2
2	Night	5	2	162	186	+24	+14.6
2	Night	2	9	450	326	-124	-27.6
2	Night	5	9	311	352	+41	+13.2
					Average Error		+4.6

Revised 2-3-64

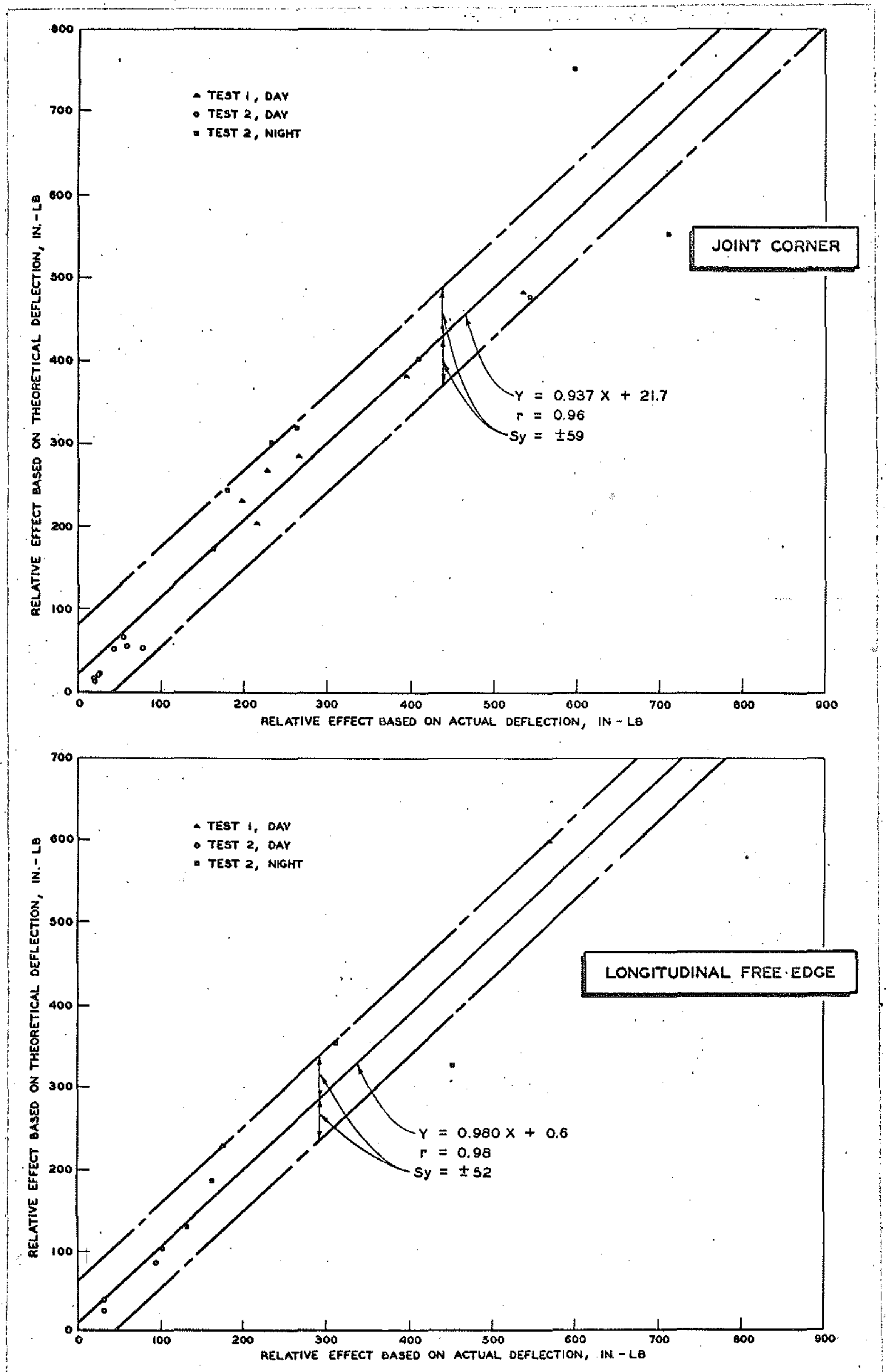


Figure 25. Comparison of relative pavement effect based on actual and theoretical deflection patterns.

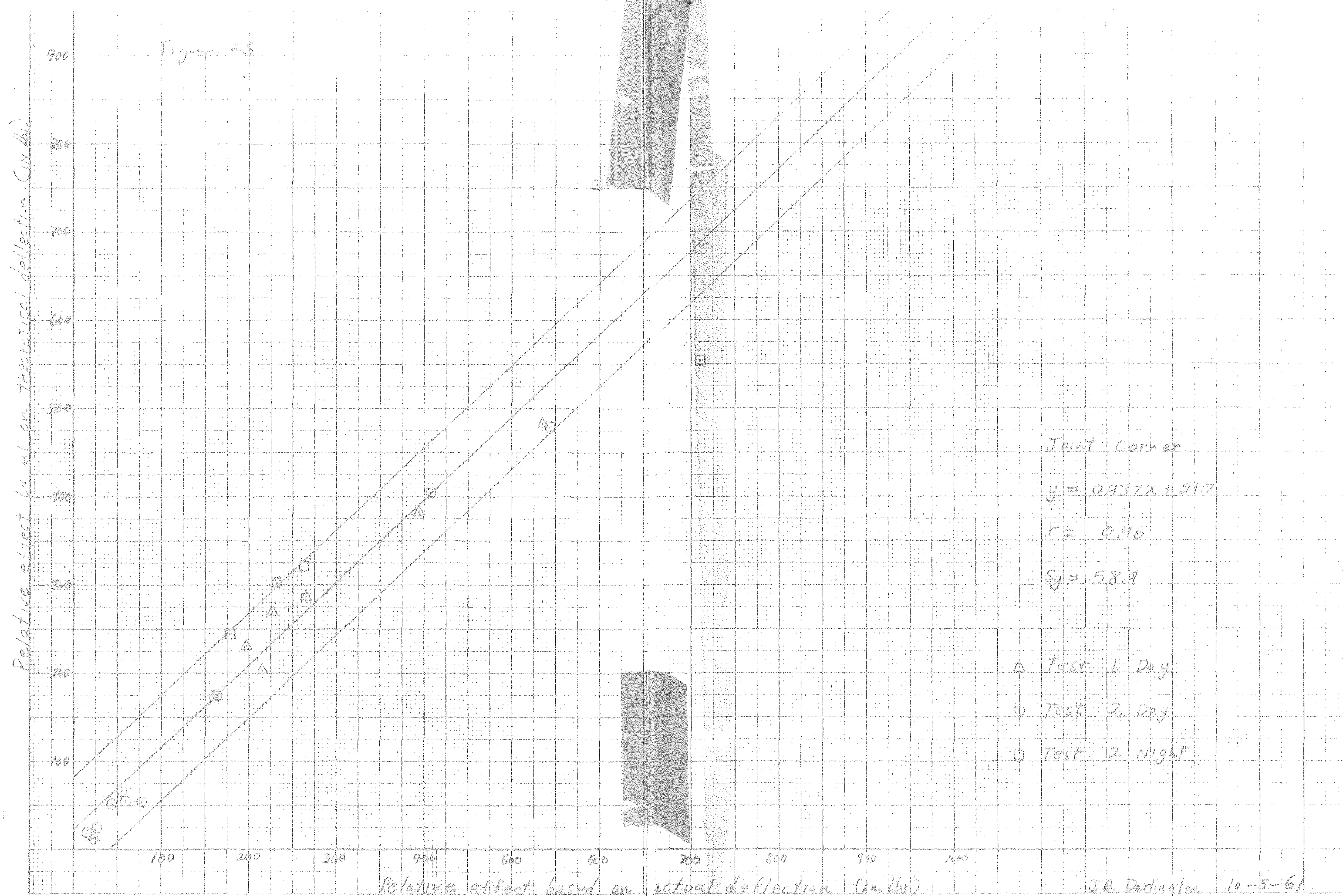
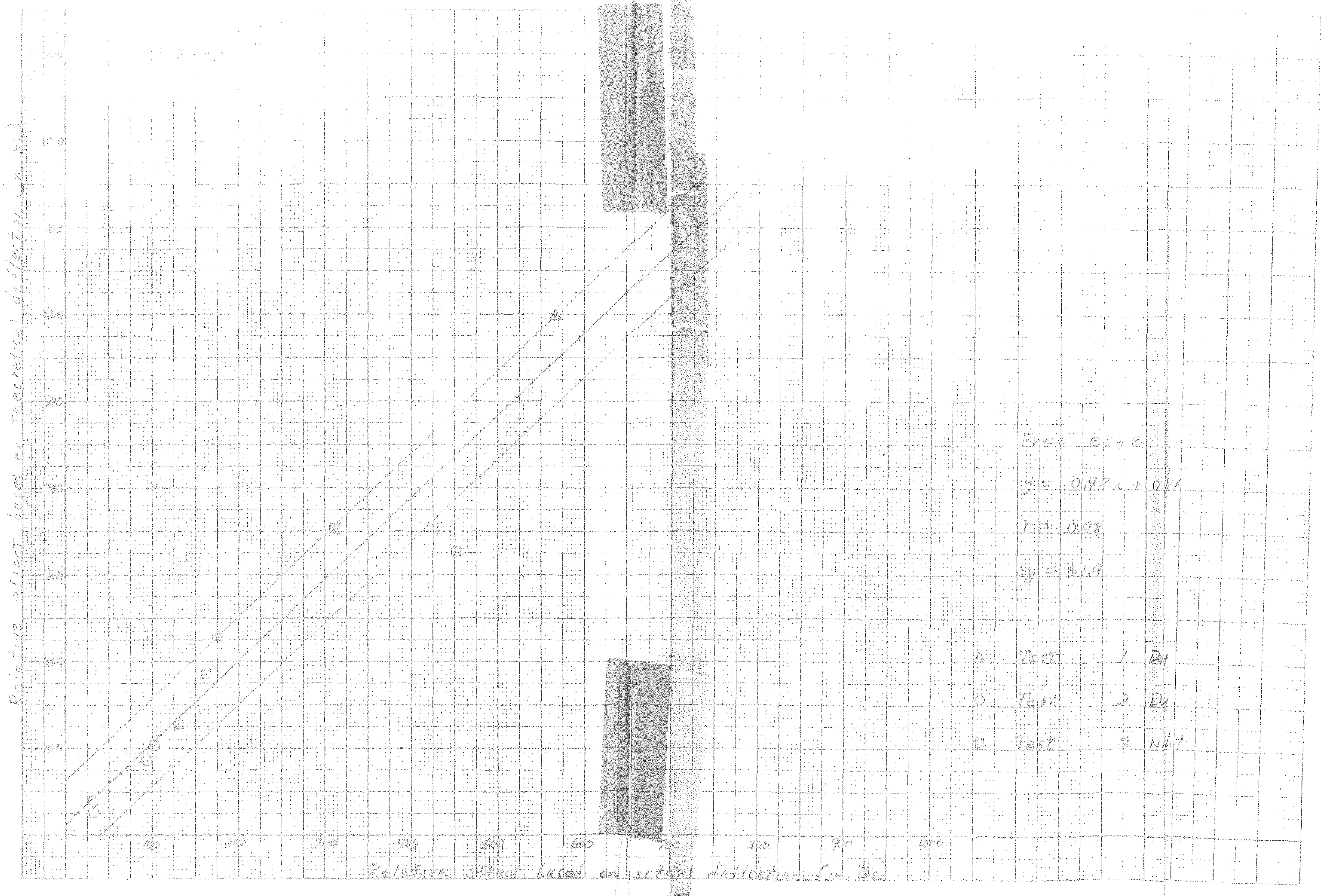
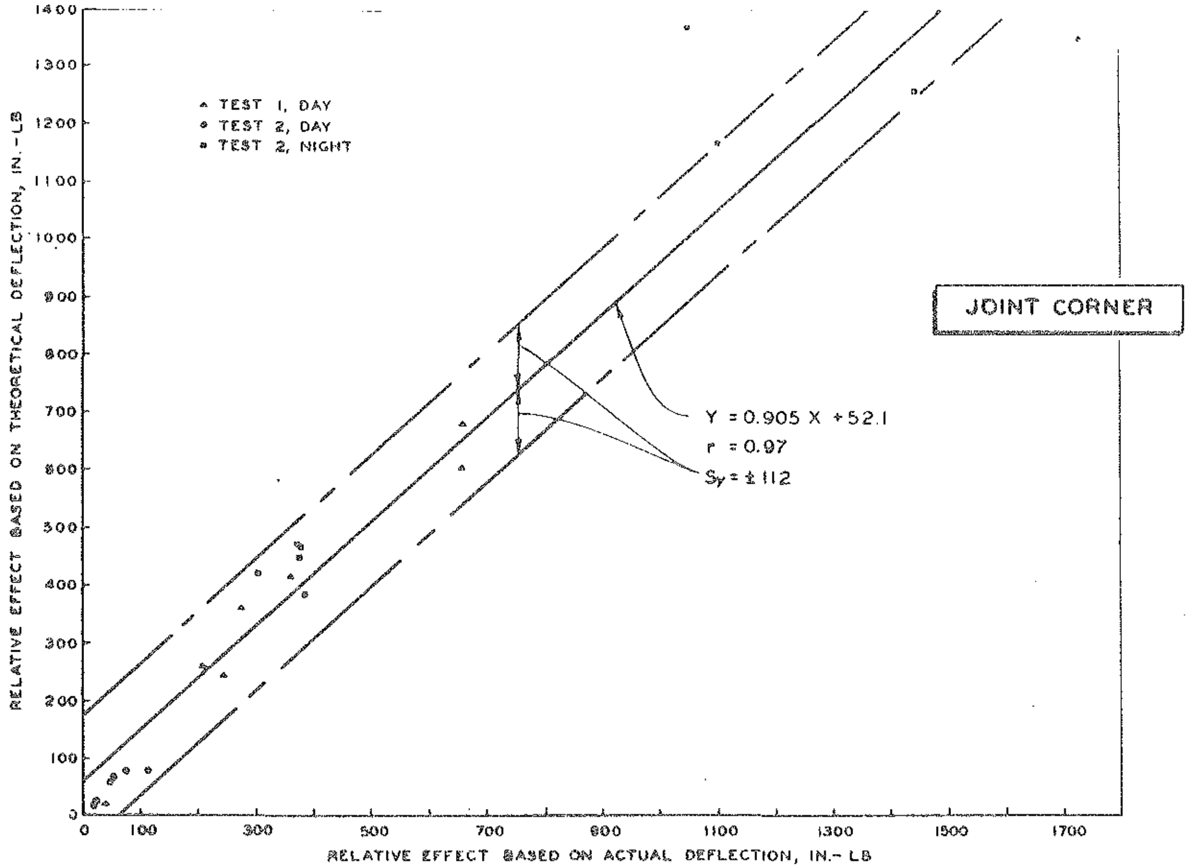


Figure 25
Relative effect based on theoretical deflection (in-lbs)
900
800
700
600
500
400
300
200
100
Relative effect based on actual deflection (in-lbs)
100
200
300
400
500
600
700
800
900
1000
Joint Corner
y = 0.937x + 21.7
r = 0.96
Sy = 58.9
Test 1 Day
Test 2 Day
Test 12 Night
J.R. Darlington 10-5-61


Free edge
r = 0.98
Test 1 D4
Test 2 D4
Relative moment based on actual deflection (in-lbs)

Redraw, with revised data - Table 3



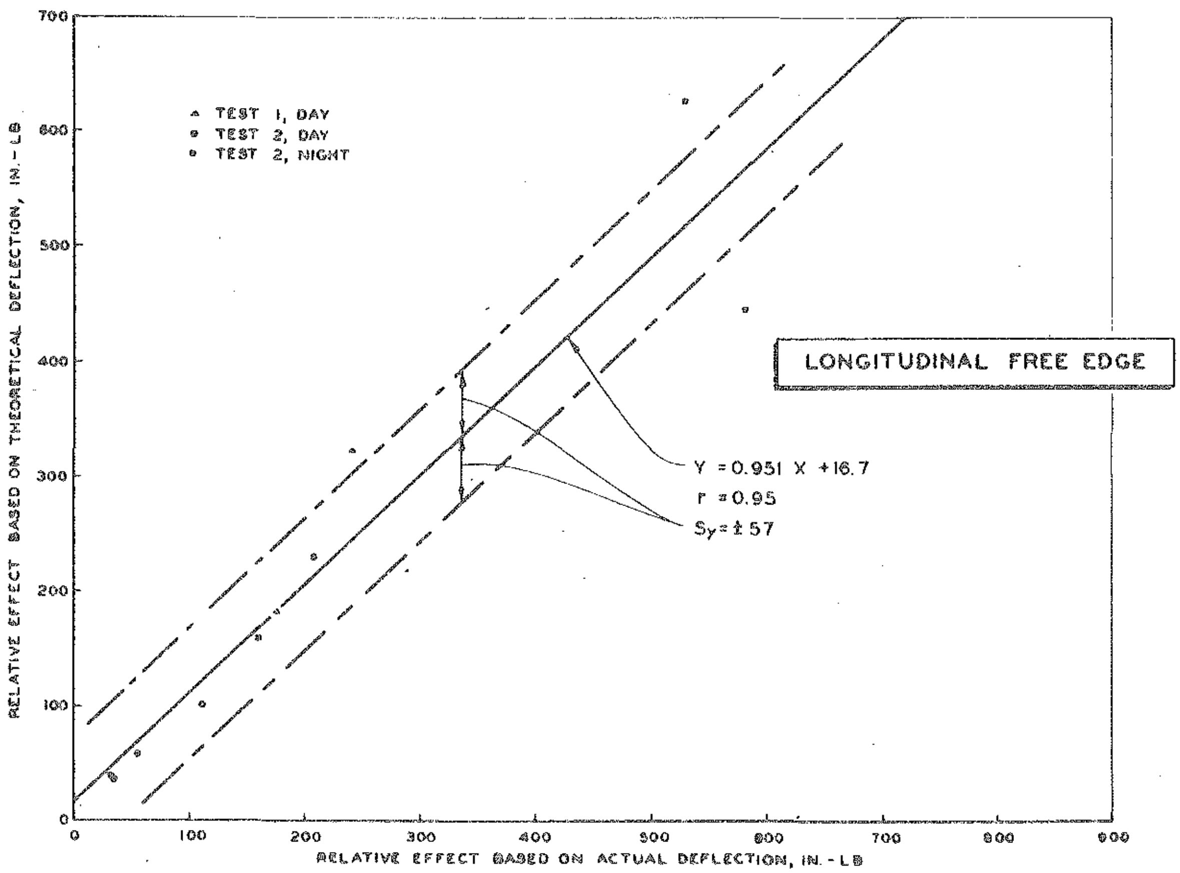


Figure 25. Comparison of relative pavement effect based on actual and theoretical deflection patterns.

Verification of Theory by Experimental Test Road Data

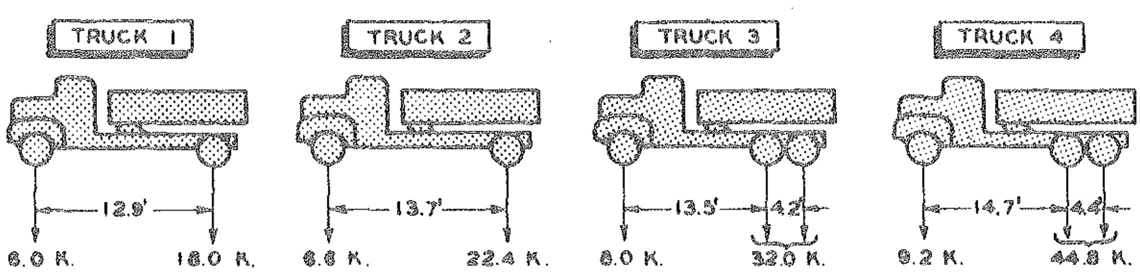
Validity of the results of any theory is subject to doubt unless the results also agree reasonably well with previous experimental data. Unfortunately test procedures in many previous experimental test roads were so arranged that the relative effects of various types of trucks and axle loads on the useful life of a given pavement section could not be determined. However, the Maryland Test Road data can be used to determine the validity of this theory, and the AASHO Road Test when it is completed may also be used in this way.

In the Maryland tests, four different vehicle types were used. The load axles were single axles of 18.0 and 22.4 kips and tandem axles of 32.0 and 44.8 kips. The criteria used in this test for comparing the relative effect of the test vehicles were first cracking and first pumping as shown in Table 4. In comparing the results of the application of the theory to relative effects of these trucks, load deflection data from several Michigan field tests have been used. The first group, labeled "Alma Test," was conducted on US 27 near Alma, Michigan, in 1952, and the other tests are those reported here.

In comparing the relative effect of these trucks, the joint corner and the longitudinal free edge positions have been treated separately, with attention to whether the data were from day or night deflections. The time of day and the pavement position have some influence on the relative effect, but in almost every case while the magnitude of actual deflection may be much greater at one time or at one location than at others, the relative effect is quite consistent. Grouping the results of data from all previous tests gives relative effect ratios of 1.00, 1.48, 1.82, and 3.24 for Trucks 1 through 4 while the actual relative effects determined by averaging the results from first pumping and first cracking are, respectively, 1.00, 1.48, 2.42, and 4.14. Trucks 3 and 4 with tandem axle loads had approximately 25 percent greater actual relative effect than predicted by the theory.

TABLE 4
COMPARISON OF THEORETICAL WITH ACTUAL RELATIVE EFFECT
MARYLAND TEST ROAD

Data Source	Maryland Test Truck			
	1	2	3	4
Maryland Test Road				
Load repetitions for first cracking	210,000	144,000	106,000	50,000
Load repetitions for first pumping	126,000	85,000	44,000	31,000
Actual Relative Effect				
First cracking	1.00	1.46	1.98	4.20
First pumping	1.00	1.49	2.86	4.07
ACTUAL AVERAGE	1.00	1.48	2.42	4.14
Computed Theoretical Relative Effect				
Alma Test				
Corner - night	1.00	1.57	1.98	3.92
Free edge - night	1.00	1.56	2.40	4.63
Average	1.00	1.56	2.19	4.28
Test 1				
Corner - day	1.00	1.38	1.42	2.50
Free edge - day	1.00	1.26	1.53	2.48
Average	1.00	1.32	1.48	2.49
Test 2				
Corner - day	1.00	1.44	1.61	2.67
Free edge - day	1.00	1.48	1.79	3.15
Average	1.00	1.46	1.70	2.91
Corner - night	1.00	1.36	1.53	2.59
Free edge - night	1.00	1.34	1.67	2.83
Average	1.00	1.35	1.60	2.71
THEORETICAL AVERAGE: ALL DATA	1.00	1.42	1.74	3.11
Percent Difference Theoretical to Actual Relative Effect	----	-4	-28	-25



APPLICATION OF THEORY

Relative Effect of Commercial Vehicles

The theory of relative effect of a vehicle on the pavement is now applied to a typical vehicle of each truck classification. This analysis will indicate how the relative effect varies for these trucks and will show that provided influence lines and load deflections data are available, the theory can be extended to any vehicle as long as its load and axle spacing are known. The procedure is as follows:

On the basis of the influence lines and load-deflection data, the deflection pattern is drawn for each axle of the vehicle as it passes over a joint corner or a longitudinal free edge position. Next, these individual deflection patterns for axles are integrated into a composite influence line of deflection for the entire vehicle, such as the one shown in Fig. 23. The relative effect of the vehicle is computed from the composite influence line in terms of in.-lb of energy as explained previously. The relative effect of all vehicles, from a passenger car to the largest commercial tractor-semi-trailer and full trailer combinations can be computed in this manner.

In Table 5 the relationship between the relative effect of a passenger car and a Type 2 truck is shown on the basis of deflection data from Test 2. The Type 2 truck is used here and consistently throughout this study to compare the relative effect of the many vehicles concerned. As shown in Table 5 the relative effect on the pavement of a passenger car compared to a Type 2 truck varies slightly depending on pavement location and whether based on day or night deflections, but is about 1/50 of that of a Type 2 truck.

In Table 6 the relative energy effected by pavement deflection resulting from the passage of each of the vehicles shown is tabulated for Test 2 at the average longitudinal free edge and joint corner positions. It may be noted that the deflection-energy effect

TABLE 5
COMPARISON OF RELATIVE EFFECTS OF A
PASSENGER CAR AND A TYPE 2 TRUCK

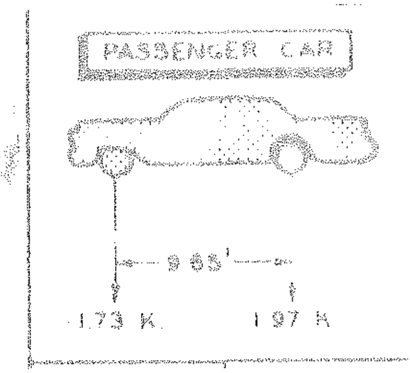
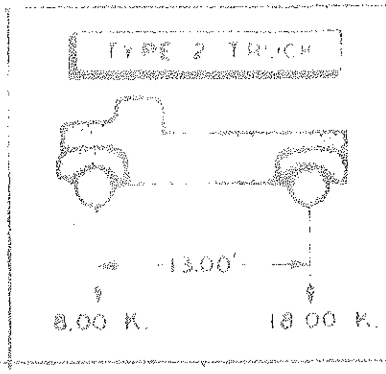
Pavement Position				
	Energy, in.-lb	Relative Effect	Energy, in.-lb	Relative Effect
Longitudinal Free Edge				
Day	0.5	0.015	33	1.00
Night	3.5	0.028	126	1.00
Average	---	0.022	--	1.00
Joint Corner				
Day	0.4	0.022	18	1.00
Night	11.7	0.065	180	1.00
Average	---	0.043	--	1.00
Overall Average	---	0.033	--	1.00

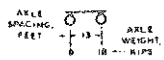
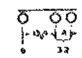
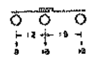
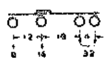
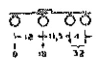
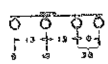
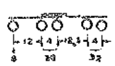
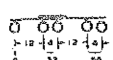
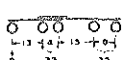
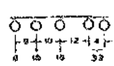
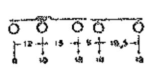
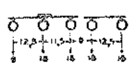
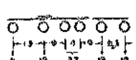
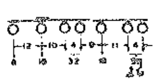
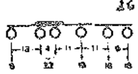
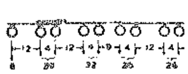
TABLE 6
RELATIVE ENERGY RESULTING FROM PAVEMENT DEFLECTIONS
CAUSED BY VARIOUS COMMERCIAL VEHICLES - TEST 2

Truck Type	Truck Axle Load & Spacing	Truck Wt. kips	Energy: Day Tests: Free Edge, in.-lb	Energy: Day Tests: Corner in.-lb	Energy: Day Tests: Ratio = Free Edge / Corner	Energy: Night Tests: Free Edge, in.-lb	Energy: Night Tests: Corner in.-lb	Energy: Night Tests: Ratio = Free Edge / Corner	Ratio = Night / Day: Free Edge	Ratio = Night / Day: Corner
2		26	32.8	18.4	1.78	126.2	180.3	0.70	3.9	9.8
3		40	55.4	27.5	2.01	201.8	268.0	0.75	3.6	9.7
2S1		44	59.2	33.1	1.79	194.6	286.6	0.68	3.3	8.7
2S2		58	82.5	40.7	2.03	317.8	362.6	0.88	3.9	8.9
2S2		58	76.8	41.2	1.86	308.2	294.2	1.05	4.0	7.1
2S2*		62	70.2	43.7	1.61	255.0	311.1	0.82	3.6	7.1
3S2		66	85.8	40.9	2.10	275.3	293.4	0.94	3.2	7.2
3S2		66	84.7	47.6	1.78	279.3	323.4	0.86	3.3	6.8
3S2*		76	95.4	52.8	1.81	324.6	399.3	0.81	3.4	7.6
2-3		76	87.2	51.3	1.70	321.9	347.8	0.93	3.7	6.8
2S1-2		80	99.5	58.7	1.70	339.2	459.4	0.74	3.4	7.8
2S1-2		80	86.8	56.8	1.53	307.1	409.0	0.75	3.5	7.2
2S2-2		94	87.8	57.1	1.54	405.0	470.5	0.86	4.6	8.2
2S2-3		102	121.7	72.8	1.67	458.9	534.0	0.86	3.8	7.3
3S1-2		90	102.8	61.7	1.67	3[illegible].2	365.3	1.06	3.8	5.9
3S2-4		118	124.9	69.2	1.81	408.2	527.5	0.77	3.3	7.6

* Long Tandem

Revised see sheet check
L.T.W. 3-22-62

TABLE 6
RELATIVE ENERGY RESULTING FROM PAVEMENT DEFLECTION
CAUSED BY VARIOUS COMMERCIAL VEHICLES - TEST 2

Truck Type	Truck Axle Load and Spacing	Truck Weight, kips	Energy							
			Day Tests			Night Tests			Ratio = Night/Day	
			Free Edge, in.-lb	Corner, in.-lb	Ratio = Free Edge/Corner	Free Edge, in.-lb	Corner, in.-lb	Ratio = Free Edge/Corner	Free Edge	Corner
2		26	34.5	20.7	1.67	177	459	0.39	5.1	22
3		40	61.2	32.5	1.88	307	672	0.46	5.0	21
2S1		44	63.0	37.8	1.67	307	820	0.38	4.9	22
2S2		58	90.7	47.5	1.91	484	1006	0.48	5.3	21
2S2		58	86.1	46.6	1.85	468	919	0.51	5.4	20
2S2*		62	77.4	51.5	1.50	412	1132	0.36	5.3	22
3S2		66	96.3	48.1	2.00	437	1023	0.43	4.5	21
3S2		66	95.9	50.5	1.90	439	1019	0.43	4.6	20
3S2*		76	106.8	62.6	1.71	537	1354	0.40	5.0	22
2-3		76	100.9	60.7	1.66	511	1283	0.40	5.1	21
2S1-2		80	109.4	69.0	1.59	567	1486	0.38	5.2	22
2S1-2		80	98.6	67.4	1.46	507	1488	0.34	5.1	22
2S2-2		94	101.9	67.4	1.51	579	1485	0.39	5.7	22
2S2-3		102	130.9	80.4	1.63	691	1649	0.42	5.3	21
3S1-2		90	119.5	73.9	1.62	630	1660	0.38	5.3	22
3S2-4		118	144.2	84.0	1.72	669	1594	0.42	4.6	19

* Long tandem

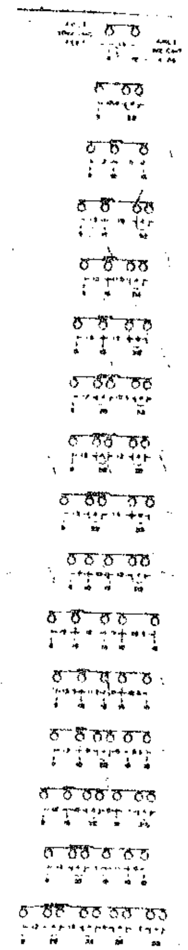
is less during the day at the ~~reverse~~ longitudinal free edge ~~and~~ joint corner. However, during the night the reverse is true, with the energy at the joint corner more than twice that at the longitudinal free edge. The much greater effect of pavement warping at the corner than at the free edge accounts for this difference between night and day energy effects at these two locations.

The specific values of deflection-energy resulting from passage of these vehicles have no intrinsic value in themselves, for as shown they vary greatly depending on period of day, and change as the pavement warps due to differential temperature effects. However, the primary value of these energy relationships is that they give a logical ~~and equitable~~ way of relating the effects of the various vehicles on the pavement structure. Even though the magnitude of energy values changes with temperature, the relative relationship between vehicles remain almost identical. This is shown in Table 7 where the relative effects are given for the same typical array of commercial vehicles. The relative effect of all vehicles is related to that for a Type 2 vehicle. The relative effect of these vehicles has been computed from the load-deflection and influence line data from Tests 1 and 2 and the Alma Test of 1952. The agreement between the relative effects of the vehicles as based on three different tests is remarkably good.

Relative Effect of Special Vehicles

In Test 2 two special vehicles were used to determine if their unique axle arrangements might have somewhat different relative effects on the pavement than regular commercial vehicles with similar loads. Vehicle 10 was a "low-boy" trailer type with a total load of 130 kips. Axle loads were grouped as follows: a single steering axle loaded to 10.8 kips, followed by a triple axle load of 56.8 kips consisting of the tandem drive axles of the tractor and a single drag axle under the front of the trailer, all with four wheels per axle, and ending with tandem axles loaded to 62.3 kips, each axle having eight wheels per axle

TAB
RELATIVE EFFECTS OF VARI COMMERCIAL VEHICLES



Truck Type	Truck Axle Load and Spacing	Truck Weight, kips			Relative Effect - Test 1			Relative Effect - Test 2							Relative Effect - Alma Test		
					Day			Day			Night			Overall Average	Night		
		Gross	Empty	Pay Load	Corner	Free Edge	Avg	Corner	ree Edge	Avg	Corner	Free Edge	Avg		Corner	Free Edge	Avg
2		26	8	18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3		40	15	25	1.38	1.45	1.42	1.50	1.69	1.60	1.49	1.60	1.55	1.57	1.84	2.36	2.10
2S1		44	17	27	1.76	1.58	1.67	1.80	1.81	1.80	1.59	1.54	1.57	1.69	1.68	1.65	1.66
2S2		58	23	35	2.02	2.06	2.04	2.21	2.52	2.37	2.01	2.52	2.27	2.32	2.63	3.04	2.84
2S2		58	22	36	1.83	2.20	2.02	2.24	2.34	2.29	1.63	2.44	2.04	2.16	2.30	2.77	2.54
2S2*		62	24	38	2.10	1.52	1.81	2.38	2.14	2.26	1.73	2.02	1.88	2.07	2.21	2.17	2.19
3S2		66	33	33	2.16	1.83	2.00	2.22	2.62	2.42	1.63	2.18	1.91	2.16	2.60	3.16	2.88
3S2		66	33	33	2.16	1.86	2.01	2.59	2.58	2.59	1.79	2.21	2.00	2.29	2.53	3.21	2.87
3S2*		76	35	41	2.73	2.30	2.52	2.87	2.91	2.89	2.22	2.57	2.40	2.64	3.13	3.50	3.32
2-3		76	29	47	2.63	2.12	2.38	2.79	2.66	2.73	1.93	2.55	2.24	2.48	2.92	3.42	3.17
2S1-2		80	29	51	3.15	2.58	2.87	3.19	3.04	3.12	2.55	2.69	2.62	2.87	3.08	2.91	3.00
2S1-2		80	29	51	2.96	2.05	2.51	3.09	2.65	2.87	2.27	2.43	2.35	2.61	2.84	2.60	2.72
2S2-2		94	35	59	2.95	2.20	2.58	3.10	2.68	2.89	2.61	3.21	2.91	2.90	3.00	3.51	3.26
2S2-3		102	38	64	3.50	2.71	3.11	3.96	3.71	3.84	2.96	3.63	3.30	3.57	3.46	4.36	3.91
3S1-2		90	35	55	3.04	2.34	2.69	3.35	3.14	3.25	2.03	3.08	2.56	2.90	3.74	4.00	3.87
3S2-4		118	42	76	3.51	2.62	3.07	3.77	3.81	3.79	2.93	3.23	3.08	3.44	4.10	4.75	4.42

* Long tandem

TABLE 7
RELATIVE EFFECTS OF VARIOUS COMMERCIAL VEHICLES

Truck Type	Truck Axle Load and Spacing	Truck Weight, kips			Relative Effect - Test 1			Relative Effect - Test 2							Relative Effect - Alma Test		
					Day			Day			Night			Overall Average	Night		
		Gross	Empty	Pay Load	Corner	Free Edge	Avg	Corner	Free Edge	Avg	Corner	Free Edge	Avg		Corner	Free Edge	Avg
2		26	8	18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3		40	15	25	1.49	1.82	1.66	1.58	1.77	1.68	1.46	1.73	1.60	1.64	1.84	2.36	2.10
2S1		44	17	27	1.82	1.72	1.77	1.83	1.83	1.83	1.79	1.73	1.76	1.80	1.68	1.65	1.66
2S2		58	23	35	2.32	2.53	2.42	2.30	2.63	2.46	2.19	2.73	2.46	2.46	2.63	3.04	2.84
2S2		58	22	36	2.72	2.30	2.51	2.25	2.50	2.38	2.00	2.64	2.32	2.35	2.30	2.77	2.54
2S2*		62	24	38	2.09	1.98	2.04	2.49	2.25	2.37	2.47	2.33	2.40	2.38	2.21	2.17	2.19
3S2		66	33	33	2.32	2.47	2.40	2.33	2.79	2.56	2.23	2.47	2.35	2.46	2.60	3.16	2.88
3S2		66	33	33	2.34	2.54	2.44	2.44	2.78	2.61	2.22	2.48	2.35	2.48	2.53	3.21	2.87
3S2*		76	35	41	2.94	2.92	2.93	3.03	3.10	3.06	2.95	3.03	2.99	3.02	3.13	3.50	3.36
2-3		76	29	47	2.86	2.99	2.92	2.94	2.93	2.94	2.80	2.88	2.84	2.89	2.92	3.42	3.17
2S1-2		80	29	51	3.28	3.10	3.19	3.34	3.17	3.26	3.24	3.20	3.22	3.24	3.08	2.91	3.00
2S1-2		80	29	51	3.11	2.84	2.98	3.26	2.86	3.06	3.24	2.86	3.05	3.06	2.84	2.60	2.72
2S2-2		94	35	59	3.28	3.04	3.16	3.26	2.96	3.11	3.23	3.27	3.25	3.18	3.00	3.51	3.26
2S2-3		102	38	64	3.54	3.47	3.50	3.88	3.79	3.84	3.60	3.90	3.75	3.79	3.46	4.36	3.91
3S1-2		90	35	55	3.35	3.37	3.36	3.57	3.47	3.52	3.62	3.55	3.58	3.55	3.74	4.00	3.87
3S2-4		118	42	76	3.82	3.78	3.80	4.06	4.18	4.12	3.47	3.77	3.62	3.87	4.10	4.75	4.42

* Long tandem

(Figs. 2 and 31). Vehicle 11 was an earth scraper with two large tires per axle and single axle loads of 29.5 and 15.1 kips per axle when unloaded.

It was not possible during the test program to vary the loads on these test vehicles in order to develop load-deflection curves, but the load-deflection points for these axle loads are shown in Fig. 26 for day and night tests. ~~For comparison, axle loads are shown in Fig. 26 for day and night tests.~~ For comparison, the regular load-deflection curves are shown for commercial vehicles, but for the heavier axle loads a great deal of extrapolation is required. In general it appears that the larger tires and only two tires per axle of the earth scraper caused deflections at the longitudinal free edge and the joint corner which were as large or larger than would be expected from single axle loads of equal magnitude with four conventional sized commercial tires per axle. The deflection under the eight tires on the tandem axle of the low-boy trailer was of a magnitude which might be expected for equal tandem axle loads and four conventional tires per axle. However, the smaller deflection resulting from the triple axle, four tires per axle, of the same vehicle is very apparent. This triple axle load of 56.8 kips had deflections comparable to single axle loads of 11 kips at the joint corner (day) and 22 kips (night). At the longitudinal free edge equal deflections were obtained for 15 kip-single axles (day) and 18 kips (night).

The relative effects of these two vehicles on the pavement are shown in Table 8 in comparison with a Type 2 vehicle. The earth scraper had an average effect of 2.60 times and the low-boy hauler of 4.32 times the effect of the Type 2 truck. The effect of the earth scraper is approximately the same as the Type 3S2 truck (total load: 66 kips). The low-boy trailer had a greater effect than the heaviest commercial vehicle, Type 3S2-4, with a total load of 118 kips.

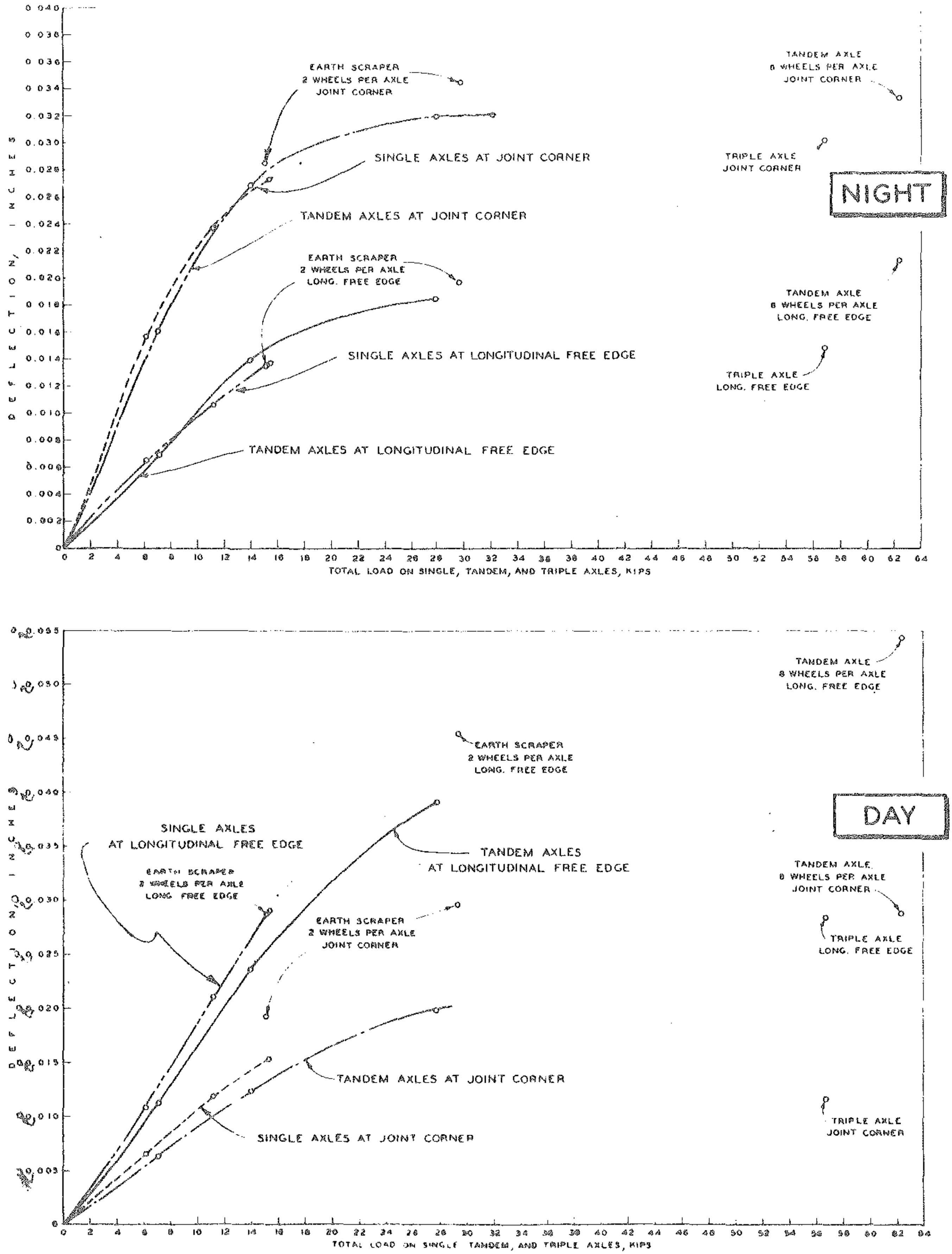
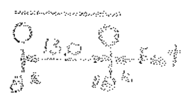
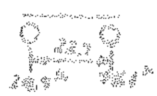
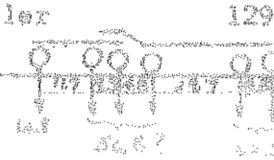


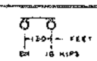
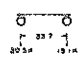
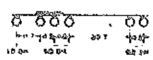
Figure 26. Load deflection relationships for single, tandem, and triple axles: Test 2.

TABLE 8
RELATIVE EFFECTS OF SPECIAL VEHICLES
TEST 2

Truck Type	Truck Axle Load and Spacing	Total Load, kips	Relative Effect						
			Day			Night			Overall
			Corner	Free Edge	Avg	Corner	Free Edge	Avg	Avg
2		26.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vehicle 11 Scraper		44.6	3.55	2.50	3.02	2.89	2.65	2.77	2.90
Vehicle 10 Low-Boy Trailer		129.9	3.09	5.06	4.08	1.31	3.32	2.32	3.20

Revised, see preceding sheet
L.F.O. 3.22.65

TABLE 8
RELATIVE EFFECTS OF SPECIAL VEHICLES
TEST 2

Truck Type	Truck Axle Load and Spacing	Total Load, kips	Relative Effect						
			Day			Night			Overall Avg
			Corner	Free Edge	Avg	Corner	Free Edge	Avg	
2		26.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vehicle 11 Scraper		44.6	2.82	2.75	2.78	2.35	2.50	2.42	2.60
Vehicle 10 Low-Boy Trailer		129.9	3.47	4.65	4.06	3.75	5.40	4.58	4.32

Verification by Comparing Results of Three Tests

As noted previously Test 1 was conducted only during the day and the Alma Test only at night, while Test 2 was conducted during both the day and night. To compare the various values of relative effect for both day and night for these two tests it was therefore necessary to determine the relationship between the relative effects for the two periods. This was done for the Test 2 joint corner and ~~the~~ longitudinal free edge positions as shown in Fig. 27. These lines indicate a very good correlation between the day and night observations of relative effect, with a correlation coefficient of 0.98 and 0.97 and a standard error of estimate of ±0.14 and ±0.19 for the joint corner and the longitudinal free edge, respectively. In each case the relationship is highly significant--chance of no correlation is less than 1 in 1000.

Since the correlation was so good between the relative effect values under day and night observations it was decided to predict the missing observations for Test 1 and the Alma Test where night or day observations were not made. This has been done in Table 9 with the predicted values identified. On the basis of data in Table 9 the average relative effect (averaging day and night and joint corner and longitudinal free edge) for each of the 16 commercial vehicles has been analyzed statistically to determine the correlation between the results of the three tests.

The results of this multiple linear regression analysis are shown in Fig. 28, where the best fit regression plane is given by the equation

$$X_2 = 0.970X_1 + 0.074X_3 - 0.040$$

and the standard error of estimate is ±0.099. The standard error of estimate indicates that the relative energy ratios for Test 2 (X_2) could be predicted from Test 1 (X_1) and the Alma Test (X_3) within ±0.099 of the actual value of Test 2, approximately 68 out of 100 times. This rather small standard error of estimate, in addition to a very good correlation coefficient of 0.991 (where 1.0 is perfect correlation and zero is no

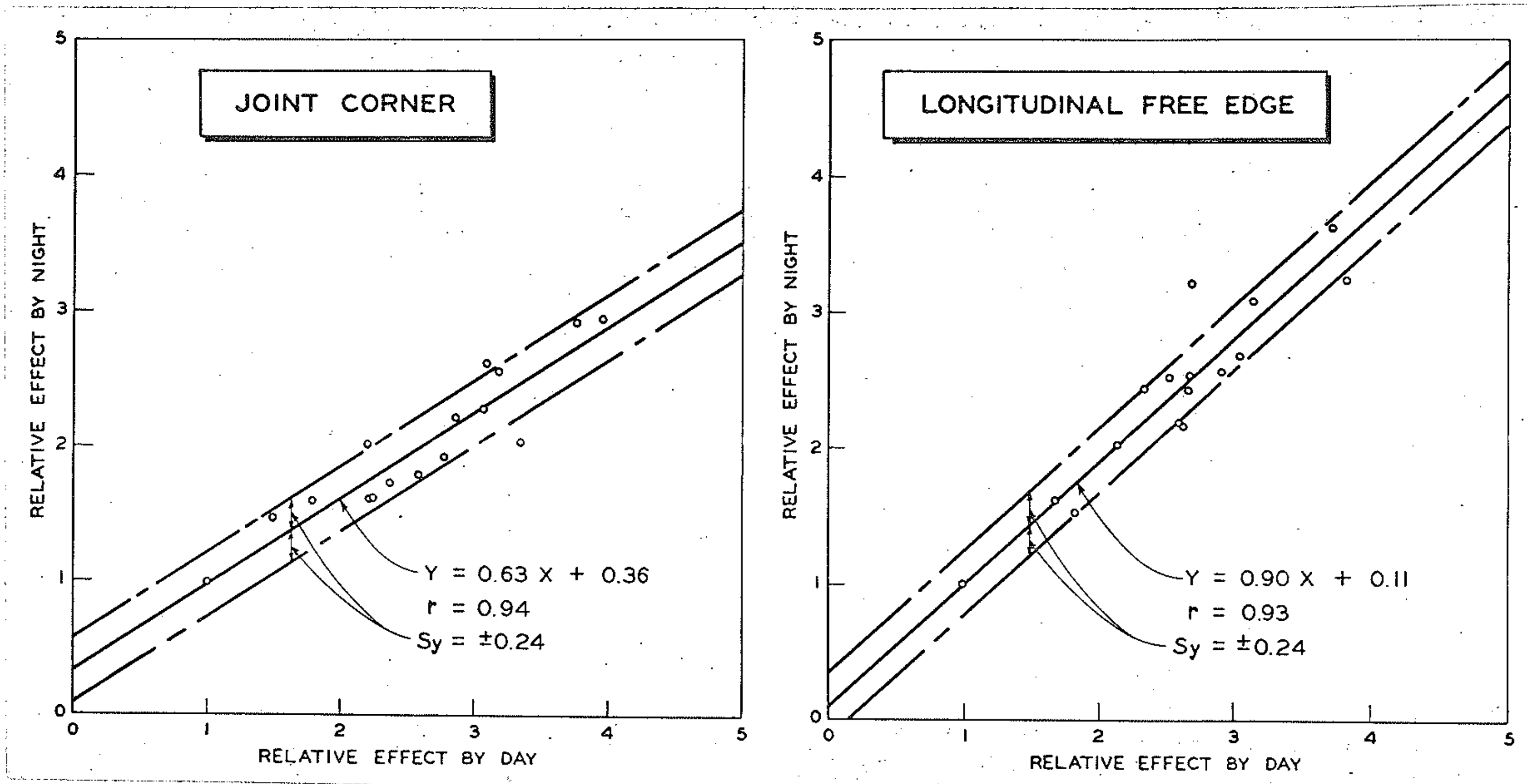


Figure 27. Correlation of relative effect values between day and night observations: Test 2.

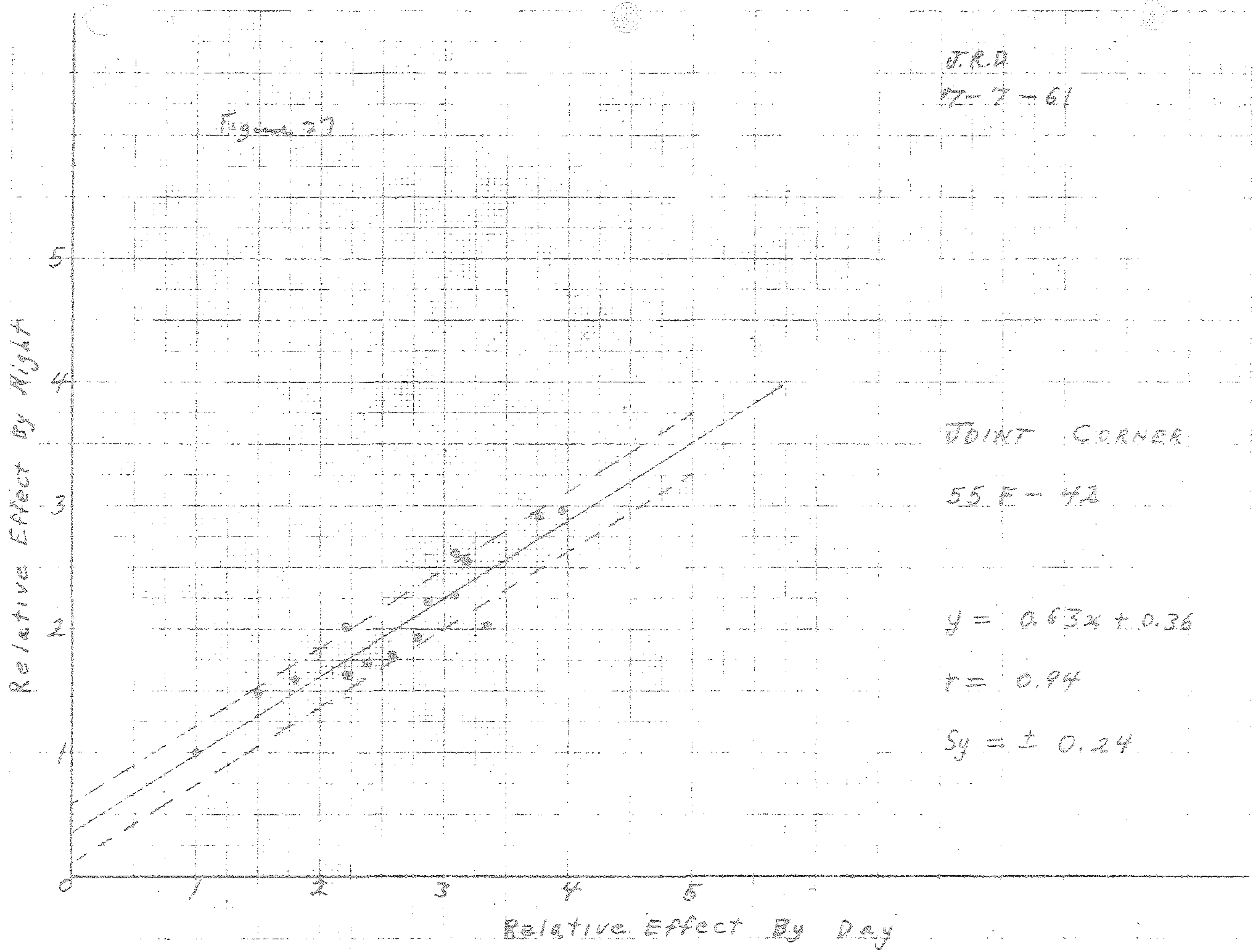
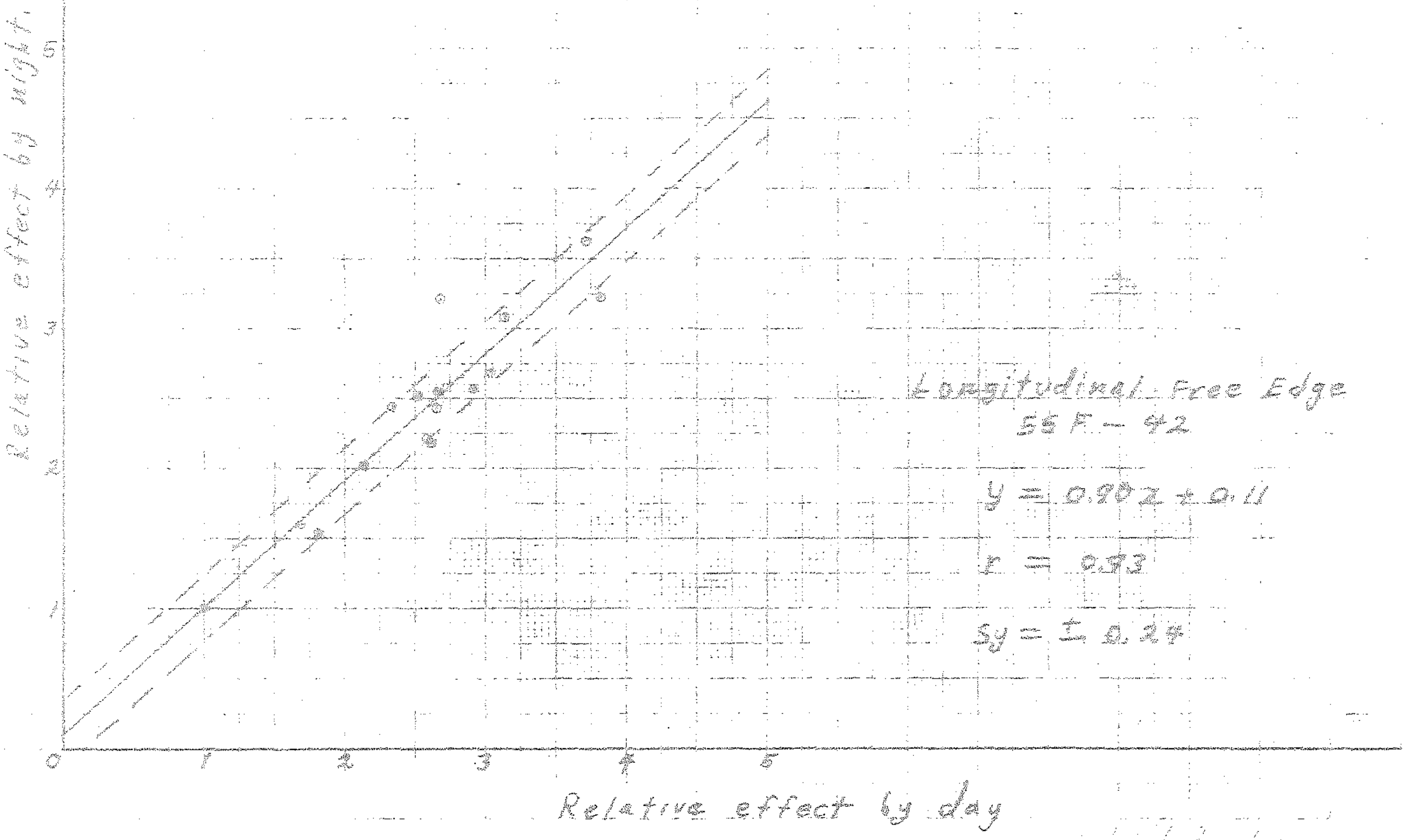


Figure 27
J.R.D.
7-7-61
JOINT CORNER
55 F - 42
y = 0.63x + 0.36
r = 0.94
Sy = ± 0.24
Relative Effect By Night
Relative Effect By Day
0
1
2
3
4
5

J. R. D.
7 – 7 – 61

Figure 27



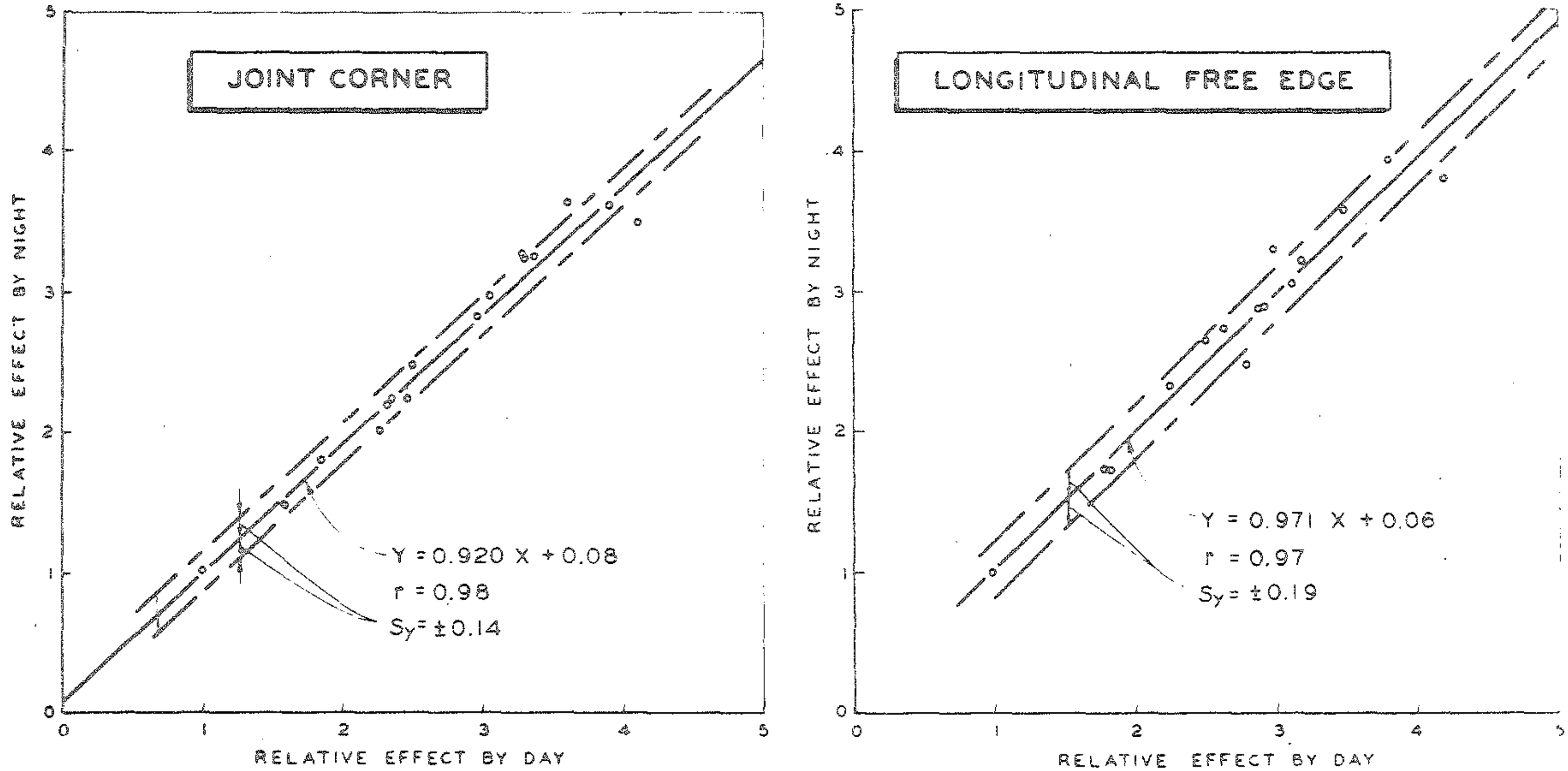


Figure 27. Correlation of relative effect values between day and night observations: Test 2.

TABLE 9

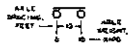
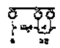
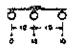
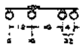
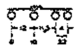
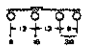
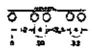
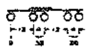
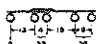
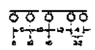
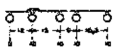
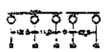
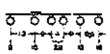
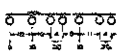
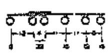
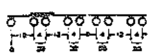
SUMMARY OF RELATIVE EFFECT RATIOS OF VARIOUS COMMERCIAL VEHICLES

Truck Type	Truck Diagram and Spacing	Test 1							Test 2							Alma Test						
		Day			Night*			Overall Avg	Day			Night			Overall Avg	Day**			Night			Overall Avg
		Corner	Free Edge	Avg	Corner	Free Edge	Avg		Corner	Free Edge	Avg	Corner	Free Edge	Avg		Corner	Free Edge	Avg	Corner	Free Edge	Avg	
2		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3		1.38	1.46	1.42	1.23	1.42	1.33	1.37	1.50	1.69	1.60	1.40	1.69	1.55	1.57	2.35	2.50	2.43	1.84	2.36	2.10	2.27
2S1		1.76	1.58	1.67	1.47	1.53	1.50	1.59	1.80	1.81	1.80	1.58	1.64	1.57	1.60	2.10	1.71	1.91	1.68	1.65	1.66	1.79
2S2		2.02	2.06	2.04	1.63	1.96	1.80	1.92	2.21	2.52	2.37	2.01	2.52	2.27	2.32	3.60	3.26	3.43	2.63	3.04	2.84	3.14
2S2		1.83	2.20	2.02	1.51	2.09	1.80	1.91	2.24	2.34	2.29	1.63	2.44	2.04	2.16	3.08	2.96	3.02	2.30	2.77	2.54	2.78
2S2***	Same Diagram as Table 7	2.10	1.52	1.81	1.68	1.48	1.58	1.70	2.55	2.14	2.26	1.73	2.02	1.88	2.07	2.94	2.29	2.62	2.21	2.17	2.19	2.41
3S2		2.16	1.83	2.00	1.72	1.76	1.74	1.87	2.38	2.62	2.42	1.63	2.18	1.91	2.16	3.56	3.39	3.48	2.60	3.16	2.88	3.18
3S2		2.16	1.86	2.01	1.72	1.78	1.75	1.88	2.59	2.56	2.59	1.79	2.21	2.00	2.30	3.44	3.44	3.44	2.53	3.21	2.87	3.16
3S2***		2.73	2.30	2.52	2.08	2.18	2.13	2.33	2.97	2.91	[illegible]	2.23	2.57	2.40	2.64	4.40	3.77	4.09	3.13	3.50	3.32	3.70
2-3		2.63	2.12	2.38	2.02	2.02	2.02	2.20	3.70	2.91	2.73	1.98	2.55	2.24	2.48	4.06	3.68	3.87	2.92	3.42	3.17	3.52
2S1-2		3.15	2.58	2.87	2.34	2.43	2.39	2.63	[illegible]	3.04	3.12	2.58	2.69	2.62	2.87	4.32	3.11	3.72	3.05	2.91	3.00	3.36
2S1-2		2.96	2.06	2.51	2.23	1.96	2.10	2.31	[illegible]	2.64	2.87	2.27	2.43	2.35	2.61	3.94	2.77	3.36	2.84	2.60	2.72	3.04
2S2-2		2.96	2.20	2.58	2.22	2.09	2.16	2.37	[illegible]	2.64	2.80	2.61	3.21	2.91	2.80	4.19	3.78	3.98	3.00	3.51	3.26	3.62
2S2-3		3.50	2.72	3.11	2.57	2.55	2.56	2.84	3.96	3.71	3.84	2.96	3.63	3.30	3.57	4.92	4.72	4.82	3.46	4.36	3.91	4.37
3S1-2		3.04	2.34	2.69	2.28	2.22	2.25	2.47	3.35	3.14	3.25	2.02	3.09	2.56	2.90	5.36	4.32	4.84	3.74	4.00	3.87	4.36
3S2-4		3.51	2.62	3.07	2.57	2.47	2.52	2.80	3.77	3.31	3.59	2.98	3.33	3.08	3.44	5.94	5.16	5.55	4.10	4.75	4.42	4.99

* Values shown for night relative effect ratios determined from day values and regression line relationship between day and night values from Test 2.
** Values shown for day relative effect ratios determined from night values and regression line relationship between day and night values from Test 2.
*** Long tandem.

TABLE 9

SUMMARY OF RELATIVE EFFECT RATIOS OF VARIOUS COMMERCIAL VEHICLES

Truck Type	Truck Axle Load and Spacing	Test 1							Test 2							Alma Test						
		Day			Night*			Overall Avg	Day			Night			Overall Avg	Day**			Night			Overall Avg
		Corner	Free Edge	Avg	Corner	Free Edge	Avg		Corner	Free Edge	Avg	Corner	Free Edge	Avg		Corner	Free Edge	Avg	Corner	Free Edge	Avg	
2		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3		1.82	1.49	1.66	1.76	1.50	1.63	1.64	1.58	1.77	1.68	1.46	1.73	1.60	1.64	1.91	2.37	2.14	1.84	2.36	2.10	2.12
2S1		1.72	1.82	1.77	1.67	1.82	1.75	1.76	1.83	1.83	1.83	1.79	1.73	1.76	1.80	1.73	1.64	1.68	1.68	1.65	1.66	1.68
2S2		2.53	2.32	2.42	2.41	2.30	2.36	2.39	2.30	2.63	2.46	2.19	2.73	2.46	2.46	2.76	3.07	2.92	2.63	3.04	2.84	2.88
2S2		2.30	2.72	2.51	2.20	2.70	2.45	2.48	2.25	2.50	2.38	2.00	2.64	2.32	2.35	2.41	2.80	2.60	2.30	2.77	2.54	2.57
2S2***		1.98	2.09	2.04	1.91	2.08	2.00	2.02	2.49	2.25	2.37	2.47	2.33	2.40	2.38	2.31	2.18	2.24	2.21	2.17	2.19	2.22
• 3S2		2.47	2.32	2.40	2.36	2.30	2.33	2.36	2.33	2.79	2.56	2.23	2.47	2.35	2.46	2.73	3.20	2.96	2.60	3.16	2.88	2.92
3S2		2.55	2.34	2.44	2.43	2.33	2.38	2.41	2.44	2.78	2.61	2.22	2.48	2.35	2.48	2.66	3.25	2.96	2.53	3.21	2.87	2.91
3S2***		2.93	2.94	2.94	2.78	2.91	2.84	2.89	3.03	3.10	3.06	2.95	3.03	2.99	3.03	3.31	3.55	3.43	3.13	3.50	3.32	3.37
2-3		2.99	2.86	2.92	2.84	2.83	2.84	2.88	2.94	2.93	2.94	2.80	2.88	2.84	2.89	3.08	3.47	3.28	2.92	3.42	3.17	3.22
2S1-2		3.10	3.28	3.19	2.94	3.24	3.09	3.14	3.34	3.17	3.26	3.24	3.20	3.22	3.24	3.25	2.94	3.10	3.08	2.91	3.00	3.04
2S1-2		2.84	3.11	2.98	2.70	3.07	2.88	2.93	3.26	2.86	3.06	3.24	2.86	3.05	3.06	2.99	2.62	2.80	2.84	2.60	2.72	2.76
2S2-2		3.04	3.28	3.16	2.88	3.24	3.06	3.11	3.26	2.96	3.11	3.23	3.27	3.25	3.18	3.17	3.56	3.36	3.00	3.51	3.26	3.31
2S2-3		3.54	3.47	3.50	3.33	3.43	3.38	3.44	3.88	3.79	3.84	3.60	3.90	3.75	3.79	3.67	4.43	4.05	3.46	4.36	3.91	3.98
3S1-2		3.35	3.37	3.36	3.19	3.31	3.25	3.30	3.57	3.47	3.52	3.62	3.55	3.58	3.55	3.97	4.06	4.02	3.74	4.00	3.87	3.94
3S2-4		3.78	3.82	3.80	3.56	3.76	3.66	3.73	4.06	4.18	4.12	3.47	3.77	3.62	3.87	4.36	4.84	4.60	4.10	4.75	4.42	4.51

* Values shown for night relative effect ratios determined from day values and regression line relationship between day and night values from Test 2.

** Values shown for day relative effect ratios determined from night values and regression line relationship between day and night values from Test 2.

*** Long tandem.

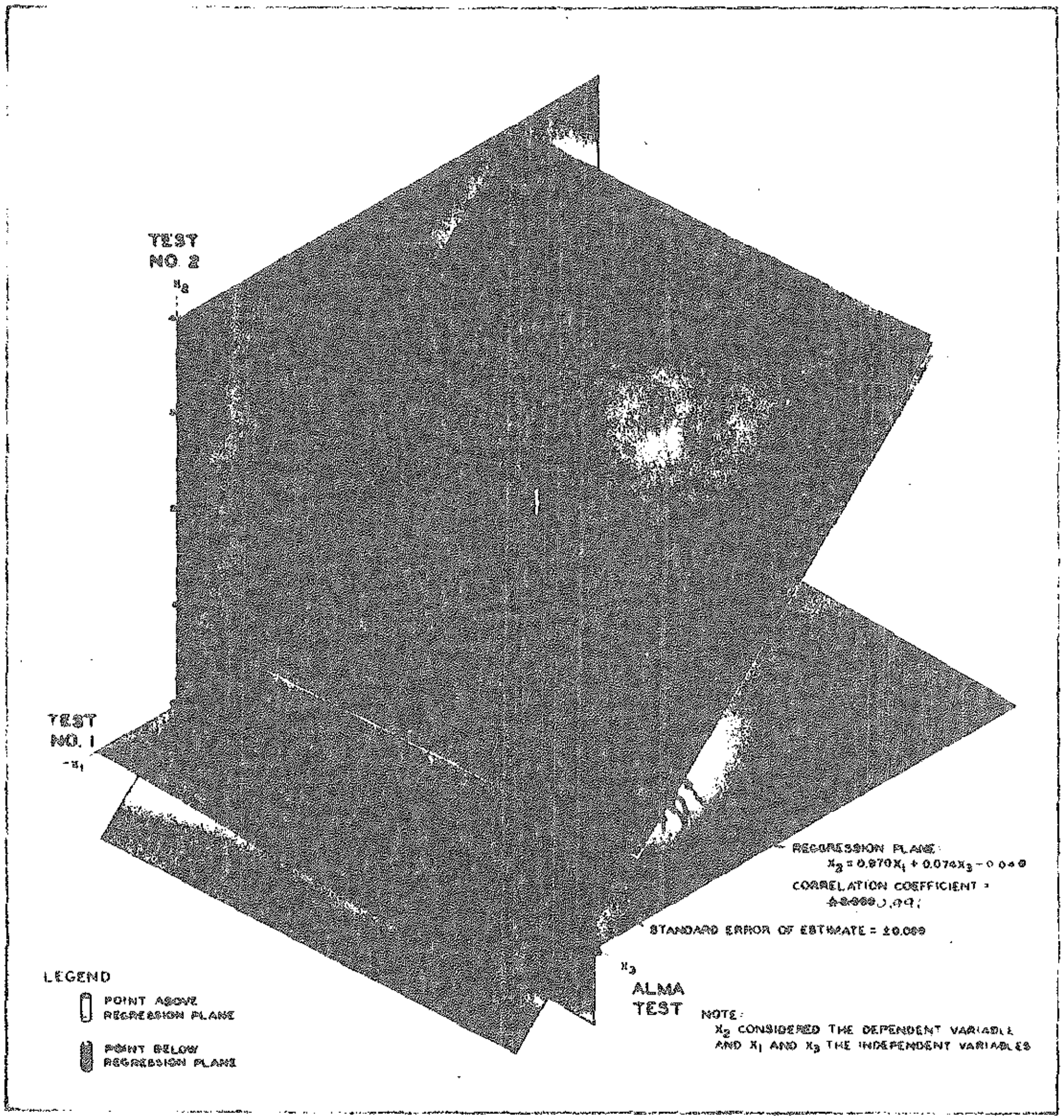


Figure 28. Multiple correlation of relative effect ratios for three separate tests.

correlation), indicates that the results of the three tests agree very closely. The results of the three tests have highly significant statistical correlation, which indicates that one or all three of the sets of load-deflection data could have been used to determine the relative effects of the various commercial vehicles, with only minor changes in the resulting relationships between them.

Vehicle Design

One interesting application of this theory is in determining the optimum axle spacing for the least relative effect on the pavement. If two axles of equal load are considered to vary in their spacing from 0 to 32 ft apart, the relative effect of these axles will be as shown in Fig. 29. The data shown were based on an axle load "P," equal to 10 kips. However, the general shape of these graphs would be basically the same for larger or smaller axle loads than this, although the relative effect values might differ slightly. These graphs indicate that the optimum spacing for two single axles is 8 ft at the joint corner and the longitudinal free edge for day deflections, and 8 and 10 ft for the joint corner and longitudinal free edge for night deflections. This same procedure could be applied to analysis of optimum spacing for minimum relative effect of three or more axles.

Changing Load Limits

The theory presented here may be used to determine the relative effect on the pavement of changing the legal load limits for commercial vehicles. Six typical vehicles have been selected, as shown in Table 10, to illustrate the relative effect on pavement of changing the legal limits from A to B. Load Limit A is 18 kips for single axle loads, 32 kips for tandem axle loads. However, only one 32-kip tandem axle load is permitted per vehicle and all other tandem axle loads are restricted to 26 kips. Load Limit B is 22.4

Revised 2-3-64

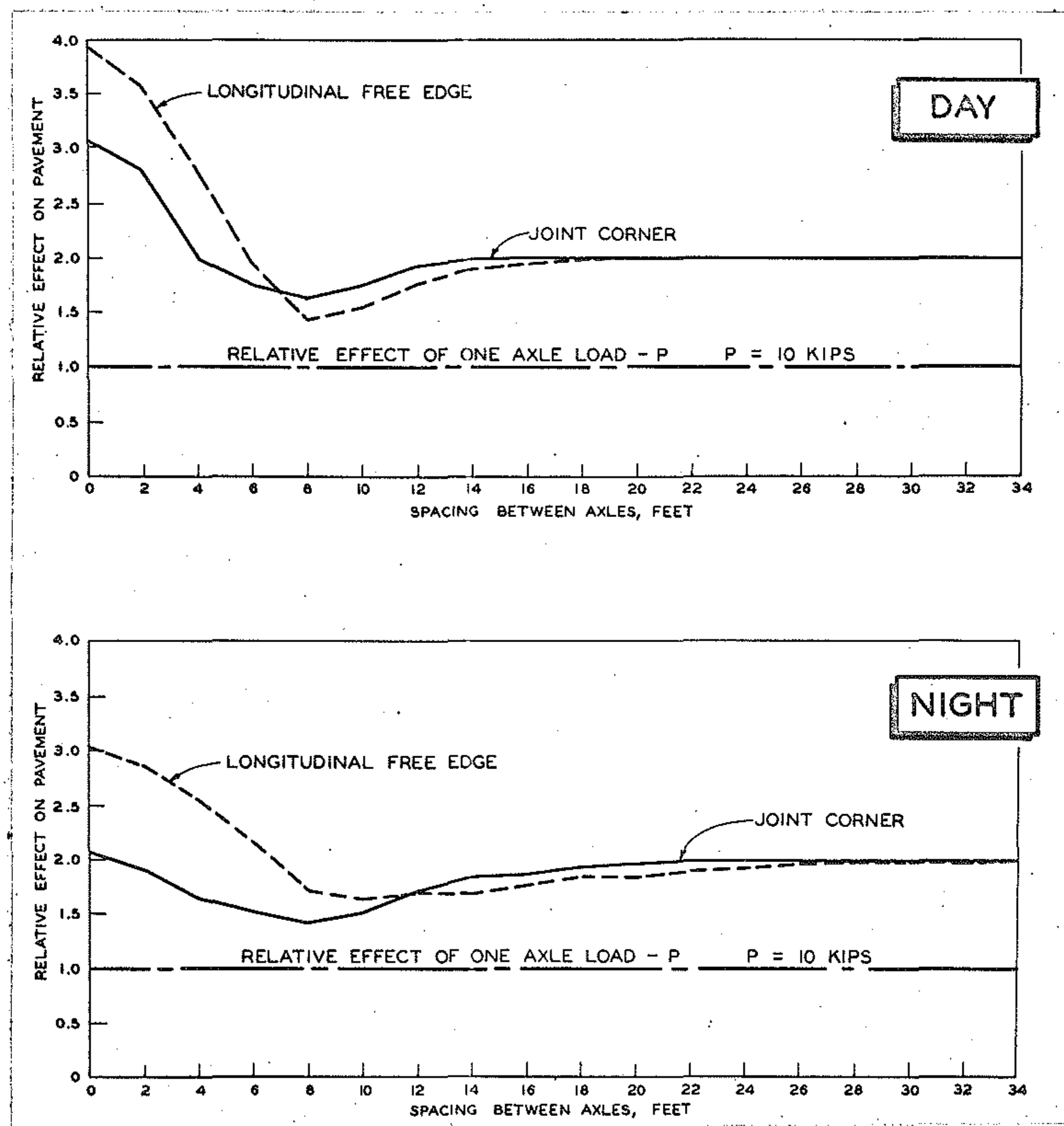


Figure 29. Relative effect of two axle loads "P" as their axle spacings vary: Test 2.

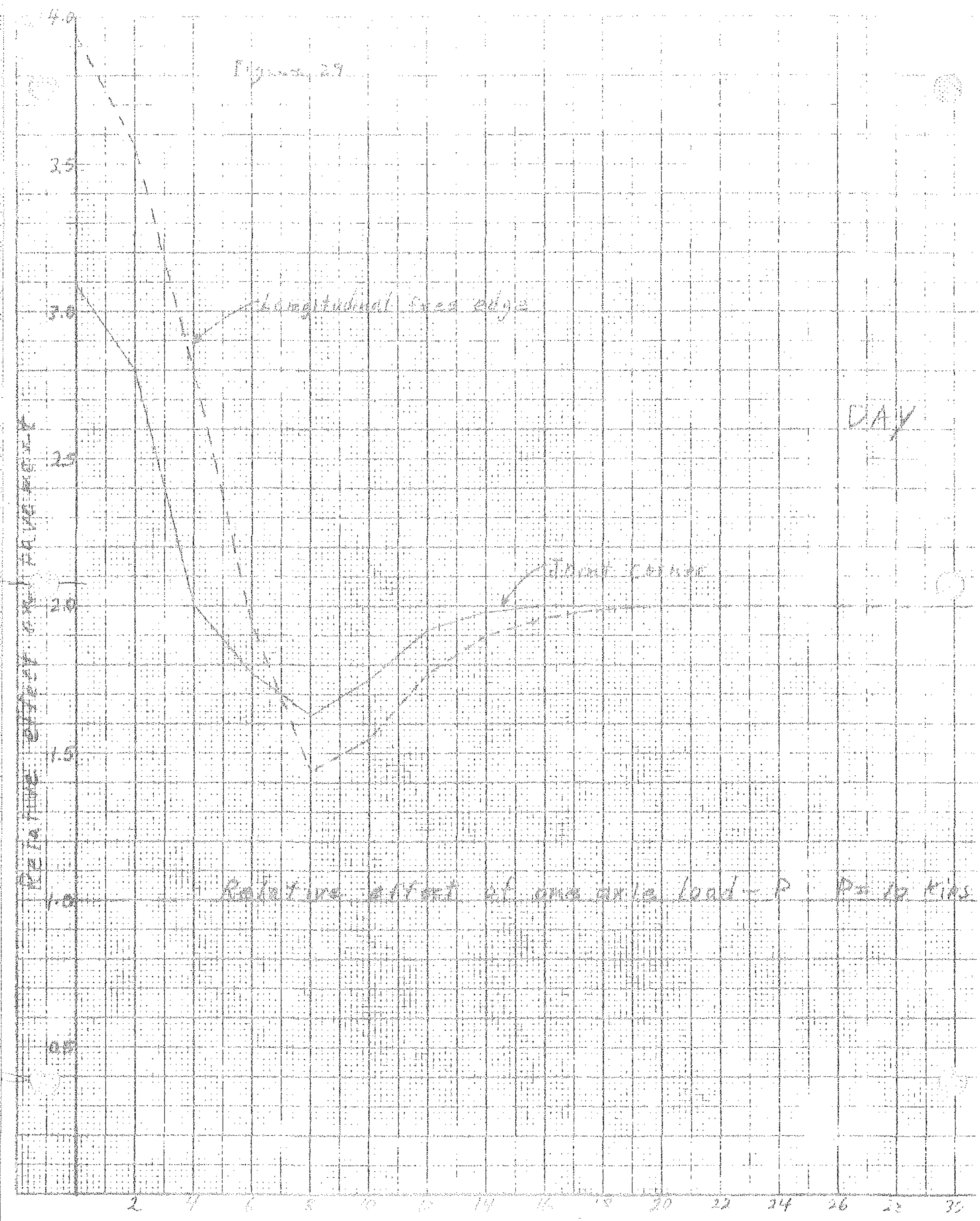


Figure 29
Longitudinal free edge
Joint corner
DAY
Relative effect of one axle load - P P = 10 kips
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

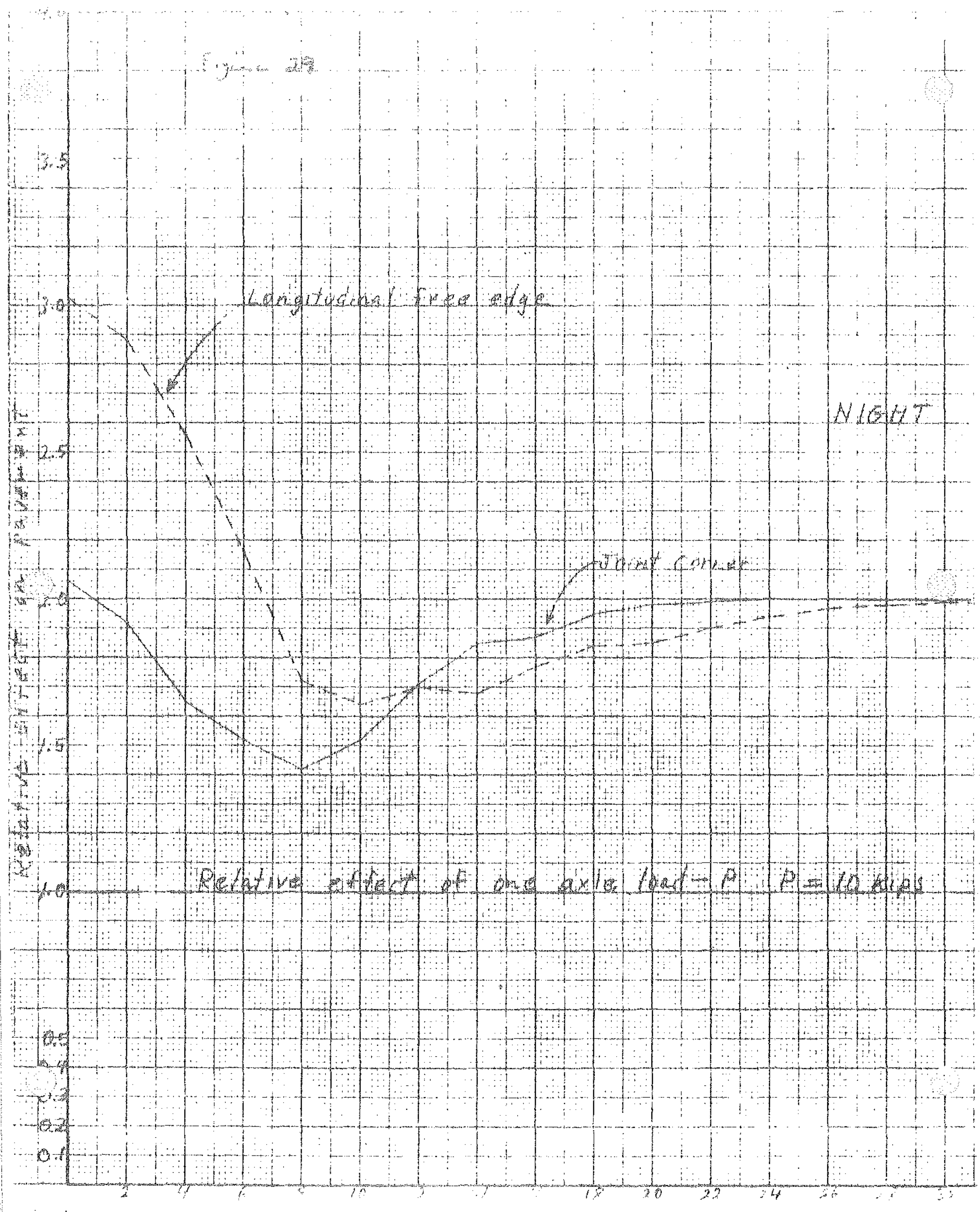


Figure 29
Longitudinal free edge
Joint Corner
NIGHT
Relative effect of one axle load – P P = 10 kips
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.4
0.3
0.2
0.1
2
4
6
8
10
18
20
22
24
26

Reduce with new data.

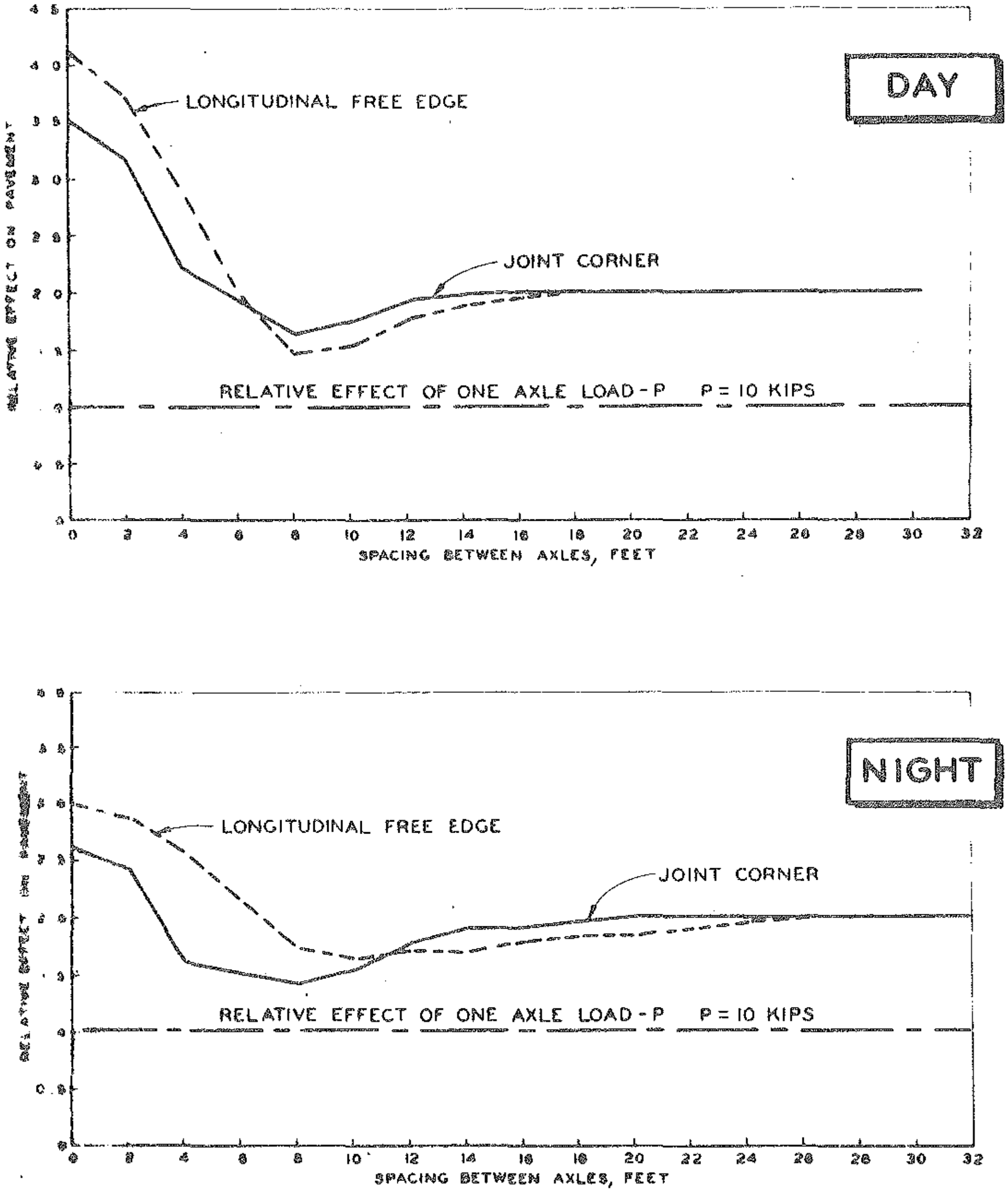
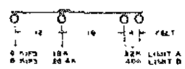
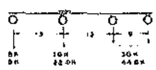
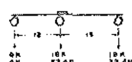
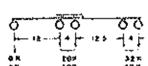
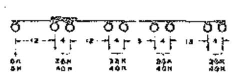


Figure 29. Relative effect of two axle loads "P" as their axle spacings vary: Test 2.

TABLE 10
EFFECT OF CHANGES IN LEGAL LIMITS
ON RELATIVE EFFECT RATIOS OF SIX TYPICAL COMMERCIAL VEHICLES
(Relative Effect Ratios based on Type 2 truck as 1.0 - Data from Test 2)

Truck Type	Truck Axle Load and Spacing	Relative Effect Ratio						Percent Increase	
		Load Limit A			Load Limit B			Relative Effect Ratio From Change of A to B	Total Vehicle Load
		Day	Night	Avg	Day	Night	Avg		
2S1		1.83	1.76	1.80	2.74	2.43	2.58	43	20
2S2*		2.46	2.46	2.46	3.64	3.28	3.46	41	21
2S2		2.37	2.40	2.38	3.51	3.38	3.44	45	21
3S2		2.56	2.35	2.46	4.33	3.80	4.06	65	33
2S1-2		3.06	3.05	3.06	4.58	4.33	4.46	46	22
3S2-4		4.12	3.62	3.87	8.12	6.82	7.47	93	42

* Long tandem

kips for single axle loads and 40 kips for tandem axle loads. Long tandems with 9 ft between axles are considered in either case as two single axle loads with regard to legal limit requirements. Considering that the vehicles are loaded to the legal limits, the change in requirements from Limits A to B increases the relative effect of the vehicles on the pavement from 41 to 93 percent with an average change of 56 percent. In comparing the increased relative effect with the percent increase in total vehicle load, it is noted that the relative effect on the pavement increases approximately twice as fast as the increase in total load. The average increase in total load was 26 percent.

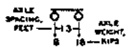
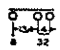
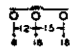
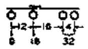
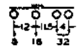
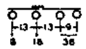
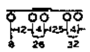
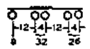
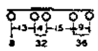
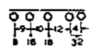
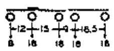
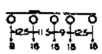
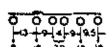
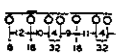
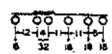
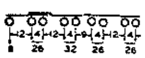
Predicting Test Road Performance

Another application of the theory which may be made is in indicating the relative effects that test vehicles will have on the durability of experimental roads such as the AASHO Road Test now under active study. The theory's only requirements are that vehicle axle loads and spacings be known. In Table 11 the relative effect ratios are shown for the AASHO test vehicles in comparison with a legally loaded Type 2 truck. The variation in relative effect ratios is from 0.02 for Vehicle 1 (a passenger car), to 5.94 for the heaviest truck, AASHO Vehicle 10, with a total load of 108 kips.

Interpretation of the performance of certain experimental test road sections with known loading may also be extended to normal constructed pavements of similar performance characteristics, when loadometer surveys give an indication of the quantity and the load characteristics of the vehicles normally using the pavement. Thus, prediction of the life of a new or existing pavement is feasible if reasonable estimates of the past, present, and future traffic loadings can be made.

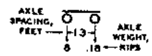
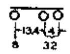
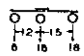
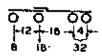
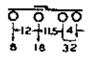
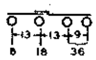
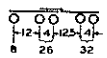
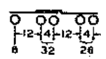
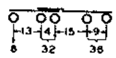
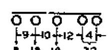
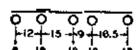
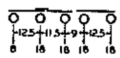
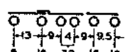
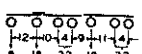
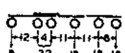
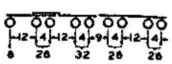
The theory may also have application in evaluating performance of normally constructed pavements throughout a state, by considering the performance of these pavements in the light of the variations in truck and passenger volumes and the character of loadings.

TABLE 9
SUMMARY OF RELATIVE EFFECT RATIOS OF VARIOUS COMMERCIAL VEHICLES

Truck Type	Truck Axle Load and Spacing	Test 1							Test 2							Alma Test						
		Day			Night*			Overall Avg	Day			Night			Overall Avg	Day**			Night			Overall Avg
		Corner	Free Edge	Avg	Corner	Free Edge	Avg		Corner	Free Edge	Avg	Corner	Free Edge	Avg		Corner	Free Edge	Avg	Corner	Free Edge	Avg	
2		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3		1.38	1.45	1.42	1.23	1.42	1.33	1.37	1.50	1.69	1.60	1.49	1.60	1.55	1.57	2.35	2.50	2.43	1.84	2.36	2.10	2.27
2S1		1.76	1.58	1.67	1.47	1.53	1.50	1.59	1.80	1.81	1.80	1.59	1.54	1.57	1.69	2.10	1.71	1.91	1.68	1.65	1.66	1.79
2S2		2.02	2.06	2.04	1.63	1.96	1.80	1.92	2.21	2.52	2.37	2.01	2.52	2.27	2.32	3.60	3.26	3.43	2.63	3.04	2.84	3.14
2S2		1.83	2.20	2.02	1.51	2.09	1.80	1.91	2.24	2.34	2.29	1.63	2.44	2.04	2.16	3.08	2.96	3.02	2.30	2.77	2.54	2.78
2S2***		2.10	1.52	1.81	1.68	1.48	1.58	1.70	2.38	2.14	2.26	1.73	2.02	1.88	2.07	2.94	2.29	2.62	2.21	2.17	2.19	2.41
3S2		2.16	1.83	2.00	1.72	1.76	1.74	1.87	2.22	2.62	2.42	1.63	2.18	1.91	2.16	3.56	3.39	3.48	2.60	3.16	2.88	3.18
3S2		2.16	1.86	2.01	1.72	1.78	1.75	1.88	2.59	2.58	2.59	1.79	2.21	2.00	2.29	3.44	3.44	3.44	2.53	3.21	2.87	3.16
3S2***		2.73	2.30	2.52	2.08	2.18	2.13	2.33	2.87	2.91	2.89	2.22	2.57	2.40	2.64	4.40	3.77	4.09	3.13	3.50	3.32	3.70
2-3		2.63	2.12	2.38	2.02	2.02	2.02	2.20	2.79	2.66	2.73	1.93	2.55	2.24	2.48	4.06	3.68	3.87	2.92	3.42	3.17	3.52
2S1-2		3.15	2.58	2.87	2.34	2.43	2.39	2.63	3.19	3.04	3.12	2.55	2.69	2.62	2.87	4.32	3.11	3.72	3.08	2.91	3.00	3.36
2S1-2		2.96	2.05	2.51	2.23	1.96	2.10	2.31	3.09	2.65	2.87	2.27	2.43	2.35	2.61	3.94	2.77	3.36	2.84	2.60	2.72	3.04
2S2-2		2.95	2.20	2.58	2.22	2.09	2.16	2.37	3.10	2.68	2.89	2.61	3.21	2.91	2.90	4.19	3.78	3.98	3.00	3.51	3.26	3.62
2S2-3		3.50	2.71	3.11	2.57	2.55	2.56	2.84	3.96	3.71	3.84	2.96	3.63	3.30	3.57	4.92	4.72	4.82	3.46	4.36	3.91	4.37
3S1-2		3.04	2.34	2.69	2.28	2.22	2.25	2.47	3.35	3.14	3.25	2.03	3.08	2.56	2.90	5.36	4.32	4.84	3.74	4.00	3.87	4.36
3S2-4		3.51	2.62	3.07	2.57	2.47	2.52	2.80	3.77	3.81	3.79	2.93	3.23	3.08	3.44	5.94	5.16	5.55	4.10	4.75	4.42	4.99

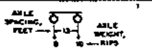
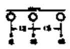
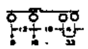
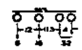
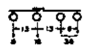
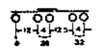
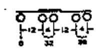
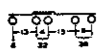
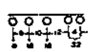
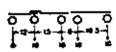
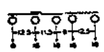
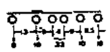
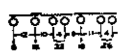
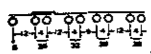
* Values shown for night relative effect ratios determined from day values and regression line relationship between day and night values from Test 2.
** Values shown for day relative effect ratios determined from night values and regression line relationship between day and night values from Test 2.
*** Long tandem.

TABLE 6
RELATIVE ENERGY RESULTING FROM PAVEMENT DEFLECTION
CAUSED BY VARIOUS COMMERCIAL VEHICLES - TEST 2

Truck Type	Truck Axle Load and Spacing	Truck Weight, kips	Energy							
			Day Tests			Night Tests			Ratio = Night / Day	
			Free Edge, in.-lb	Corner, in.-lb	Ratio = Free Edge / Corner	Free Edge, in.-lb	Corner, in.-lb	Ratio = Free Edge / Corner	Free Edge	Corner
2		26	32.8	18.4	1.78	126.2	180.3	0.70	3.9	9.8
3		40	55.4	27.5	2.01	201.8	268.0	0.75	3.6	9.7
2S1		44	59.2	33.1	1.79	194.6	286.6	0.68	3.3	8.7
2S2		58	82.5	40.7	2.03	317.8	362.6	0.88	3.9	8.9
2S2		58	76.8	41.2	1.86	308.2	294.2	1.05	4.0	7.1
2S2*		62	70.2	43.7	1.61	255.0	311.1	0.82	3.6	7.1
3S2		66	85.8	40.9	2.10	275.3	293.4	0.94	3.2	7.2
3S2		66	84.7	47.6	1.78	279.3	323.4	0.86	3.3	6.8
3S2*		76	95.4	52.8	1.81	324.6	399.3	0.81	3.4	7.6
2-3		76	87.2	51.3	1.70	321.9	347.8	0.93	3.7	6.8
2S1-2		80	99.5	58.7	1.70	339.2	459.4	0.74	3.4	7.8
2S1-2		80	86.8	56.8	1.53	307.1	409.0	0.75	3.5	7.2
2S2-2		94	87.8	57.1	1.54	405.0	470.5	0.86	4.6	8.2
2S2-3		102	121.7	72.8	1.67	458.9	534.0	0.86	3.8	7.3
3S1-2		90	102.8	61.7	1.67	388.2	365.3	1.06	3.8	5.9
3S2-4		118	124.9	69.2	1.81	408.2	527.5	0.77	3.3	7.6

* Long Tandem

TABLE 7
RELATIVE EFFECTS OF VARIOUS COMMERCIAL VEHICLES

Truck Type	Truck Axle Load and Spacing	Truck Weight, kips			Relative Effect - Test 1			Relative Effect - Test 2							Relative Effect - Alma Test		
					Day			Day			Night			Overall Average	Night		
		Gross	Empty	Pay Load	Corner	Free Edge	Avg	Corner	Free Edge	Avg	Corner	Free Edge	Avg		Corner	Free Edge	Avg
2		26	8	18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3		40	15	25	1.38	1.45	1.42	1.50	1.69	1.60	1.49	1.60	1.55	1.57	1.84	2.36	2.10
2S1		44	17	27	1.76	1.58	1.67	1.80	1.81	1.80	1.59	1.54	1.57	1.69	1.68	1.65	1.66
2S2		58	23	35	2.02	2.06	2.04	2.21	2.52	2.37	2.01	2.52	2.27	2.32	2.63	3.04	2.84
2S2		58	22	36	1.83	2.20	2.02	2.24	2.34	2.29	1.63	2.44	2.04	2.16	2.30	2.77	2.54
2S2*		62	24	38	2.10	1.52	1.81	2.38	2.14	2.26	1.73	2.02	1.88	2.07	2.21	2.17	2.19
3S2		66	33	33	2.16	1.83	2.00	2.22	2.62	2.42	1.63	2.18	1.91	2.16	2.60	3.16	2.88
3S2		66	33	33	2.16	1.86	2.01	2.59	2.58	2.59	1.79	2.21	2.00	2.29	2.53	3.21	2.87
3S2*		76	35	41	2.73	2.30	2.52	2.87	2.91	2.89	2.22	2.57	2.40	2.64	3.13	3.50	3.32
2-3		76	29	47	2.63	2.12	2.38	2.79	2.66	2.73	1.93	2.55	2.24	2.48	2.92	3.42	3.17
2S1-2		80	29	51	3.15	2.58	2.87	3.19	3.04	3.12	2.55	2.69	2.62	2.87	3.08	2.91	3.00
2S1-2		80	29	51	2.96	2.05	2.51	3.09	2.65	2.87	2.27	2.43	2.35	2.61	2.84	2.60	2.72
2S2-2		94	35	59	2.95	2.20	2.58	3.10	2.68	2.89	2.61	3.21	2.91	2.90	3.00	3.51	3.26
2S2-3		102	38	64	3.50	2.71	3.11	3.96	3.71	3.84	2.96	3.63	3.30	3.57	3.46	4.36	3.91
3S1-2		90	35	55	3.04	2.34	2.69	3.35	3.14	3.25	2.03	3.08	2.56	2.90	3.74	4.00	3.87
3S2-4		118	42	76	3.51	2.62	3.07	3.77	3.81	3.79	2.93	3.23	3.08	3.44	4.10	4.75	4.42

* Long tandem

TABLE 8
RELATIVE EFFECTS OF SPECIAL VEHICLES - TEST 2

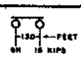
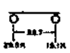
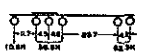
Truck Type	Truck Axle Load and Spacing	Total Load, kips	Relative Effect						
			Day			Night			Overall Avg
			Corner	Free Edge	Avg	Corner	Free Edge	Avg	
2		26.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vehicle 11 Scraper		44.6	3.55	2.50	3.02	2.89	2.65	2.77	2.90
Vehicle 10 Low-Boy Trailer		129.9	3.09	5.06	4.08	1.31	3.32	2.32	3.20

TABLE 2
MAXIMUM AND MINIMUM EQUIVALENT LOAD STRESSES DUE TO A 19.9-KIP SINGLE AXLE LOAD - TEST NO. 3
(Modulus of Elasticity assumed 5 x 10^6 psi)

Longitudinal Free Edge Position	Tensile Stress, psi		Compressive Stress, psi	
	Maximum (Night)	Minimum (Day)	Maximum (Night)	Minimum (Day)
8 ft from transverse joint	175	5	168	115
6 ft	250	55	210	110
5 ft	255	55	210	125
4 ft	205	45	185	75
2 ft	120	65	175	90
Midslab point	88	15	262	145

All pavement strains measured on top surface.

TABLE 3
RELATIVE PAVEMENT EFFECT BASED ON ACTUAL AND THEORETICAL DEFLECTION PATTERNS

	Test	Time	Test Position	Vehicle	Relative Pavement Effect in Inch-Pounds			
					Actual Deflection	Theoretical Deflection	Difference	Percent Difference
JOINT CORNER	1	Day	1	8	535	483	- 52	- 9.8
	1	Day	2	8	226	269	+ 43	+19.1
	1	Day	4	8	215	203	- 12	- 5.8
	1	Day	5	8	197	231	+ 34	+17.2
	1	Day	7	8	393	383	- 10	- 2.6
	1	Day	8	8	265	286	+ 21	+ 7.8
	2	Day	1	2	23	22	- 1	- 5.5
	2	Day	3	2	23	20	- 3	-12.1
	2	Day	4	2	19	16	- 3	-15.5
	2	Day	6	2	20	20	0	- 0.5
	2	Day	1	9	76	54	- 22	-29.2
	2	Day	3	9	55	66	+ 11	+20.8
	2	Day	4	9	44	51	+ 7	+14.7
	2	Day	6	9	59	55	- 4	- 6.4
	2	Night	1	2	262	321	+ 59	+22.4
	2	Night	3	2	232	302	+ 70	+30.2
	2	Night	4	2	177	244	+ 67	+37.6
	2	Night	6	2	163	174	+ 11	+ 6.9
	2	Night	1	9	597	754	+157	+26.2
	2	Night	3	9	710	554	-156	-21.9
	2	Night	4	9	543	479	- 64	-11.8
	2	Night	6	9	407	405	- 2	- 0.6
							Average Error	+ 3.7
LONGITUDINAL FREE EDGE	1	Day	3	8	175	228	+ 53	+30.6
	1	Day	6	8	566	598	+ 32	+ 5.7
	2	Day	2	2	32	36	+ 4	+13.8
	2	Day	5	2	31	32	+ 1	+ 3.8
	2	Day	2	9	102	104	+ 2	+ 1.9
	2	Day	5	9	94	86	- 8	- 8.4
	2	Night	2	2	130	128	- 2	- 1.2
	2	Night	5	2	162	186	+ 24	+14.6
	2	Night	2	9	450	326	-124	-27.6
	2	Night	5	9	311	352	+ 41	+13.2
							Average Error	+ 4.6

TABLE 4
COMPARISON OF THEORETICAL WITH ACTUAL RELATIVE EFFECT
MARYLAND TEST ROAD

Data Source	Maryland Test Truck			
	1	2	3	4
Maryland Test Road				
Load repetitions for first cracking	210,000	144,000	106,000	50,000
Load repetitions for first pumping	126,000	85,000	44,000	31,000
Actual Relative Effect				
First cracking	1.00	1.46	1.98	4.20
First pumping	1.00	1.49	2.86	4.07
ACTUAL AVERAGE	1.00	1.48	2.42	4.14
Computed Theoretical Relative Effect				
Alma Test				
Corner - night	1.00	1.57	1.98	3.92
Free edge - night	1.00	1.56	2.40	4.63
Average	1.00	1.56	2.19	4.28
Test 1				
Corner - day	1.00	1.38	1.42	2.50
Free Edge - day	1.00	1.26	1.53	2.48
Average	1.00	1.32	1.48	2.49
Test 2				
Corner - day	1.00	1.44	1.61	2.67
Free edge - day	1.00	1.48	1.79	3.15
Average	1.00	1.46	1.70	2.91
Corner - night	1.00	1.36	1.53	2.59
Free edge - night	1.00	1.34	1.67	2.83
Average	1.00	1.35	1.60	2.71
THEORETICAL AVERAGE: ALL DATA	1.00	1.42	1.74	3.11
Percent Difference Theoretical to Actual Relative Effect	----	-4	-28	-25

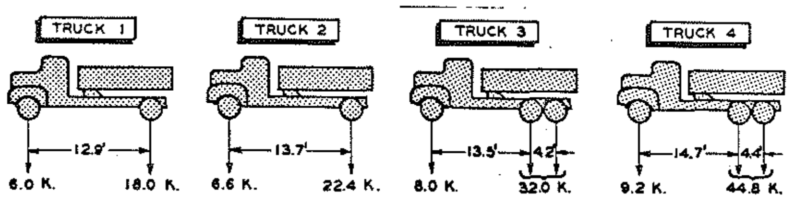
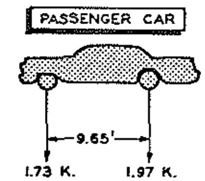
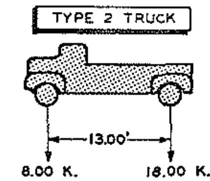


TABLE 5
COMPARISON OF RELATIVE EFFECTS
OF A PASSENGER CAR AND A TYPE 2 TRUCK





Pavement Position	Passenger Car		Type 2 Truck	
	Energy, in.-lb	Relative Effect	Energy, in.-lb	Relative Effect
Longitudinal Free Edge				
Day	0.5	0.015	33	1.00
Night	3.5	0.028	126	1.00
Average	---	0.022	--	1.00
Joint Corner				
Day	0.4	0.022	18	1.00
Night	11.7	0.065	180	1.00
Average	---	0.043	--	1.00
Overall Average	---	0.033	--	1.00