An Investigation of the Destructive Effect of Flotation Tires on Flexible Pavement

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As a result of the increased usage of flotation or "wide base" tires in lieu of the normal dual-wheel configuration during the last three years, an investigation has been completed to compare the relative destructive effect or to determine the single-axle loading which would produce the same destructive effect as that resulting from the dual-wheel single-axle legal loading of 18,000 lb. The two criteria of destructive effect selected for this investigation were pavement deflection and strain. Deflection measurements were made using linear variable differential transformer gage installations and the Benkelman beam. Pavement strain measurements were made using SR-4 strain gages attached to the top and bottom of the AC surfacing. Test sites with widely varying structural sections were selected for this study. Analysis of strain and deflection data indicates that the destructive effect of a flotation tire with a single-axle loading of 12,000 lb equals or exceeds that of the dual-wheel configuration at an axle loading of 18,000 lb. Relationships between tire pressure, pavement temperature, axle loading, pavement deflection, surface tensile strain, and type of wheel loading are presented.

•IN THE LAST two years, the use of flotation or "wide base" tires in lieu of the normal dual-wheel configuration has become increasingly commonplace, particularly on transit mix concrete trucks. The reasons advanced by the tire manufacturers for the increased popularity of these tires include lower rolling resistance, reduced dead weight, improved riding qualities, off-the-road mobility, and a high-load front axle capacity. With the increased usage of these tires, it was apparent that a comparison should be made of the destructive effect of trucks utilizing this type of tire with that induced by the normal single-axle dual-wheel configuration at its maximum legal load limit of 18,000 lb.

An investigation of a similar nature was included and reported on during the AASHO Road Test (1). In this investigation, various test sections of Loop 2 were subjected to 32,000 lb tandem-axle loads with conventional·and low-pressure low-silhouette (LPLS) tires. The results of this study indicated that loss of pavement serviceability was slightly less over those sections on which the LPLS tires were utilized. However, it is believed that these results are not significant to this investigation because the tires involved were of a military type. An examination of the contact prints shown in the report of the test (1, Fig. 9) reveals an entirely different dual and flotation tire configuration than that resulting from standard commercial truck tires of both types. In fact, the overall width of the two military duals is equal to or less than that of the military LPLS tire. The reverse holds true in the case of the commercial flotation and dual truck tires used in this investigation.

CRITERIA OF DESTRUCTIVE EFFECT

To compare the destructive effects of two types of truck tire configuration, criteria on which rational judgments may be based must first be selected. Certainly destructive effect of wheel loads on flexible pavements may be evaluated in many different ways. In this particular case, however, the difference between the wheel configurations is relatively minor so that a valid appraisal requires sensitive criteria. In addition, these criteria must be related to flexible pavement performance. It is believed these requirements are effectively fulfilled by measurements of AC surfacing tensile strain and transient pavement deflection.

The choice of AC surfacing tensile strain was based on the preliminary findings of Pell (2) and others, who observed that the fatigue life of an AC surfacing is primarily a function of tensile strain and independent of surfacing temperature or speed of loading. Application of the layer theory and of the limited data available indicates that tensile strain at the bottom of the AC surfacing is substantially greater than that which occurs on the surface.

Unfortunately, the time available for this investigation did not permit the installation of strain gages at the bottom of the AC surfacing, except for the one project installation at the Shell Avenue test road. It is reasonable to assume, however, that surface tensile strain measurements, if not as large in an absolute sense as the bottom strain measurements, are at least directly proportional so that for the purpose of comparison they may be considered valid criteria.

The selection of pavement deflection was made with considerable confidence in view of the amounts of very productive pavement deflection research of the last twenty years. In addition to the extensive deflection work done on the two major test roads (AASHO and WASHO), the California Division of Highways and other agencies have, with some success, related allowable levels of transient pavement deflection to fatigue cracking of AC surfacing. The California Division of Highways has, in fact, for some years utilized deflection measurements in the design of reconstruction of distressed roadways. There can be little doubt that transient pavement deflection provides an excellent indicator of the in-place strength of an existing roadway and a reasonably accurate forecast of future fatigue cracking.

Considerations of plastic deformation or lateral displacement have not been taken into consideration because for a given axle load the pressures induced by both wheel configurations at depths greater than 6 in. are, for all practical purposes, the same.

TEST EQUIPMENT AND INSTRUMENTATION

This study, undertaken in April 1963 was accomplished using pavement deflection and strain measurements taken over several different structural sections in Northern California. Two trucks, both with single rear axles, were used as test vehicles. In one case, the axle was loaded to California's legal limit of 18,000 lb and supported with dual wheels using 10.00-20 truck tires with the 12-ply casings inflated to a pressure of 70 psi. The rear axle of the other truck carried a variable load and was supported by 18.00-19.5 flotation tires with 16-ply wide-base casings inflated to 75 psi (Fig. 1).

Pavement deflection measurements were obtained with a Benkelman beam and, at three locations, with linear variable differential transformer (LVDT) gages. Strain measurements were taken at varying distances from the outside edge of the loaded tires utilizing surface set SR-4 strain gages attached to the pavement surface (Figs. 2 and 3). At the Shell Avenue test road in Martinez, instrumentation installed previously in support of the test road project sponsored jointly by the University of California and Contra Costa County made it possible to obtain pavement strain measurements at the bottom of the AC surfacing layer.

After grinding the surface to remove large irregularities, two transversely oriented SR-4 strain gages were placed at each test location. These gages, placed at 6-in. intervals, were cemented into place with Duco cement and then covered with Gagekoat No. 5 for physical protection. During the early trials, it was noted that actual contact between the strain gage and the tire resulted in extremely erratic and obviously incorrect readings. Because unprotected gages were prone to damage by tire contact, this protective coating was necessary.

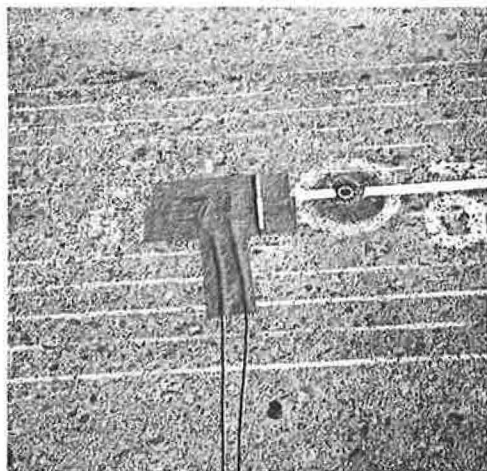Figure 1. Truck with single-axle flotation tire configuration.

Figure 2. SR-4 pavement strain and LVDT deflection gage installations at Shell Ave. test road at Martinez.
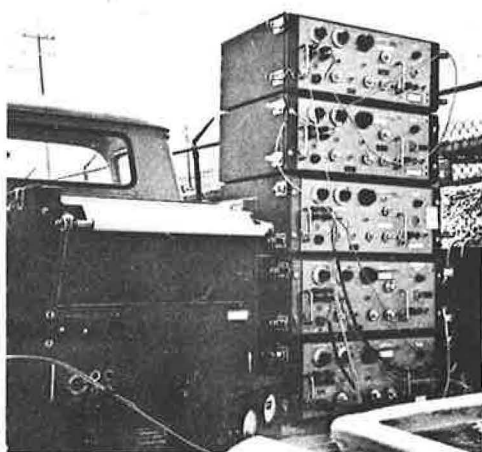
Figure 3. Strain recording equipment operated by personnel of University of California at Shell Ave. test road.

TEST SECTIONS

It was apparent from the beginning of the investigation that a study involving the variables of load, tire configuration, structural section, pavement deflection, and pavement strain could, unless limited in scope, become extremely unwieldy, time consuming, and expensive. The relatively few test sections were chosen, therefore, to represent the most common types of AC surfaced structural sections, and in addition, to present a large range of pavement deflection for increased sensitivity. The sites selected for this study are given in Table 1.

TABLE 1

TABULATION OF PEAK VALUES OF TRANSVERSE SURFACE TENSILE STRAIN

Location	Structural Section	Pav. Temp (° F)	Flotation Tire Axle Loading (lb)	Max Surface Tensile Strain (Flotation) (μ in./in.)	Max Surface Tensile Strain (Dual Wheel) (μ in./in.)
III-Sac-232-A	3¾-in. AC	110 - 118	11,000	28[a]	36[a]
Sta. 304+04	8-in. CTB(C1"A")	94 - 98	12,000	48[a]	42[a]
	Exist. Pav.				
III-Sac-232-A	3¾-in. AC	93 - 94	11,000	112	108
Sta. 405+90	3-in. AC (Base)	92 - 99	11,000	170	185
	6-in. AB	85 - 90	12,000	170	170
	Exist. Pav.	87 - 92	12,000	175	163
III-Sac-232-A	3¾-in. AC	75 - 77	10,000	90	125
Sta. 354+00	12-in. AB	130 - 132	12,000	62	49
	Exist. Pav.	68 - 71	12,000	105	116
Service & Supply	3-in. AC	105 - 115	10,000	314	352
Yard (60th St.	9-in. AB	85 - 95	11,000	257	277
& Folsom Blvd.)		118 - 128	12,000	352	310
City of Woodland	3-in. AC	100 - 110	10,000	385	468
(Pendergast St.)	6-in. AB	70 - 75	11,000	473	588
		61 - 64	12,000	427	463
Shell Ave.	3-in. AC (new)				
test road	2-in. AC (old)				
	Var. AB	70 - 71	12,000	795[b]	800[b]
State Fair Grounds	2-in. AC				
(Women's Bldg.)	4-in. AB				
Gage 1		40 - 42	10,000	145	190
		42	12,000	167	205
		46	15,000	253	228
		43 - 46	18,000	283	188
Gage 2		40 - 42	10,000	80	122
		42	12,000	100	125
		46	15,000	148	140
		43 - 46	18,000	160	119
Gage 3		40 - 42	10,000	110	150
		42	12,000	124	162
		46	15,000	190	177
		43 - 46	18,000	215	155
Gage 4		40 - 42	10,000	110	158
		42	12,000	135	167
		46	15,000	205	198
			18,000	232	155

[a] Point of stress reversal not determined.
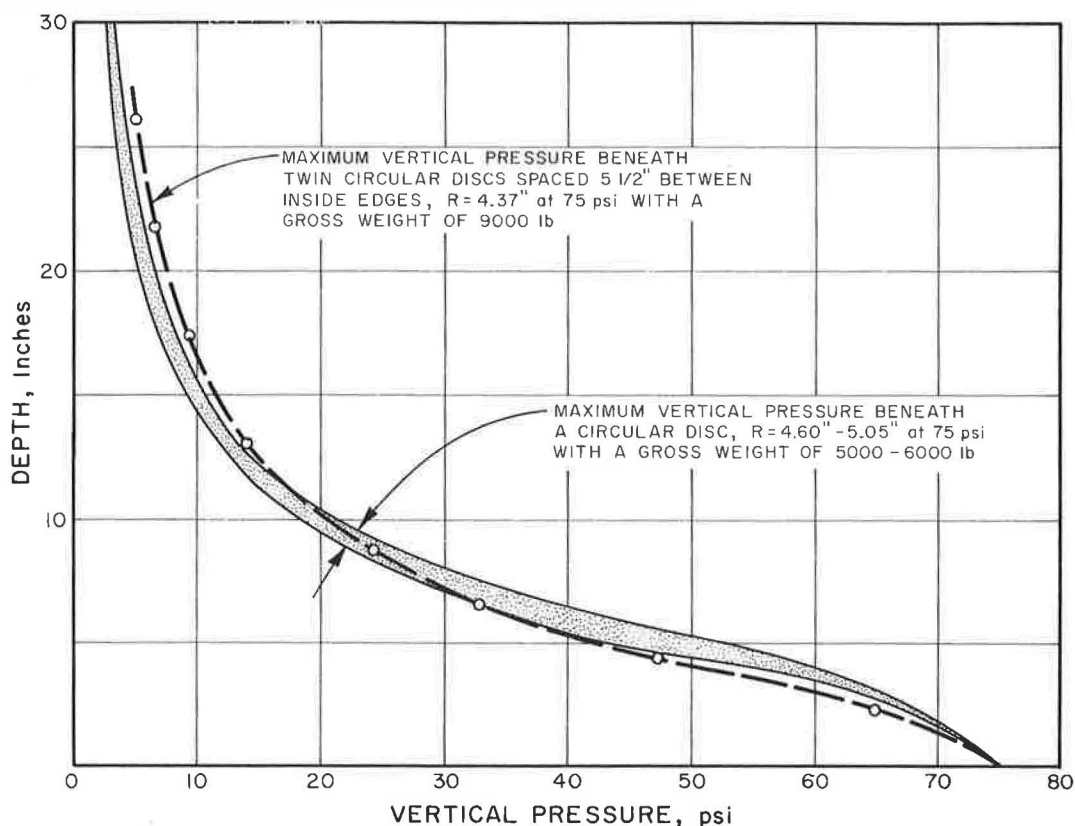[b] Transverse tensile strain at bottom of AC layer.

Figure 4. Vertical pressure vs depth (Boussinesq equation).

The initial range of flotation tire loading was determined by utilizing the theoretical Boussinesq equation. With this analysis, a comparison of vertical pressure induced by twin circular discs at 75 psi carrying a gross weight of 9,000 lb was compared to that induced by a single circular disc at 75 psi loaded from 5,000 to 6,000 lb. The results of this analysis (Fig. 4) correspond to calculations made earlier by personnel of the Washington State Highway Department. Examination of Figure 4 shows that at depths of from 0 to 6 in., the vertical pressure induced by the single circular disc would exceed that of the twin circular discs. Beyond approximately 11-in., the vertical pressure induced by the twin discs exceeds that of the single circular disc. Although the Boussinesq equation is purely a mathematical development of the elastic theory for an isotropic, elastic, homogenous, and infinite mass, it has been shown to be reasonably accurate for flexible sections as demonstrated by Herner (3) and Sowers (4) and the results by the Stockton test track (5). It was decided, based on this analysis, that a single flotation tire loading range of 5,000 to 6,000 lb would provide a good starting point for the comparison of the two types of tire and wheel configuration.

It was also decided to confine both deflection and pavement strain measurements to the axis normal to the direction of travel at each test point. This selection is based on long experience in California in which it has often been observed that the initial manifestation of alligator cracking is, in almost every case, longitudinal cracking in or close to the wheelpath. The fact that transverse bending is generally more pronounced is obvious from examination of deflection contour maps resulting from the WASHO (6) and AASHO (7) test roads. The test program for each test section, therefore, consisted of applying SR-4 strain gages oriented transversely and, on completion of instrumentation, measuring pavement surface strain at varying distances from the edge of the

loaded wheel. At each location, strain gage measurements were determined for a dual-wheel loading of 9,000 lb and single flotation tire loaded at 5,000, 5,500, and 6,000 lb. Where these installations were available, LVDT deflection measurements were also obtained for the aforementioned wheel loadings. At those locations where LVDT gages were not available, however, Benkelman beam deflection measurements were obtained.

During the final phase of the investigation, a series of surface strain and LVDT deflection measurements were obtained at a roadway immediately in front of the Women's Building of the California State Fair Grounds. This site offered advantages not available elsewhere, including (a) complete freedom from traffic interference, (b) a high range of pavement deflection, (c) availability of electric power for instrumentation, and (d) close proximity to the Headquarters Laboratory. Because of these advantages, a more comprehensive instrumentation was accomplished and the scope of the investigation increased to study the effects of two more variables: (a) a wider range of flotation tire single-axle loadings, and (b) the effect on pavement deflection and surface tensile strain of lowered flotation tire pressures.

ANALYSIS OF DATA

During the first few trials it was observed that even relatively minor variations in pavement surface temperature resulted in very significant differences in the strain measurement induced by a given wheel load. Because the principal objective of this program was a comparison of destructive effect induced by two different vehicles with differing wheel configurations and loadings, it became apparent that the variable of pavement surface temperature had to be eliminated or minimized. This was accomplished by continuously alternating the two different trucks during every test series. Thus, for each balloon tire strain measurement, a corresponding dual-wheel measurement was obtained to provide the basis of the comparison (Fig. 5).

The effect of variations in temperature on surface tensile strain is shown by Figure 6, which is a plot of surface strain vs distance to edge of loaded tire for three different pavement temperatures at one test location. Examination of these plots reveals that maximum tensile strain for the dual-wheel configuration varied from 460 to 585 μ in./in. These plots also show the very definite reversal of a surface stress from tension to compression, which generally occurs at from 2 to 5 in. from the edge of the loaded wheel.
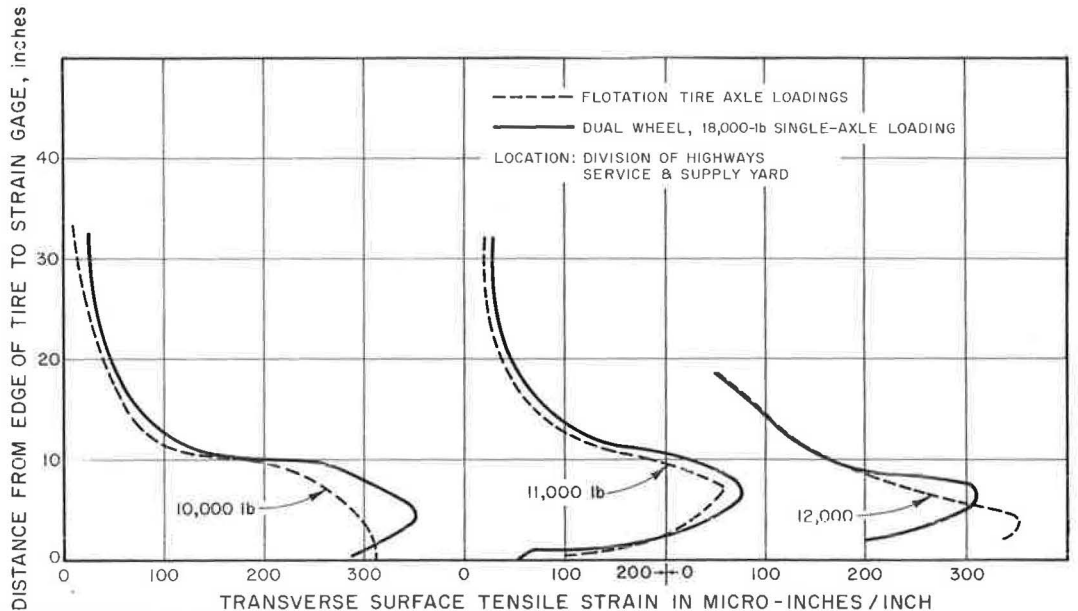

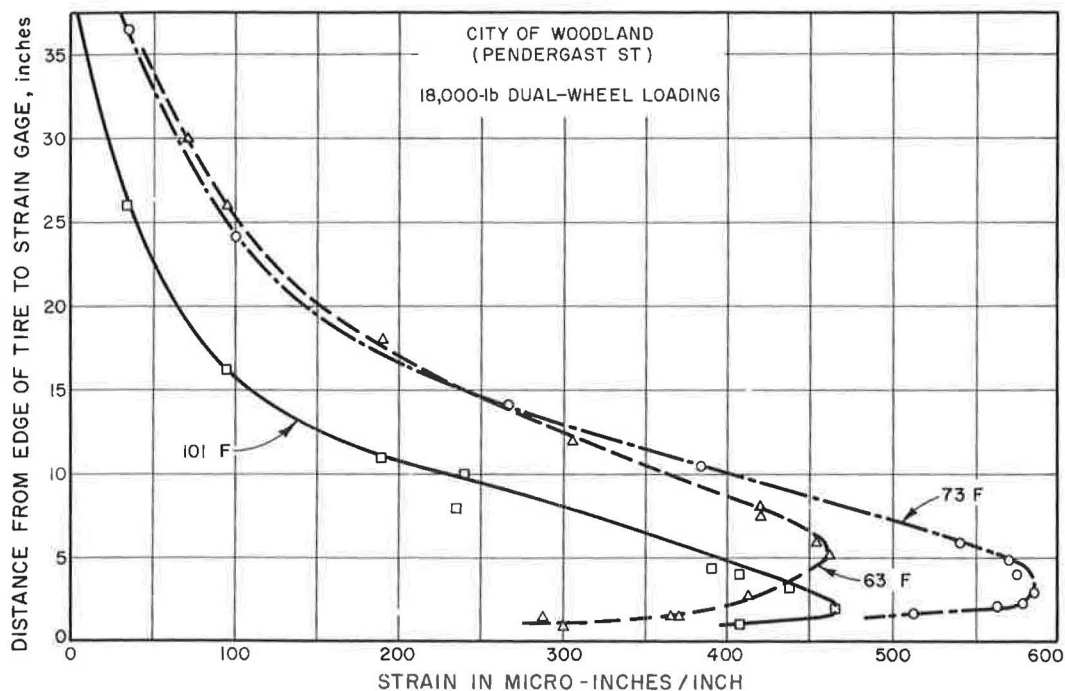Figure 5. Pavement surface tensile strain.

Figure 6. Variation in transverse surface strain induced by change of pavement temperature.

Another interesting aspect of Figure 6 is that maximum tensile strain occurred, for this gage installation, at the middle pavement temperature (73 F) with the strains at 63 and 101 F being about equal. This may indicate the existence of an optimum value of pavement temperature for a given AC surfacing insofar as surface strain is concerned. It is possible that increased cohesion at low temperatures and strain attenuation over a relatively large area due to plastic flow at high temperatures results in low strains at temperature extremes.

Over the cement-treated base section on III-Sac-232-A, the data did not reveal any peaking out of tensile strain. It is possible that inability to attain the critical distance to the edge of the tire due to the strain gage insulation precluded the determination of this peak value. This section, however, produced extremely low strain values, so there is some doubt as to the relative importance of this section to the study.

The relationship between strains induced by both wheel configurations for all sections revealed a very noticeable lack of consistency insofar as type of structural section is concerned. This is shown by the relatively weak structural section of Pendergast Street in the City of Woodland. Here, it was found that the equivalent flotation tire axle loading, insofar as destructive effect was concerned, was 12,300 lb as compared to the 11,000 lb equivalency for the cement-treated base overlay section at El Centro Road. Further examination of the data revealed that relative surface tensile strain can be related more directly to pavement temperature than to structural section. This is shown by Figure 7, a plot of the ratio of surface tensile strain induced by 11,000- and 12,000-lb flotation tire axle loadings and an 18,000-lb dual-wheel single-axle loading vs pavement temperature. A relatively good correlation exists for the ratio involving a flotation tire axle loading of 12,000 lb and pavement temperature. The beginning of a trend is also apparent for the 11,000-lb flotation tire axle loading. These data would indicate that, regardless of the structural section, the surface tensile strain induced by the flotation tire with a 12,000-lb single-axle loading is equivalent to a dual-wheel axle loading of 18,000 lb at a pavement temperature of approximately 80 F. At lower tempera-
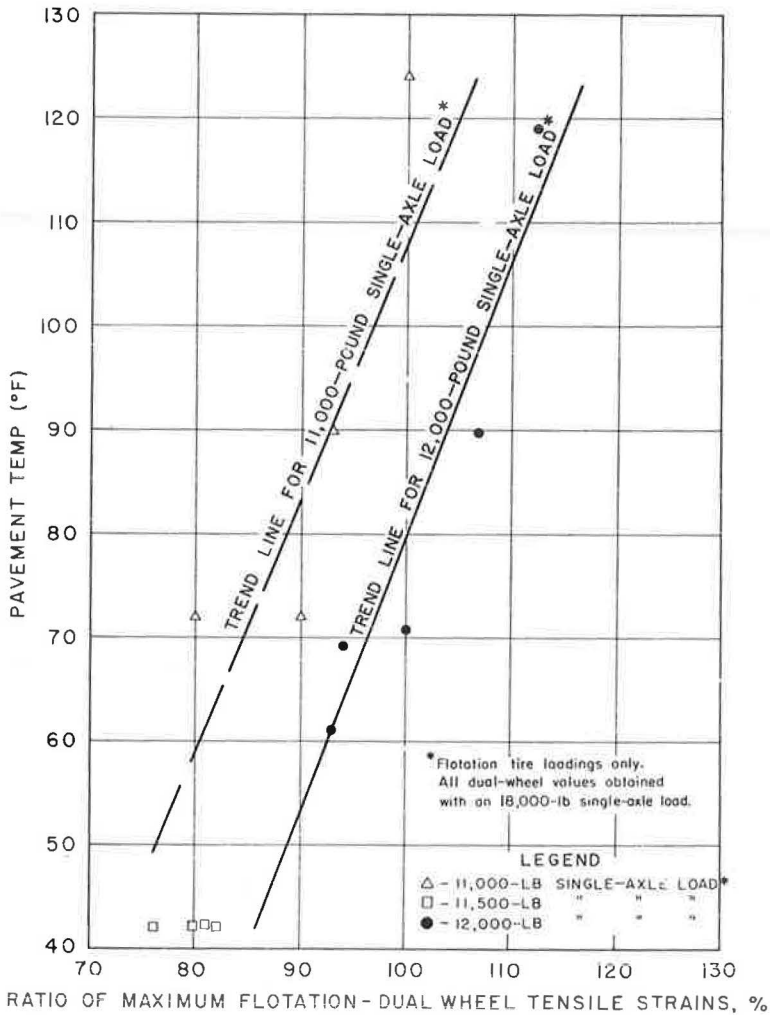
Figure 7. Flotation-dual tire surface tensile strain ratios vs pavement temperature.

tures the strain induced by the flotation tire is less and at higher temperatures the strain is greater. This general trend is also apparent for the flotation tire at an 11,000-lb axle loading, which is equivalent in surface strain to the dual-wheel loading at approximately 105 F.

Table 1 presents peak values of surface tensile strains for varying flotation tire axle loadings and the dual-wheel loading at 18,000 lb for varying structural sections and temperatures. These data show that the heavier structural sections tested on Road III-Sac-232-A produce substantially lower surface tensile strains than were obtained on the relatively weak sections at the Shell Avenue test road, City of Woodland, and the State of California Service and Supply Yard. It is also interesting to note that the maximum surface tensile strains induced by the dual wheels did not occur at the maximum test temperature at any of the test sections except the asphalt-treated base section on Road III-Sac-232-A. A comparison at this location was somewhat difficult, however, because of the limited range of pavement temperature.

At the Shell Avenue test section, it was possible to determine both transverse and longitudinal strain measurements from the bottom of the surfacing. These results are shown by Figures 8 and 9. Because the strain gage involved was fully protected from direct approach of the loaded tire, the full range of tensile and compressive strain
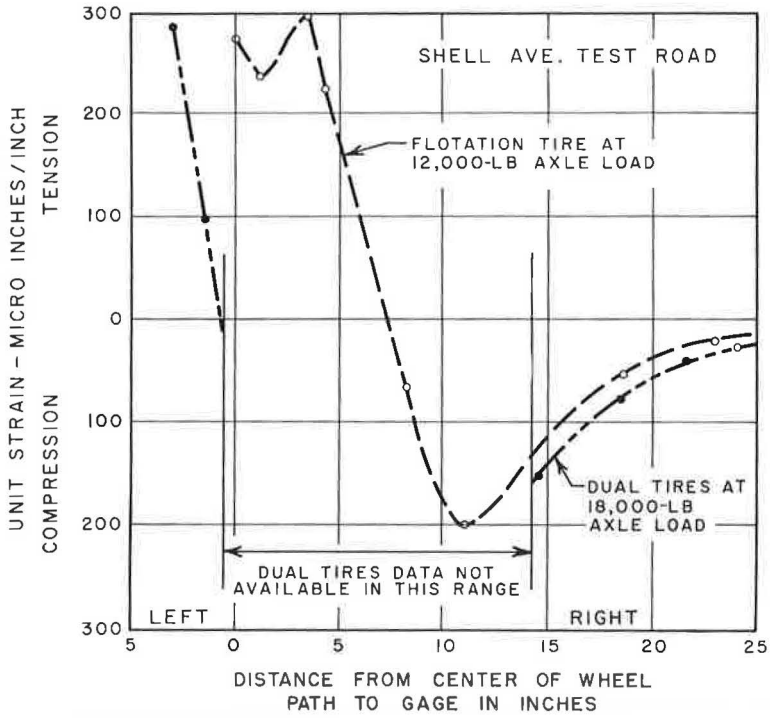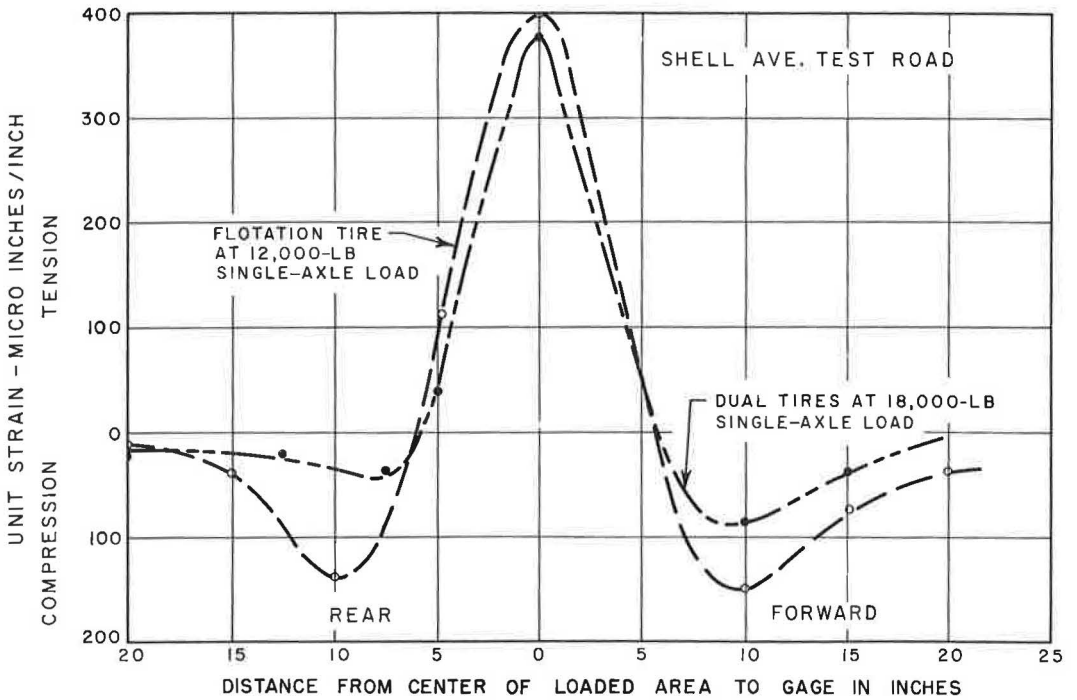
Figure 8. Bottom transverse strain.

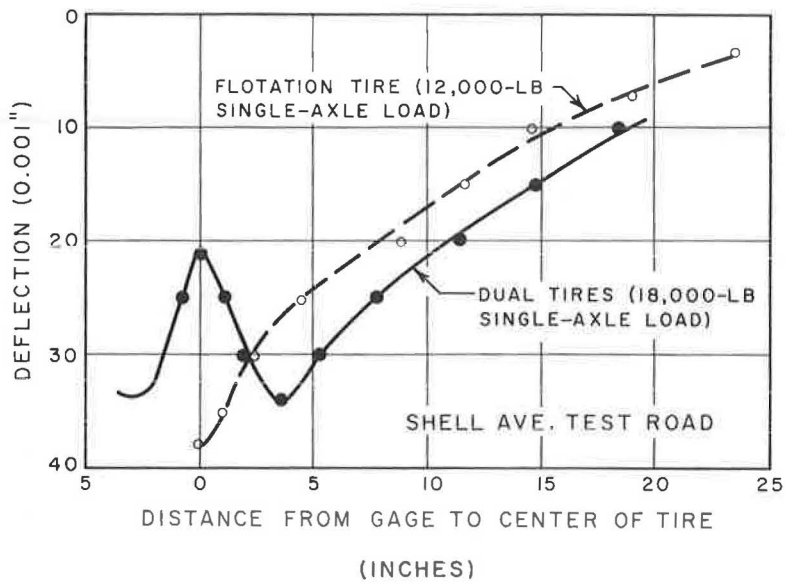Figure 9. Bottom longitudinal strain.

Figure 10. Transverse deflection profile LVDT gage unit.
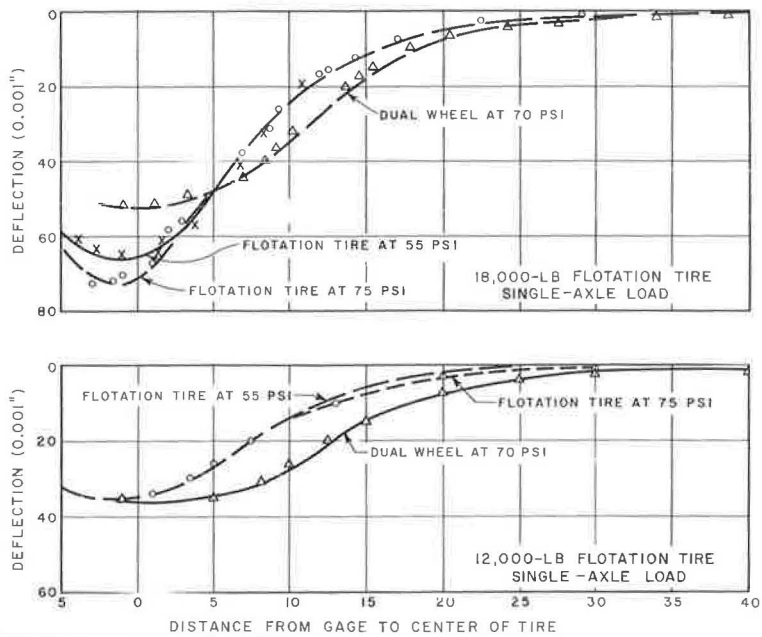

Figure 11. Effect of lowering flotation tire pressure on transverse deflection profile
LVDT gage unit.

measurements could be determined for the dual-wheel configuration with an axle load of 18,000 lb and a flotation tire single-axle configuration loaded to 12,000 lb. It was found that longitudinal strain is higher at the bottom of this pavement than is the transverse strain. Figure 8 reveals that the bottom transverse strain of the flotation tire with an axle loading of 12,000 lb is almost equal to that induced by the dual tires. The bottom longitudinal strain induced by the flotation tire (Fig. 9), however, was well in excess of that for the dual tires.

At three locations it was possible to compare pavement deflection values for both balloon and dual wheels with LVDT gage installations. The data from two of these in-
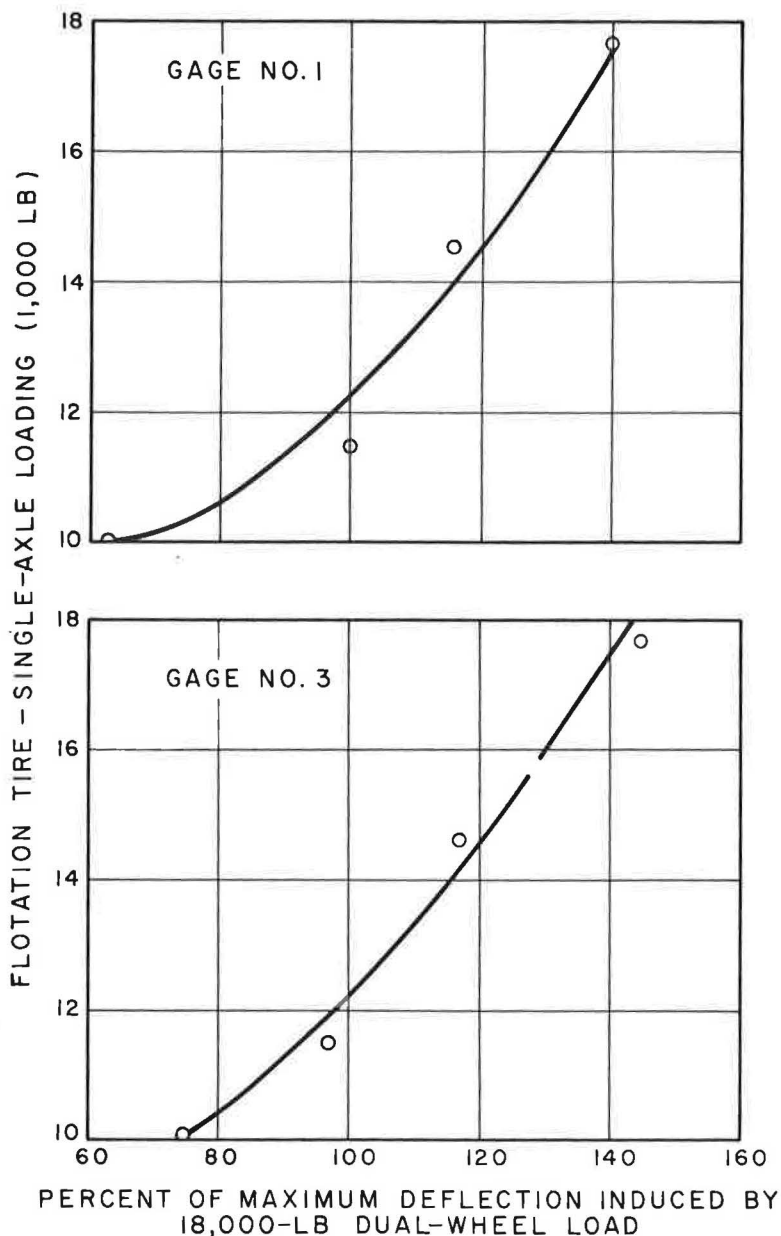

Figure 12. Flotation-dual tire deflection ratios vs flotation single-axle loading.
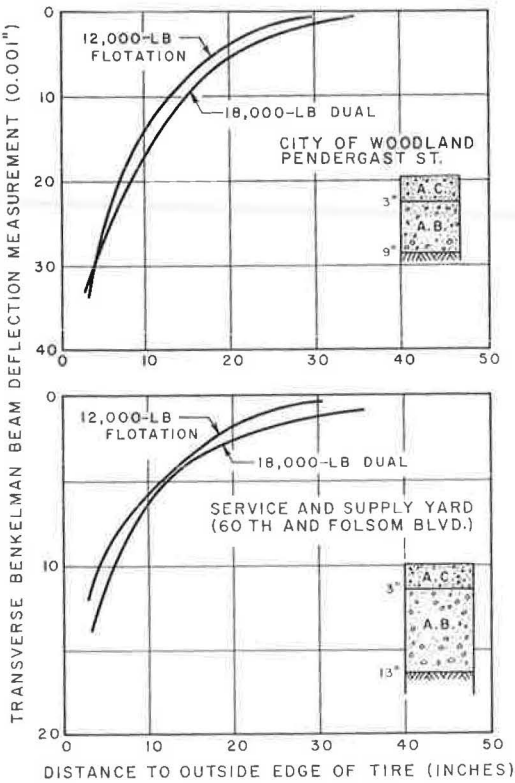
140

Figure 13. Transverse deflection profile.

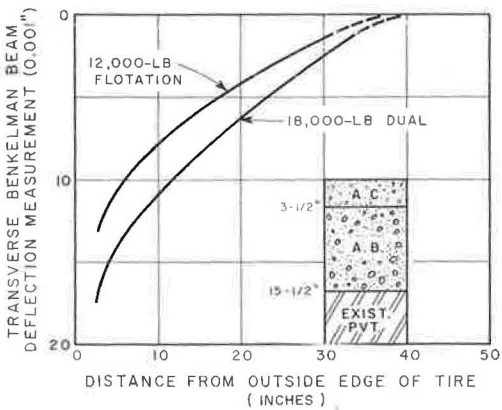
Figure 14. Transverse deflection profile, Road III-Sac-232-A, Sta.354+00.

stallations are shown in Figures 10 and 11. In Figure 10, the transverse deflection profile obtained at Shell Avenue reveals a higher maximum deflection value for the flotation tire axle loaded to 12,000 lb (0.038 in.) than the dual-wheel axle configuration at 18,000 lb (0.034 in.).

At all three locations, however, the maximum value of pavement deflection for the flotation tire with an axle loading of 12,000 lb exceeded that of the dual-wheel axle configuration loaded to 18,000 lb. The flotation tire axle loading at 11,000 lb was less, however, than that of the dual-wheel axle configuration at 18,000 lb.

A plot of flotation-dual tire deflection ratios for varying flotation tire loads is presented in Figure 12 for two gage locations at the State Fair Grounds. These data are considered significant because of the very minor temperature differential during the test period. At both gage locations, an equivalence in pavement deflections is attained at a flotation tire single-axle loading of 12,200 lb, which is in accordance with the earlier data.

Although it was impossible to compare maximum pavement deflections at those installations where LVDT gage installations were not available, the Benkelman beam data did provide an opportunity to compare the shapes of the transverse deflection profiles from the outside tire edge for each wheel configuration. These plots are shown in Figures 13 through 15. They indicate, in every case, a smaller area of influence and, hence, sharper bending of the pavement by the flotation tire.

As previously mentioned, a final portion of the program at the State Fair Grounds was devoted to a determination of the effect of lowered flotation tire pressures on transverse tensile strain and deflection. In addition to the strain and deflection measurements obtained at flotation tire single-axle loadings of 10,000, 12,000, 15,000, and 18,000 lb, additional data were obtained at the 12,000- and 18,000-lb flotation tire single-axle loadings for a flotation tire pressure of 55 psi. This tire pressure was selected as the minimum at which the flotation

tires could be operated without incurring tire damage. Deflection and strain data resulting from the lowered flotation tire pressures are presented by Figures 11, 16, and 17. Figure 11 indicates that pavement deflection at the flotation tire single-axle loading of 12,000 lb was not significantly reduced by lowering the tire pressure. At the
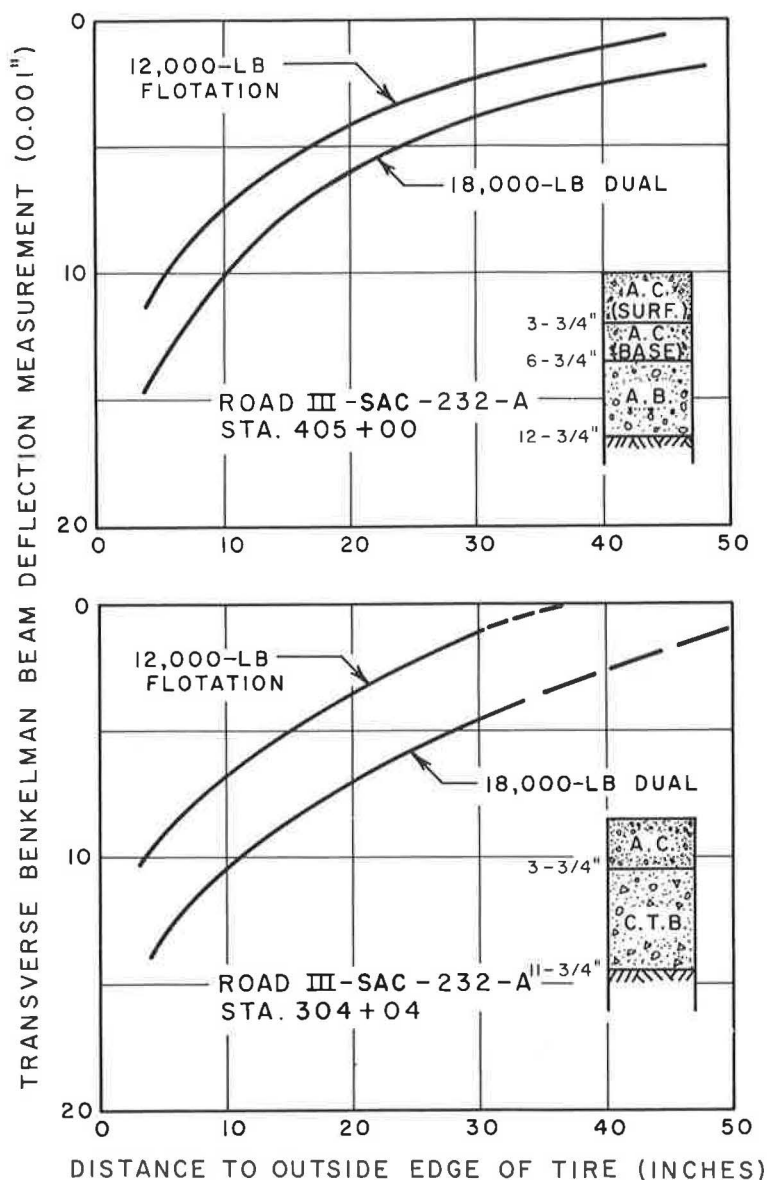
Figure 15. Transverse deflection profile.

18,000-lb flotation tire single-axle loading, however, the lowered flotation tire pressure induces a 10 percent reduction in pavement deflection. Figures 16 and 17 indicate that lateral surface tensile strain was actually increased by 13 percent at both the 12,000- and 18,000-lb flotation tire single-axle loadings, with a reduction in flotation tire pressure. This phenom-enon is apparently the result of an increased pressure concentration at the side walls due to the reduction of pressure. This conclusion tends to be borne out by the work of Freitag and Green, who show vertical stress contours under an 11.00-20, 12-ply smooth tire loaded to 3,000 lb for three inflation pressures (8, Fig. 4). Here, side wall vertical stress remains relatively high for all three inflation pressures, with interior vertical stresses increasing in approximate proportion to increased inflation pressure. It is interesting to note that maximum edge or side wall stress was attained at the median inflation pressure rather
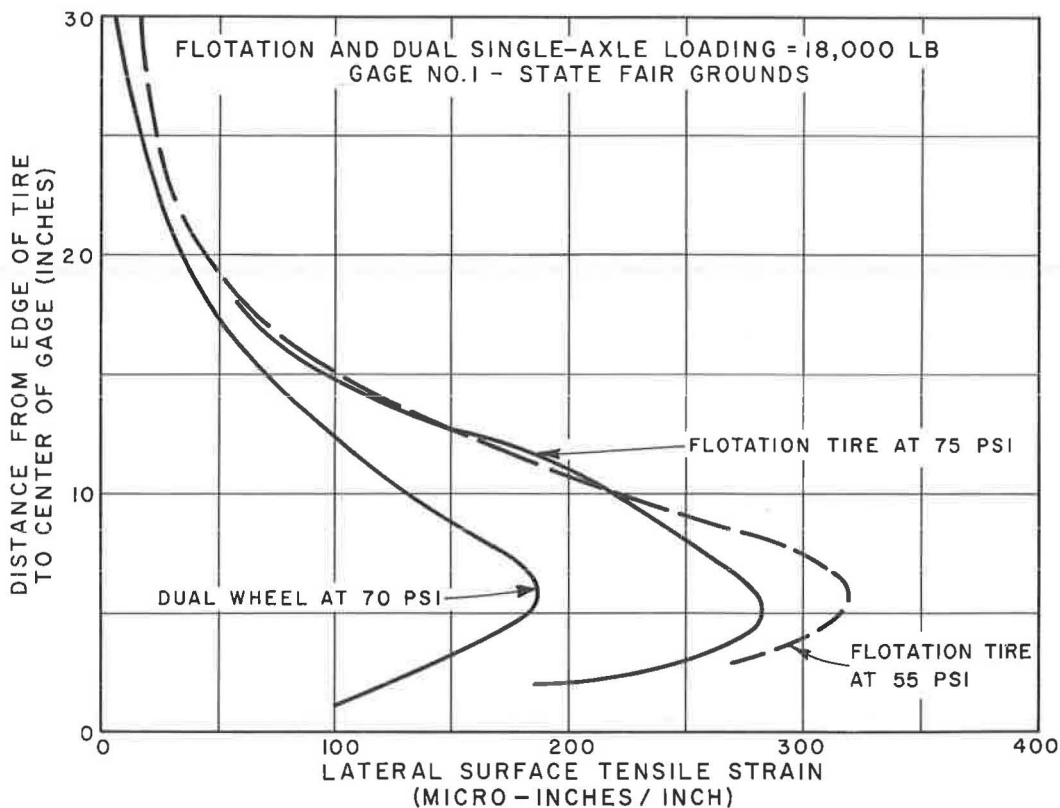
Figure 16. Effect of lowering flotation tire pressure on lateral surface tensile strain.
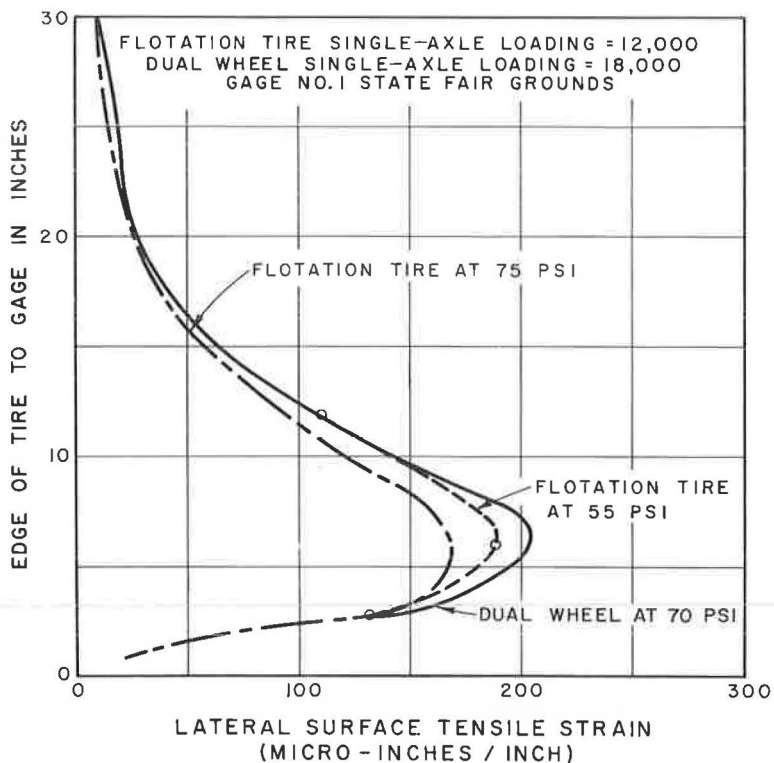

Figure 17. Effect of lowering flotation tire pressure on lateral surface tensile strain.

than at the highest or design inflation pressure. The data presented in the paper also indicate that vertical stress is very much a function of the construction or ply of the tire; i.e., the lower the ply, the more closely the contact pressure approximates air pressure. Therefore, a tangible reduction in surface tensile strain through lowered air pressure could be accomplished only by a tire specifically designed for the lower pressure and as low a ply rating as possible, consistent with the operational demands of the truck.

SUMMARY

From April until November 1963, an investigation for the purpose of comparing the destructive effect of wide-base flotation tires and the standard dual-wheel configuration on pavement was completed by the Pavement Section of the Materials and Research Laboratory. Transient pavement deflection and surface tensile strain were selected as the two criteria for evaluating destructive effect. Pavement deflection and strain measurements were obtained over eight roadways, representing a relatively wide range of flexible and composite structural section. Sufficient data were accumulated to evaluate the effect of pavement temperature, single-axle load, and tire inflation pressure on pavement deflection and surface tensile strain. With the cooperation of the University of California, it was possible to obtain bottom longitudinal and transverse strain measurements at the Shell Avenue test road.

Analysis of the data resulting from this investigation indicates that:

1. Using maximum pavement deflection as a criterion, the destructive effect of a flotation tire with a single-axle loading of 12,000 lb equals or exceeds that of a dual-wheel configuration at an axle loading of 18,000 lb.

2. The relationship between the maximum transverse tensile surface strains induced by flotation tires at various axle loadings and the dual wheel at an 18,000-lb single-axle loading relates directly to pavement temperature.

3. At a pavement temperature of 80 F, a 12,000-lb flotation tire axle loading is equivalent to the dual-wheel axle configuration at 18,000 lb. Balloon tire strains are less at lower temperatures and are greater at higher temperatures than those induced by the dual-wheel configuration.

4. At 105 F, the flotation tire axle loading at 11,000 lb is approximately equivalent to the dual-wheel axle configuration at 18,000 lb.

5. Absolute surface strain values are significantly greater for weaker structural sections for both wheel configurations than those resulting from relatively strong structural sections.

6. The data available indicate surface tensile strain is relatively low at extremes of temperature and approaches a definite peak at an intermediate temperature range. The temperature for peak tensile strain is probably a function of the type of structural section. Therefore, it is probable that even though the ratio of flotation to dual wheel strain increases with temperature, absolute values of strain for both types of wheel configuration decrease at higher temperatures.

7. At a flotation tire single-axle loading of 18,000 lb, pavement deflection decreased by 10 percent with a reduction in inflation pressure from 75 to 55 psi. At a flotation tire single-axle loading of 12,000 lb, the reduction in deflection due to fluctuations of inflation pressures was not significant.

8. Lateral surface tensile strain increased by 13 percent at both the 12,000- and 18,000-lb flotation tire single-axle loadings with a reduction in tire pressure of from 75 to 55 psi. This is believed to be the result of a greater concentration of contact stress at the side walls resulting from a decrease in tire pressure.

CONCLUSION

A standard flotation tire with a 12,000-lb single-axle loading is, insofar as relative destructive effect on a flexible or composite pavement is concerned, the equal to a standard dual-wheel configuration with an 18,000-lb single-axle loading. This equivalency, however, is subject to a certain degree of variation with pavement temperature.

Also, it appears that variations in flotation tire pressure will have a beneficial effect on this equivalency only with an accompanying change in the tire structure. In terms of absolute destructive effect, both tire and wheel configurations induce greater destructive effect on a relatively thin or weak structural section than a thick or composite pavement section.

ACKNOWLEDGMENTS

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Discussion

J. B. DONALDSON, Truck Tire Engineering, The Goodyear Tire and Rubber Company, Akron, Ohio. —Interest in all factors affecting highway durability is evident from the support obtained for research and development studies directed toward safer and more efficient highway use. On occasion, comments may prove useful towards relating new information to existing highway use, concepts and practices.

Zube and Forsyth relate surface tensile strain and transient pavement deflection to final fatigue failure in asphaltic concrete surfaces of flexible road structures. Their study concludes that the destructive effect of flotation tires, at a single-axle loading of 12,000 lb, equals or exceeds that of a dual-wheel configuration at a single-axle loading of 18,000 lb. The scope of this investigation, however, does not include an analysis of all axle positions and characteristics to establish critical axle location with regard to pavement fatigue.

Surface tensile strain and pavement deflection developed by an 18-19.5 tire at 75-psi inflation, having approximately 130-sq in. contact area and a tread width of 12 in., are compared to a dual-wheel configuration at 70-psi inflation, having approximately 130 sq

in. of contact area and 20 in. effective tread width in the dual mounting. It is apparent that the dual-tire configuration benefits substantially from the separation of the load areas and the corresponding increase in effective contact width.

The study assumes that all single axles loaded to 18,000 lb would utilize a dual-wheel configuration or, conversely, that a single axle utilizing only one conventional tire at each axle hub would have an axle loading of approximately 9,000 lb. A large, and increasing, segment of the transportation industry utilizes vehicles which develop steering axle loads of between 12,000 and 18,000 lb. This vehicle characteristic has developed over the past decade and many vehicle concepts are committed to steering axle loads of 15,000 lb or more. The development of this vehicle class incorporated the use of conventional tires on the steering axle.

An evaluation of a single axle loaded to 12,000 lb and utilizing single 10.00-20 tires at 100 psi indicates that pavement deflection is substantially higher than for the same axle load on 18-19.5 flotation tires. A comparison of the relative tire contact areas, 72 sq in. vs 130 sq in., and tread widths, 7.5 in. vs 12 in., indicates that directionally the use of the conventional 10.00-20 tire must develop substantially higher pavement deflection and surface strain. A similar parallel exists where a single axle loaded to 18,000 lb and utilizing 14.00-20 conventional tires at 85 psi is compared to the same axle load using 18-19.5 flotation tires at 75 psi. In this service, the 14.00-20 tire develops approximately 110-sq in. contact area over a 10-in. tread width compared to an 18-19.5 contact area of 130 sq in. and tread width of 12 in.

As stated previously, these examples represent substantial segments of current transport industry practice and conditions which have prevailed for a number of years. To develop an accurate perspective of the destructive effect of flotation tires on flexible pavement it is necessary that the entire vehicle be studied. Such studies should incorporate conditions currently existing in the transport industry and justified through long use and experience. An expansion of this investigation into this area appears justified.

R. P. POWERS and W. E. MOORE, Respectively, Manager, Testing and Advanced Tire Engineering, and Manager, Truck and Mileage Tire Engineering, Firestone Tire and Rubber Company. — The paper by Messrs. Zube and Forsyth is well written and documented with much test data which have no doubt been carefully acquired. However, we do not agree with their basic conclusions and respectfully take issue with the following:

1. The choice of title is unfortunate; it states a conclusion of damaging and far-reaching significance based on a specific series of tests, ignoring other facets.

2. We question whether measurements taken at creep speeds under ideal conditions are representative of what happens under dynamic conditions, where admittedly most road damage must occur.

3. No mention is made of any surface strain measurements taken between the duals. Undoubtedly, there must be a significant reversal of stress in this area and such an action is known to be more detrimental to flexible materials than higher stress without a reversal.

Based on our own tests and those of others with which we are acquainted, we suggest that the flotation or wide-base single tire under comparable loads and inflation will actually be easier on the pavement than will duals. This is primarily because of the inherent lower spring rate of the wide-base single tire and secondarily because dual tires are subject to the effects of mismating, unequal inflation, and road crown. These conditions are almost impossible to avoid (except with single tires) and must produce stresses far different than those measured under ideal circumstances by Zube and Forsyth. Also, the fact that roads are not smooth but irregular suggests that the dynamic factors cannot be ignored.
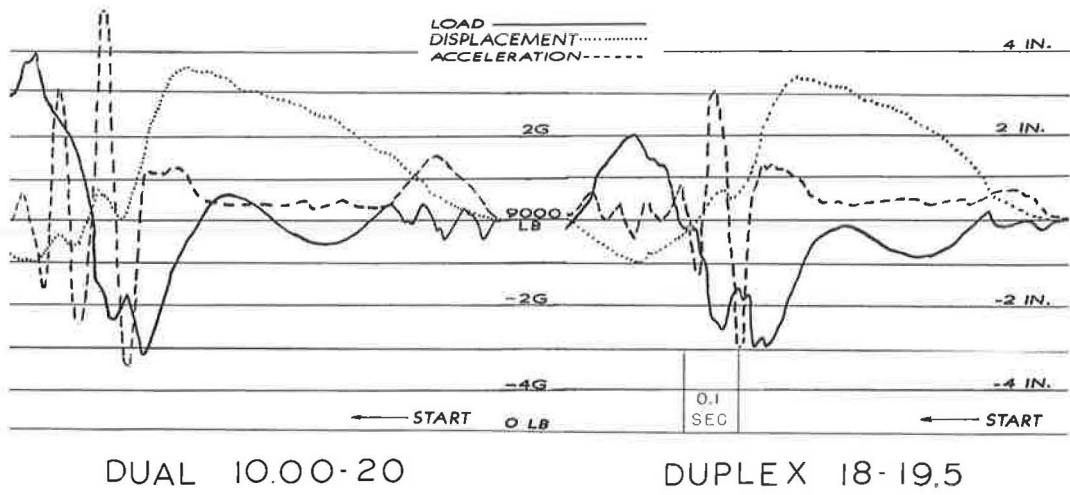
Figure 18. Impact loading, axle acceleration, and axle displacement for 18,000-lb axle load, 75 psi, 10 mph, no springs, up and over 4-in. ramp.

Figure 19. Effect of road crown: (a) on dual-tire loading, 11-22.5 duals, 18,000-lb axle; and (b) on single tire, 18-19.5, 18,000-lb axle.

CONTACT AREA

91 - SQ. IN. - 44

ON 3½° ROAD CROWN

6070# LOAD

2930# LOAD

CONTACT AREA

78 - SQ. IN. - 66

4875# LOAD

INNER 90 PSI

4125# LOAD

OUTER 65 PSI

Figure 20. Effect of inflation differences, 11-22.5 duals, 18,000-lb axle.

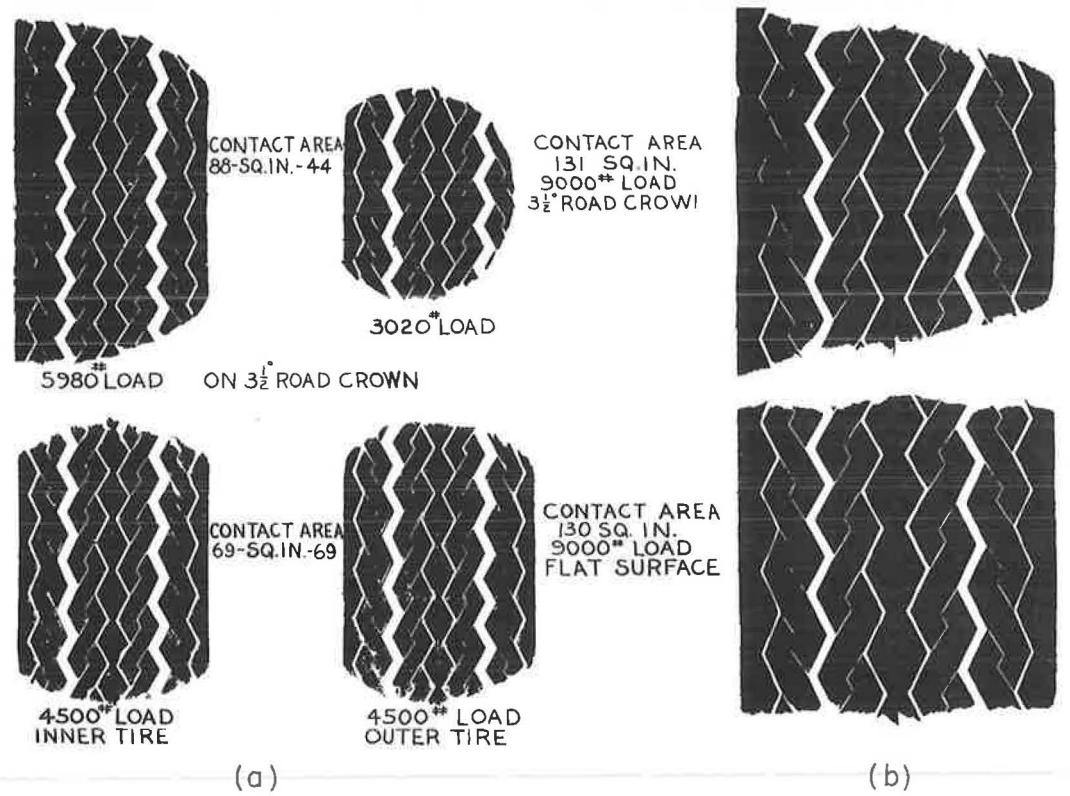In a previous paper (9), Moore presented test data on dual tires vs wide-base single tires obtained under dynamic conditions. These data, shown in Figure 18, were obtained by running a truck up and over a 4-in. ramp with the springs blocked out. Measurements were recorded for axle load, axle acceleration, and axle displacement. The axle load was determined by measuring the amount of axle bending. Analysis of the curves show that under dynamic shock load conditions, less load and acceleration are imparted to the axle by the wide-base single tire than by the dual tires. For example, the peak load with the wide-base single tire was 12,600 lb, and with the duals was 16,200 lb. In addition, the magnitude of the axle acceleration was also considerably less for the single tire. Other tests, under less exaggerated conditions and with the springs allowed to function normally, were also run and in every comparison the single tire transmitted less shock and acceleration to the truck. Although these data indicate only the effect of the dynamic impact on the truck (in particular, the axle), to say that the pavement does not feel the same load would be a violation of Newton's Third Law. Such data indicate an advantage in the wide-base single tire insofar as the truck is concerned, and we fail to see why the pavement would not be similarly affected.

Along the same lines as these tests, missile transporters were evaluated by a manufacturer on both single and dual tires, and here again, the wide-base single tires transmitted much less shock to the vehicle than did the duals.

Preliminary unofficial results of a road test being conducted by the Forestry Service and the University of Washington are reported to show less road deterioration with the wide-base singles than with dual-tired trucks. This test also shows less shock transmitted to the road base by vehicle travel with single than with dual tires.

Among data illustrating some of the inherent disadvantages of duals, Figure 19 shows how dual tires are affected by a crowned road. In this case, the inflation in all tires is 75 psi. As the tires pass over a $3\frac{1}{2}°$ crowned road, the inside tire on the dual assembly is loaded more than the outside tire, 5,980 lb ($\frac{2}{3}$ of the 9,000-lb dual load) vs 3,020 lb for the outside tire. The condition is further exaggerated when the outer dual drops off the edge of the pavement, leaving the full 9,000-lb load on one narrow tread.

Figure 20 shows the effect of inflation differences on dual tires. On a flat road the tire at 90 psi is carrying 4,895 lb of the 9,000-lb dual load, and the tire at 65 psi is carrying 4,125 lb or 46 percent. On a crowned road, the effect of inflation is even more important. Here the inside tire is carrying 67 percent of the load.

In addition to the points mentioned previously, there are other factors to consider in evaluating the effect of flotation tires on flexible pavement. In many instances, wide-base single tires at normal or lower inflation are being used to replace conventional tires at high inflation on front axles. In this case, a tire with a large contact area is replacing a tire with a much smaller contact area, which should result in less pavement strain and deflection.

With all due respect to Mr. Zube and Mr. Forsyth, their study appears to us to be incomplete and certainly in conflict with vehicle test data and ride reports from users everywhere. It is recommended that they be encouraged to extend their investigation to include the dynamic effect of these same tires on pavements.

Reference

9. Powers, R. P., and Moore, W. E. Ride Characteristics of the Wide Base Tire. Paper prepared for Society of Automotive Engineers.

ERNEST ZUBE and RAYMOND FORSYTH, Closure. —We have read with a great deal of interest the discussion by R. P. Powers and W. E. Moore of the Firestone Tire and Rubber Company. It is surprising to the authors that at this late date (the results of this investigation have been available to representatives of the tire industry for over a year) there is still a basic misconception as to the reason for this study and the selection of the criteria utilized.

As stated in our original presentation, we have no opinions or comments on the relative merits of dual vs flotation tires with respect to vehicle riding characteristics and wear rate and, thus, vehicle maintenance. Certainly there is every reason to believe that the use of flotation tires has a very beneficial effect on the dynamic characteristics of trucks and would very likely, therefore, offer significant economic benefits for truckers. Our primary concern is the effect of this product on the highway itself.

We must take issue with several specific points in the discussion of Messrs. Powers and Moore. The choice of the title of the paper was not intended to criticize or cast a shadow on flotation tires. At the time, it appeared to be an adequate and succinct description of the study because an evaluation of the detrimental effect of any new product on highways is of primary concern to our agency, whether this product be less or more damaging than the standard of comparison.

We must take strong exception to Item No. 2. It is a well-known fact that pavement deflection is highest at creep speed and diminishes lineally as the speed increases. Work to this effect has been published by innumerable investigators and most recently was presented in the findings of the AASHO Road Test (7). Visual evidence of this is many times apparent on highways in mountainous or hilly country subject to heavy truck traffic, in which we often note distress first appearing on the upgrades near the peaks of hills where trucks are moving at their lowest speeds. Another commonly observed example of this is the preponderance of cracking on any street at intersections where the vehicles come to rest.

With respect to Item No. 3, we will admit to a very limited amount of strain data in the zone between dual tires. Some readings were obtained in the very successful installations at our State Fair Grounds. However, during that phase of the study (involving reduction of tire pressure), strain values between the duals were relatively low, with some being in tension and others in compression (Table 2). As Messrs. Powers and Moore point out, there is definitely stress reversal in this zone. In terms of absolute tensile strain, however, maximum readings were obtained at from 5 to 8 in. from the outside edge of the tire, then rapidly reversing and going into compression as the edge of the tire came closer to the gage. There can be little doubt that highest tensile strain and, hence, the most critical reversal, occurs in this outside zone. This is also borne out be examination of transverse deflection profiles at the LVDT locations with the single exception from the plot of the Shell Avenue test road. These profiles show sharper bending and thus indicate higher tensile strains from the edge of the tire outward. This seems reasonable in view of the restraint afforded by the tires in the zone between the duals. We must, therefore, adhere to our original position that maximum tensile strain occurs near the outside edge of the loaded tire until evidence to the contrary is presented.

At this point Messrs. Powers and Moore proceed with what is believed to be their principal argument with regard to this paper; that is, their contention that the factor of truck dynamics has been neglected. There can be little argument, based on the results of various impact tests, that the use of flotation tires offers real advantages for truckers with respect to the shock or impact. Recently there has been evidence presented to the effect that the use of flotation tires on unimproved or unsurfaced roads is beneficial to the road itself. For this type of road, dynamic considerations have a significant effect on the tendency of a road to rut or "washboard." A report recently com-

TABLE 2

COMPARISON OF PAVEMENT STRAINS AT VARIOUS CRITICAL DUAL WHEEL LOCATIONS
(State Fair Grounds)

Run No.	Gage No.	Temperature (°F)	Strain (μ in./in.)[a]		
			Gage Centered Under 1 Wheel	Gage Centered Between Wheels	Max Tensile Strain Recorded[b]
1	1	45	−570	+180	+186
	2	45	−330	−84	+119
	3	45	−450	−120	+155
	4	45	−430	+60	+157
	5	45	−570	+30	+200
2	1	46	−770	+208	+228
	2	46	−400	+6	+138
	3	46	−500	+40	+182
	4	46	−500	+80	+200
	5	46	−700	−95	+280
3	1	42	−600	+155	+190
	2	42	−430	−80	+120
	3	42	−450	−125	+150
	4	42	−440	+30	+165

[a] Minus sign indicates compressive strain; plus sign indicates tensile strain.
[b] At 5 to 8 in. from outside edge of tire.

pleted by the University of Washington and the U. S. Forest Service on this subject presents convincing evidence to this effect (10).

Our prime concern, however, was a comparison of the destructive effects of flotation and standard dual tires on improved highways (surfaced with asphalt concrete) in California. Because, in general, our pavements are quite smooth, measurements involved in truck dynamics or impact effects on the roadway were not considered to be a factor in this investigation. We, therefore, concerned ourselves only with AC pavement flexure as indicated by measurements of strain and deflection because these criteria, and particularly that of pavement deflection, have been successfully related to pavement performance by many past investigations. We fail to see how impact data resulting from trucks dropping from a 4-in. ramp are applicable to our problem.

At the other extreme, our study indicates that for highways which we would consider primary (that is, those utilizing heavy AC surfacing and/or cement-treated bases), even though flotation tires are relatively more destructive, the difference in absolute units of strain or deflection are minimal. We would, therefore, anticipate no real detrimental effect in the use of these tires. This is also undoubtedly the case with respect to PCC pavements. Our prime concern is, therefore, roads with relatively thin AC surfacings and a flexible structural section which can be subject to early deterioration by way of fatigue failure of the surfacing if exposed to unusually high pavement strains and deflections. It appears that the critical zone in this evaluation is the possible detrimental effect of flotation tires on secondary roads and city streets.

We would agree that one dual may be more heavily loaded than the other due to crown slopes. This variable is, we believe, automatically introduced into this investigation because our data were obtained on roadways with widely varying crown slopes. The matter of variation in tread wear was of some concern early in this investigation. At one gage site, a worn and a new dual were purposely matched so that the strain measurements for this pair could be compared with those from two evenly worn duals on the opposite wheel. No significant difference in absolute transverse tensile strain was noted. These results and those from that phase of the investigation involving reduction in tire pressure lead us to believe that tire structure is a much more important variable with regard to surface strain than degree of tread wear.

With respect to the concluding paragraph of the discussion, we fail to see how any of the data presented in this investigation conflict with the results of any other study. In fact, to the best of our knowledge, this is the first time that an evaluation of flotation tires, based on pavement strain deflection measurement, has been undertaken. Because our primary concern is the design, construction, and maintenance of highways, we must, of necessity, leave investigations involving truck dynamics and wear rates to representatives of the tire and trucking industry.

Reference

10. University of Washington and U. S. Forest Service. Logging Road Test. Univ. of Washington College of Engineering, Dept. of Civil Engineering, Suppl. No. 7, Nov. 1964.