FINAL REPORT

EVALUATION OF STRAINS IN BITUMINOUS SURFACES
Phase II: Stiffness-Fatigue Investigation

by

G. W. Maupin, Jr.
Highway Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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INTRODUCTION

Fatigue failure is a primary source of distress in asphaltic concrete pavements, and in recent years a great deal of time and effort have been directed toward investigations of the mechanism of this type of failure. Most of the investigations have been carried out in the laboratory on small asphaltic concrete test specimens; however, at least one agency, Ohio State University, has performed large-scale pavement fatigue testing on a section housed in a tent.[1]

Fatigue investigations have studied the effect of materials characteristics such as asphalt type and aggregate type and gradation; the effect of asphaltic concrete properties such as void content and asphalt content; and the effects of temperature and the mode of loading. The single material characteristic which has been found to be most closely associated with fatigue life is mixture stiffness. It is generally true that an increase in stiffness will increase fatigue life under constant stress fatigue tests but decrease fatigue life under constant strain fatigue tests.

The equipment necessary for performing fatigue tests is quite expensive and the tests are quite lengthy, which make routine design fatigue testing for each mix impractical. A simple, inexpensive fatigue test that could be performed routinely and incorporated into the pavement design is needed. Since fatigue life had been shown to be dependent on stiffness, a study was undertaken to determine if a relationship could be developed between fatigue life and tensile stiffness as determined by the indirect tensile test.[2] It was reasoned that if a relationship was found to exist, the indirect tensile test, which is simple and inexpensive, might be used to predict fatigue life. The correlation developed showed promise of being useful in predicting fatigue life.

In order to determine if the strains were sufficient to cause premature fatigue failure, fatigue life-strain lines were developed for each mix tested in the study. These lines indicated that approximately a 140 micro in./in. strain level could be maintained for 1 million cycles. This finding was consistent with the results of Kasianchuk et al.,[3] who had indicated that a normal mix should withstand 1 million cycles at a 150 micro in./in. strain level.

PURPOSE

The investigation reported here was designed to determine the approximate magnitude of strain experienced on thin asphalt pavements in the field. It was believed that if these strains exceeded the maximum value indicated by research, 150 micro in./in., then steps should probably be taken to incorporate fatigue design into the overall procedure for designing thin asphalt pavements.

SCOPE

The methods used to obtain strain magnitude were: (1) Field measurements utilizing strain gages and a dynamic 18^k axle loading and, (2) theoretical computations utilizing a computer program developed by Chevron Corporation. Field measurements were obtained on four pavements with differing cross sections, and computer computations were performed using several combinations of material moduli for each pavement section.

TEST LOCATIONS

Since the stiffness-fatigue investigation utilized constant strain tests, which apply to pavements with thin asphalt layers (2 in. or less),[4] it was desirable to locate pavements with such thin layers. (Constant stress fatigue tests apply to pavements with asphalt layers thicker than 6 inches, and pavements with asphalt layers 2 to 6 in. thick behave in an intermediate mode. Although three of the pavements tested had 2 to 6 in. asphalt layers (Table 1) and would probably behave in an intermediate fatigue failure mode, it was felt they would give strains sufficiently close to thin layer strains.) In addition, it was decided to measure surface strains on a fresh overlay of a badly cracked section that would probably exhibit constant strain behavior.

Table 1

Structure of Test Pavements

Route	Asphaltic Concrete, inches	Crushed Aggregate, inches	Soil Cement, inches
20	4.5	6	6
250 Bypass	7.0	10	-
151	3.0	6	8
6	6.0	6	6

Route 20

One of the locations selected was on Route 20 approximately 0.2 mile west of Locust Grove in Orange County. This highway carries approximately 2,500 vpd in both directions. The structural cross section consists of 4.5 in. of asphaltic concrete, 6 in. of crushed stone, and 6 in. of soil cement. According to Vaswani[5], the subgrade is close to the boundaries between regions having soil support values of 6 and 9. The soil support values for Virginia range from 4 to 33, therefore; the relatively low values indicate the CBR would probably be low at this location.

Route 250 Charlottesville Bypass

A second location was a two-lane section of the Route 250 Bypass in Charlottesville between Emmet Street and Route 250 west in Albemarle County, which carries approximately 5,400 vpd. The structural cross section consists of 7 in. of asphaltic concrete, including two overlays and a surface treatment and 10 in. of crushed stone. Vaswani[5] has indicated that this location is in a region which has a low soil support value (4 to 5). This location had experienced localized alligator cracking of the original and subsequent asphaltic concrete layers, which was visible before the overlay was placed. However, the overlay did not have any visible cracking.

Route 151

The third location is a two-lane section of Route 151 several hundred feet south of Avon in Nelson County that carries approximately 2,200 vpd. This section has 3 in. of asphaltic concrete, 6 in. of crushed stone, and 8 in. of soil cement, and is in a region which has a low soil support value. This project has extensive cracking, however, measurements were made in an area with no cracks. This area probably had lower strains than the cracked sections.

Route 6

The fourth test location was on Route 6 approximately 0.5 mile east of Avon in Nelson County, and carries approximately 2,400 vpd. This section has 6 in. of asphaltic concrete, 6 in. of crushed stone, and 6 in. of soil cement. It also is in a region which has a low soil support value. The project had no visible cracks.

TEST EQUIPMENT AND GAGE INSTALLATION

The strains were recorded with a Honeywell model 1508 visicorder oscillograph that was equipped to record two channels simultaneously. The equipment was capable of accurately recording the dynamic strains caused by a moving vehicle.

1611 Two strain gages were installed at each location as illustrated in Figure 1. The wire strain gages used to measure the pavement surface strains were of the $2\frac{1}{2}$-in. SR-4 type. It was necessary to attach the gages to the pavement quickly so that traffic would not be severely interrupted, therefore, the adhesive could not have a long curing time nor require a lengthy procedure. Since most epoxy adhesives have long curing times and other adhesives have other disadvantages, it was decided to use asphalt cement, which had been used successfully in the laboratory on previous studies.

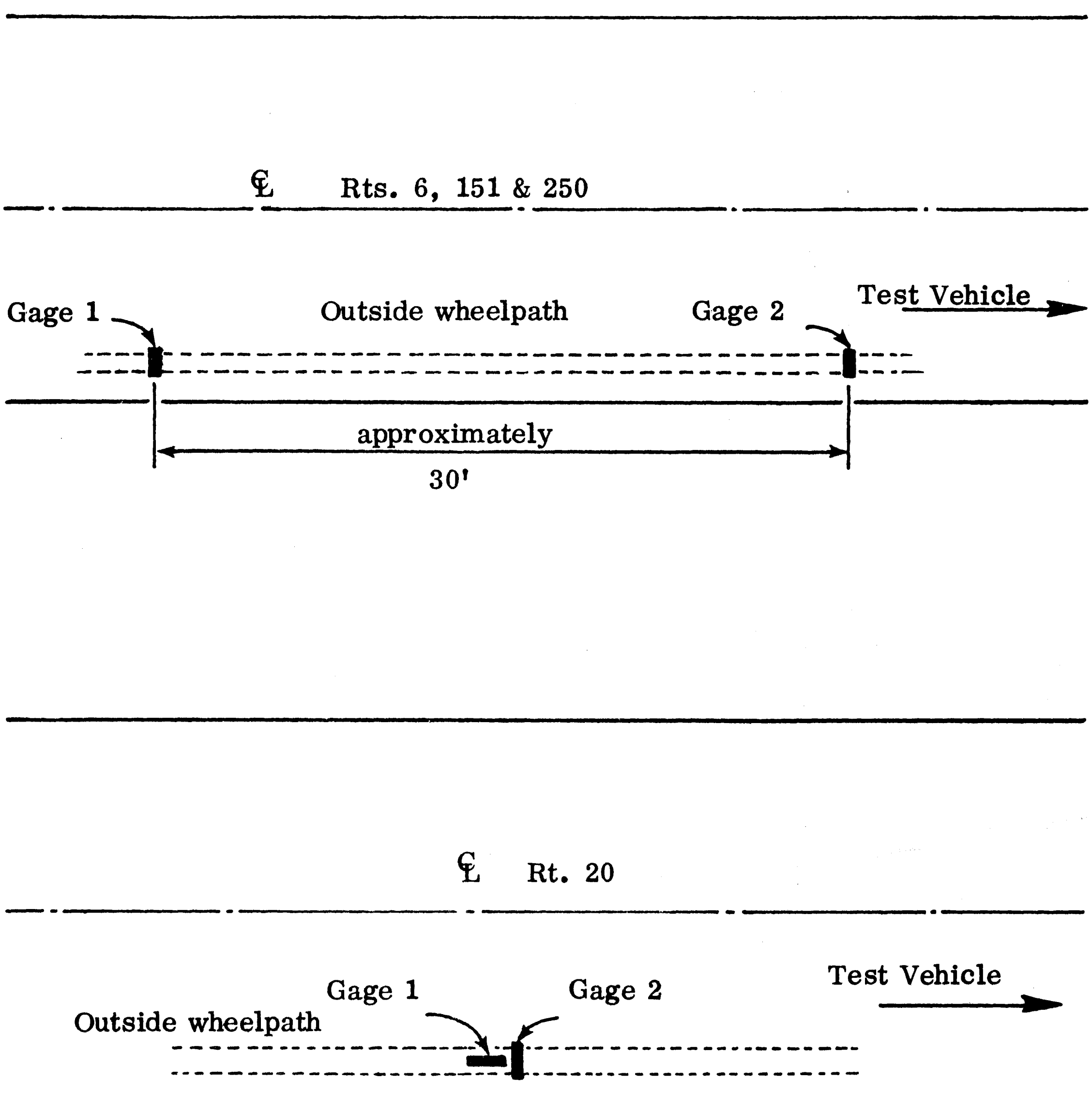

Figure 1. Gage locations.

The pavement surface was prepared by grinding it smooth with an abrasive wheel. The asphalt cement was then heated to a flowable consistency and spread onto the prepared surface with a hot knife. The gage was pressed onto the asphalt cement, the pressure being applied with a special hot tool pressed against the felt covering. A neoprene patch with an integral rubber polymer and aluminum plate was placed over the gage to protect it from traffic. After connecting the gages to the recorder with cable and wiring, measurements were taken.

The loads were applied to the road surface with a Virginia Department of Highways dump truck loaded to an 18^k rear axle loading. The test runs were performed at several speeds from 5 to 40 mph and at various transverse positions, including those in which the dual wheels were centered over the gage and to the left and right of the gage center line. If the tire came into contact with the gage, the viscoelastic nature of the asphalt adhesive allowed the gage to deform transversely, which resulted in incorrect strain readings. The gage was observed during testing and these readings were disregarded.

STRAIN COMPUTATIONS

Strains were computed on Routes 20, 250, 6, and 151 with the aid of a Chevron multilayer computer program. Although only an 18^k axle loading was used, two separate sets of computations were made using a single 9^k wheel load and superimposing two 4.5^k wheel loads in a dual wheel configuration (Figure 2). These loadings would possibly give different results, particularly between the dual wheels, as can be deduced from the deflection basins and strain plots illustrated in Figure 2.

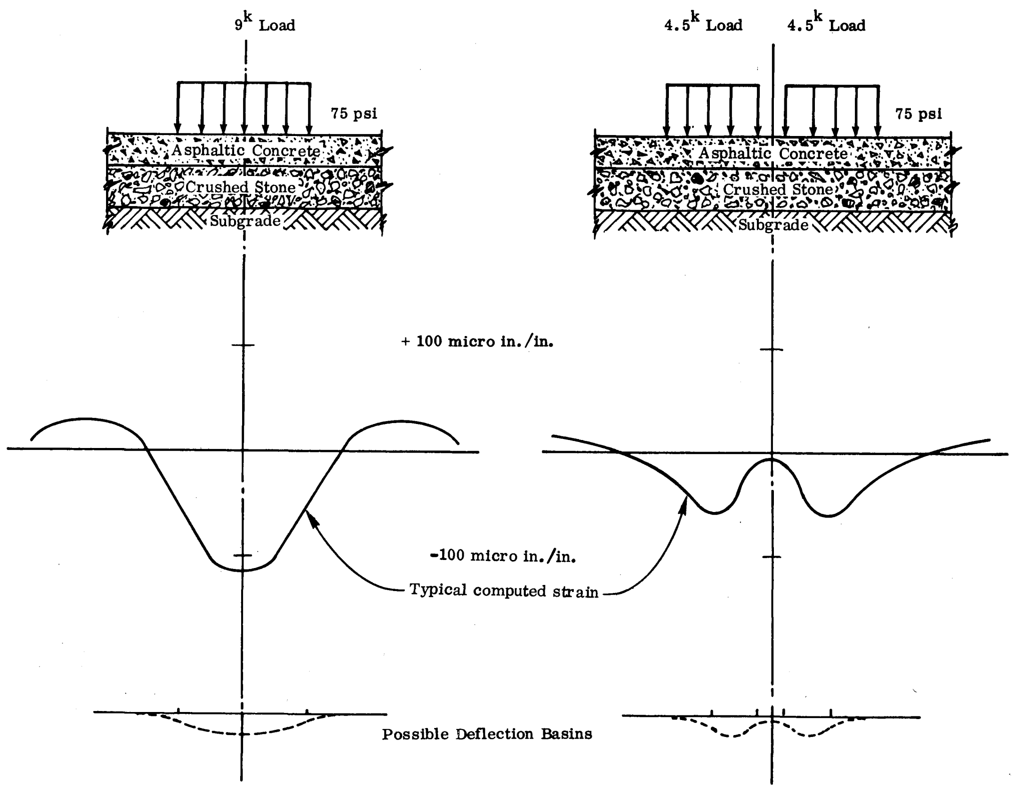

Figure 2. Load configurations used to compute strains.

RESULTS

Measured Strains

Appendix A contains "influence diagrams" which show the measured strain at the fixed gage location for different transverse positions of the dual wheel 9^k load. The strain is presented as the average of several test runs at 20 mph. Although other speeds were used, speed did not seem to affect the strain magnitude significantly, therefore, it is not reported here. As expected strains were higher for pavements with less asphaltic concrete, crushed stone and soil cement.

Route 20

Route 20 had 6 in. of soil-cement, 6 in. of crushed stone, and 4.5 in. of asphaltic concrete. Relatively high tensile surface strains (50-120 micro in./in.) were present between the dual wheels and the compressive strains were very small. Possibly higher compressive strains would have been measured directly under the tire if such measurements could have been obtained.

Route 250

Route 250 displayed the highest compressive surface strains, in the order of 100-200 micro in./in., which occurred between the dual wheels. The high strains are a probable result of the weak supporting structure consisting of 10 in. of crushed aggregate and 7 in. of asphaltic concrete, of which approximately 3 in. is maintenance overlay. The latest overlay was placed approximately 6 months before testing on a section characterized by severe alligator cracking; therefore, the structural stiffness of the lower layers of asphaltic concrete was poor. This section was included since it was felt the recent asphaltic concrete overlay would behave in a constant strain mode.

Route 151

Route 151 showed moderate tensile surface strains (30-90 micro in./in.) when the wheel was in both the inside and outside positions relative to the gage. The maximum measured compressive strain (145 micro in./in.) occurred between the dual wheels. Although the section tested had no visible cracks, adjacent areas on the same project were severely cracked and must have experienced higher strains than those that were recorded. The pavement structure consisted of 8 in. of soil cement, 6 in. of crushed aggregate, and 3 in. of asphaltic concrete.

Route 6

Route 6 yielded compressive strains that were approximately 20 percent less than those on Route 151, and the tensile strains were approximately the same as those on Route 151. Since Route 6 had 3 in. of additional asphaltic concrete, it is logical that less strain would be experienced.

General Comments on Measured Strains

Compressive strains occurred between the dual wheels on Route 151, 6, and 250, whereas Route 20 experienced tensile strains. These findings may indicate a more flexible structure on Route 20 as illustrated in Figure 3.

On Routes 151, 6, and 250 there was a trend for higher strains to occur on the surface when the wheel was positioned outside the wheelpath than when inside the wheelpath. Since pavements often fail prematurely when vehicles consistently travel on the pavement edge, it is logical that high strains exist in this test situation.

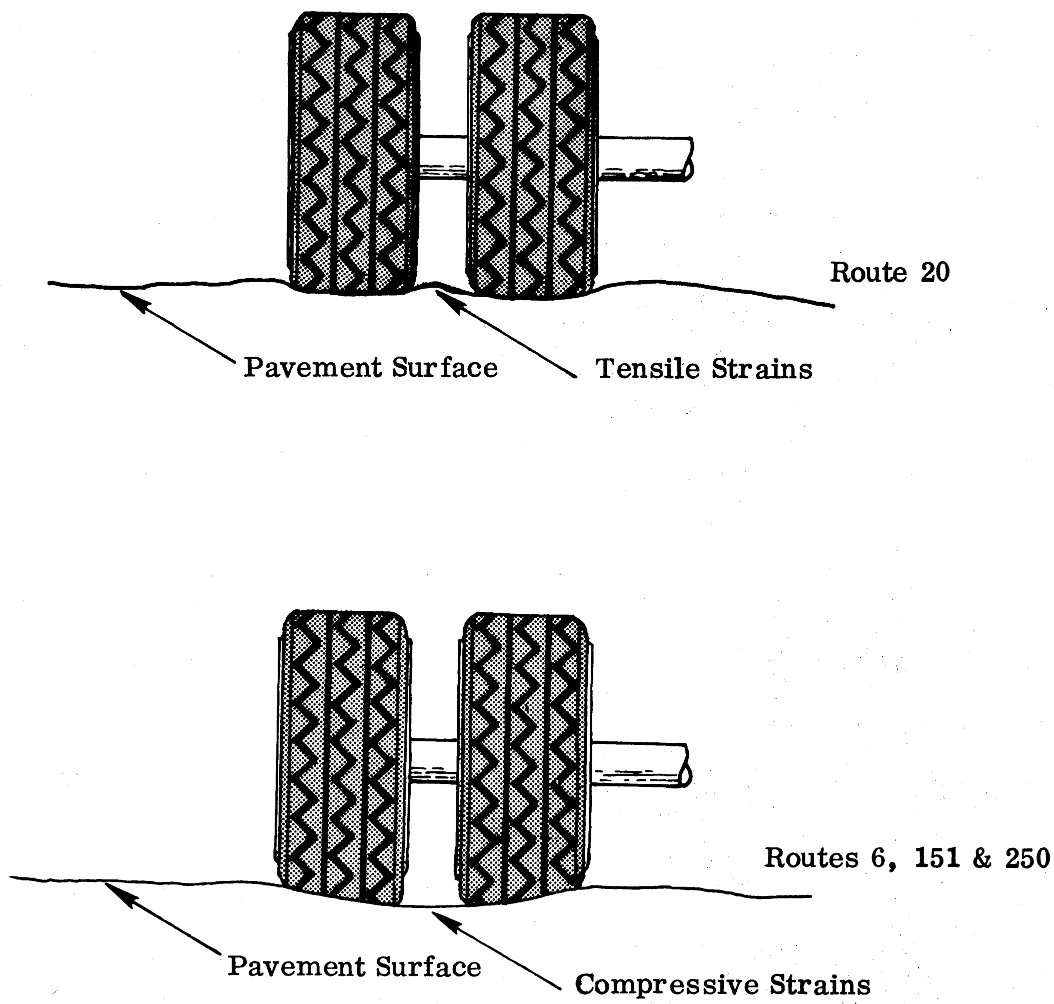

Figure 3. Possible strain and/or deflection configurations under dual wheel load.

Will surface tensile strains of the magnitude mentioned above cause early fatigue failure? Kasianchuk et al. have indicated that a pavement should be designed to endure 1 million cycles at a 150 micro in./in. strain level.(3) The author's previous study, which correlated constant strain fatigue life and strain magnitude, indicated a fatigue life of 1 million cycles for normal Virginia hot plant mixes at a 140 micro in./in. strain level. Since measured tensile surface strains were well below the 140 micro in./in. strain level, there probably is no need to design thin pavement surfaces for fatigue.

Dynaflect measurements(6) were obtained on Routes 151 and 6 at the exact locations of the strain gage measurements. The dynaflect deflections were measured in a longitudinal direction whereas the wheel positions for strain measurements were in a transverse position. More bending occurred on Route 151 than on Route 6 as is evident from the dynaflect measurements (Appendix A); therefore, the influence diagram should also show a greater strain change for the transversely positioned wheel load on Route 151. On Route 151 the strain change was approximately 165 micro in./in. vs. 80 micro in./in. on Route 6, when the center of the dual wheels was shifted 10.5 in. from the gage center line. This was expected, since Route 6 had 3 in. more of asphaltic concrete and thus a stiffer structure.

Strain Computations Results

The Chevron Multilayer Computer Analysis was used to compute strains on each section for comparison with the measured strains. In the computer analysis, strain was determined on the surface and bottom of the asphaltic concrete layer under the center of the wheel load, at the edge of the loaded area, and at other regularly spaced intervals. Two conditions of wheel loading were assumed as follows: (1) Two 4.5^k wheel loads spaced in a dual wheel configuration, and (2) a single 9^k wheel load. Also, five different combinations of materials moduli were utilized. It was necessary to assume materials moduli since they nor facilities for determining them were available, but, in any case, the strain levels did not appear to differ greatly with changes in moduli.

The strain computations indicate that relatively low tensile strains should be expected on the surface and that these occur near and outside of the outer edge of the loaded area. The highest tensile surface strain computed, 27 micro in./in., was on Route 151 at the outside edge of the 9^k loaded area.

The strains computed at the center of loading were generally higher for the single 9^k wheel load than for the dual arrangement of two 4.5^k wheel loads. This can be explained by referring to Figure 2. The figure shows strain trends that were computed under the two 4.5^k wheel loads and under a single 9^k wheel load. The two wheel loads cause tensile strains or lower compressive strains than the single wheel load on the pavement surface in the center of the loaded area.

COMPARISON OF COMPUTED AND MEASURED VALUES

Generally the computed strains were much less than the measured strains. This is not surprising since all of these highways have been subjected to considerable traffic, which usually increases deflections and strains over the original values. The ranges of assumed values of stiffness moduli used in the strain computations were: 4×10^5 - 1×10^6 psi for asphaltic concrete, 7.5×10^4 - 1×10^5 psi for crushed stone base and soil cement, and 8×10^3 - 14×10^3 psi for subgrade. The value of Poisson's ratio assumed for all materials was 0.5. The material values of Poisson's ratio and/or moduli may have been incorrect; however, even though low moduli were used, large strains were computed. The strains computed from the 9^k wheel load corresponded more closely with the measured strains.

Table 2 is a summary of comparative values for computed and measured strains.

Table 2

Computed and Measured Strains for 9^k Loading

Route	Maximum Surface Strain — micro in./in.				Remarks
	Center of Loaded Area		Edge of Loaded Area		
	Measured	Computed	Measured	Computed	
20	+120	-104 to -159	-20	-31 to -63	Computed by 9^k single wheel load
	+120	-40 to - 57			Computed by 2 - 4.5^k wheel loads
250	-169	-62 to - 99	-30 to -175	-23 to -31	Computed by 1 - 7" asphalt layer
	-169	-124 to -150	-30 to -178	12 to 28	Allowance made for cracked asphalt using reduced modulus
6	-112	-69 to -119	+55	-17 to -24	
151	-145	-114 to -150	+45	+15 to +27	

Note 1: All computations made using single 9^k wheel load unless noted otherwise.

Note 2: - signifies compressive strains
+ signifies tensile strains

Route 20

On Route 20 the computed surface strain under the center of the load ranged from -104 micro in./in. to -159 micro in./in. for the 9^k load and -40 micro in./in. to -57 micro in./in. for the two 4.5^k wheel loads. The measured strain under the center of the load was 120 micro in./in.; therefore, there is not very good agreement between the computed and the measured results. The computed strain at the outside edge of the wheel ranged from -31 micro in./in. to -63 micro in./in., and the measured value was -20 micro in./in., which is a somewhat better agreement than for the center of load position.

Route 250

The computed surface strain under the load on Route 250 ranged from -62 micro in./in. to -99 micro in./in., and the measured surface strain at 20 mph averaged -169 micro in./in. The computed surface strain at the outside edge of the loaded area ranged from -23 micro in./in. to -31 micro in./in., and the measured values averaged -175 micro in./in. when the wheel was outside and only -30 micro in./in. when the wheel load was inside the gage.

Since it was known that the lower asphalt layer was badly cracked and probably offered less stiffness than the fresh overlay, additional computations were performed, assigning a lower modulus to the cracked layer. The computed surface strain under the loaded area ranged from -124 micro in./in. to -150 micro in./in. compared to the -169 micro in./in. average measured strain. The computed surface strain at the outside edge of the loaded area ranged from 12 micro in./in. to 28 micro in./in. compared to the -178 micro in./in. measured strain when the wheel was outside and -30 micro in./in. when the wheel was inside. Therefore, the computed values compared more closely with measured values when the cracked asphalt layers were considered to be weaker.

Route 6

The computed surface strain under the load on Route 6 ranged from -69 micro in./in. to -119 micro in./in. and the measured strain averaged -112 micro in./in., which is reasonably good agreement. The computed strain at the outside edge of the loaded area ranged from -17 micro in./in. to -24 micro in./in., and the measured value was 55 micro in./in.

Route 151

There was good agreement between the measured and computed strains on Route 151. The computed surface strains under the load ranged from -114 micro in./in. to -150 micro in./in. for the five combinations of moduli used. The measured values averaged -145 micro in./in. The computed surface strain at the outside edge of the loaded area ranged from 15 micro in./in. to 27 micro in./in., and the averaged measured strain was 45 micro in./in.

The results above illustrate that reasonable agreement between measured and computed surface strains were obtained on Routes 6, 151, and 250. Route 20 had measured tensile strains between the dual wheels but the computed values were compressive. This was probably caused by excessive flexing resulting from a weak structure, and it might be that the soil cement is not providing the strength originally anticipated.

SUMMARY OF RESULTS

1. Measured tensile strains on the upper surfaces of bituminous pavements were well below 150 micro in./in., the value considered critical.

2. The highest measured tensile surface strains occurred between the dual wheels on Route 20.

3. The highest measured compressive strains occurred under the center of the wheel load on Route 151 (105-130 micro in./in.) and when the wheels were on the outside edge of the pavement on Route 250 (100-250 micro in./in.).

4. The surface strains computed from a single 9^k wheel load agreed best with the measured values.

CONCLUSIONS

The magnitude of the strains measured was not sufficient to warrant provisions for constant strain fatigue in the design procedure. Instead, emphasis should be shifted toward the investigation of constant stress fatigue testing and design.

IMPLEMENTATION

This investigation revealed that the only measured surface tensile strains that were sufficient to cause premature fatigue failure were on weak sections and overlaid sections of badly cracked pavements. It is felt that there is little need for a simplified test method for use in designing against fatigue failure in thin asphalt pavements in Virginia, since the strains measured were low and other methods are being considered for the prevention of the cracking of overlays on badly cracked sections (reflection cracks).

It is the author's opinion that attention should be concentrated on a simplified design method for thick pavements, which behave in the constant stress mode.

ACKNOWLEDGEMENTS

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APPENDIX A

INFLUENCE DIAGRAMS OF AVERAGE STRAIN MEASUREMENTS AND DYNAFLECT MEASUREMENTS

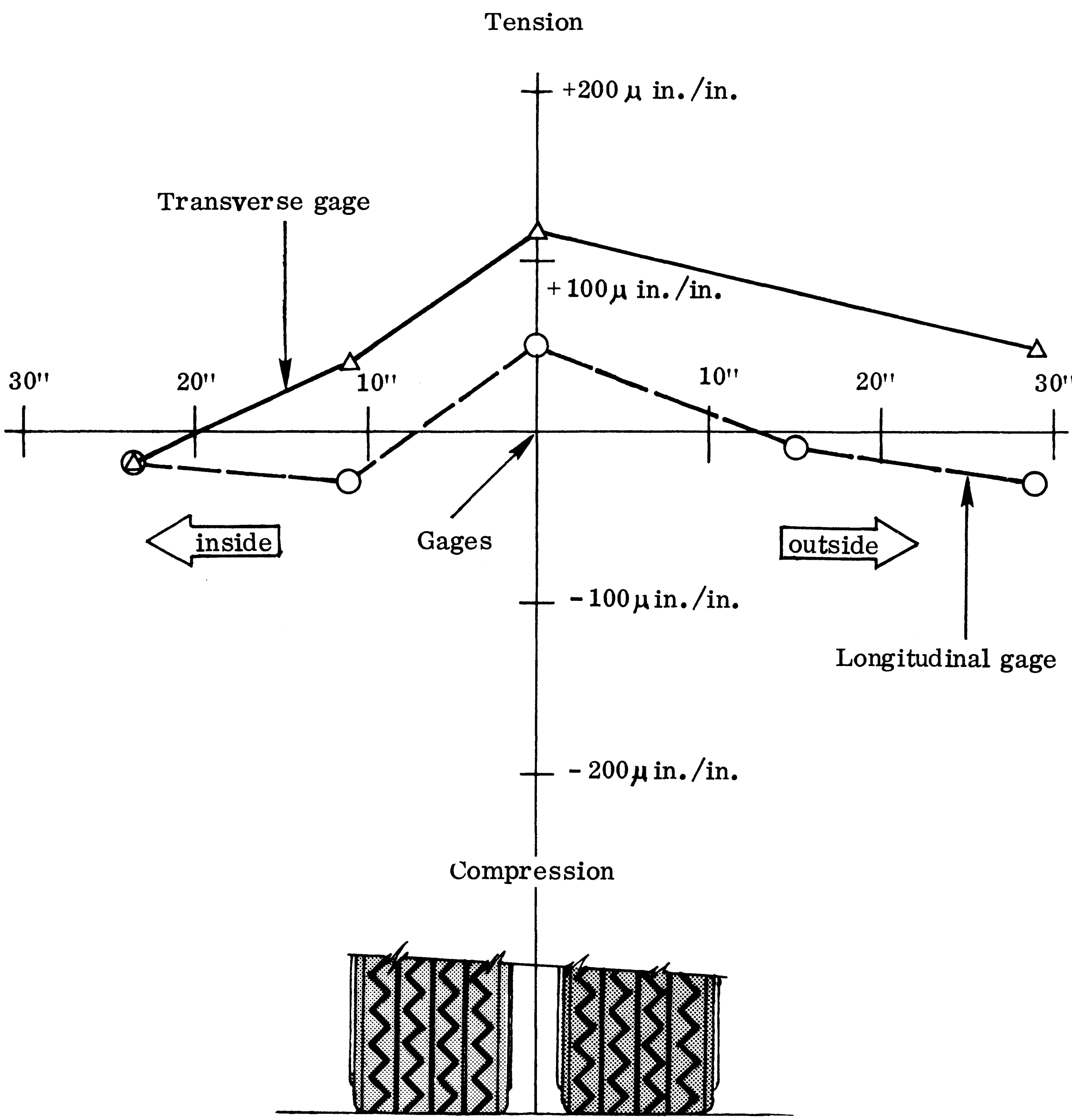


Figure A-1. Influence diagram for surface strain at ℄ of established wheelpath — Route 20.

Route 250

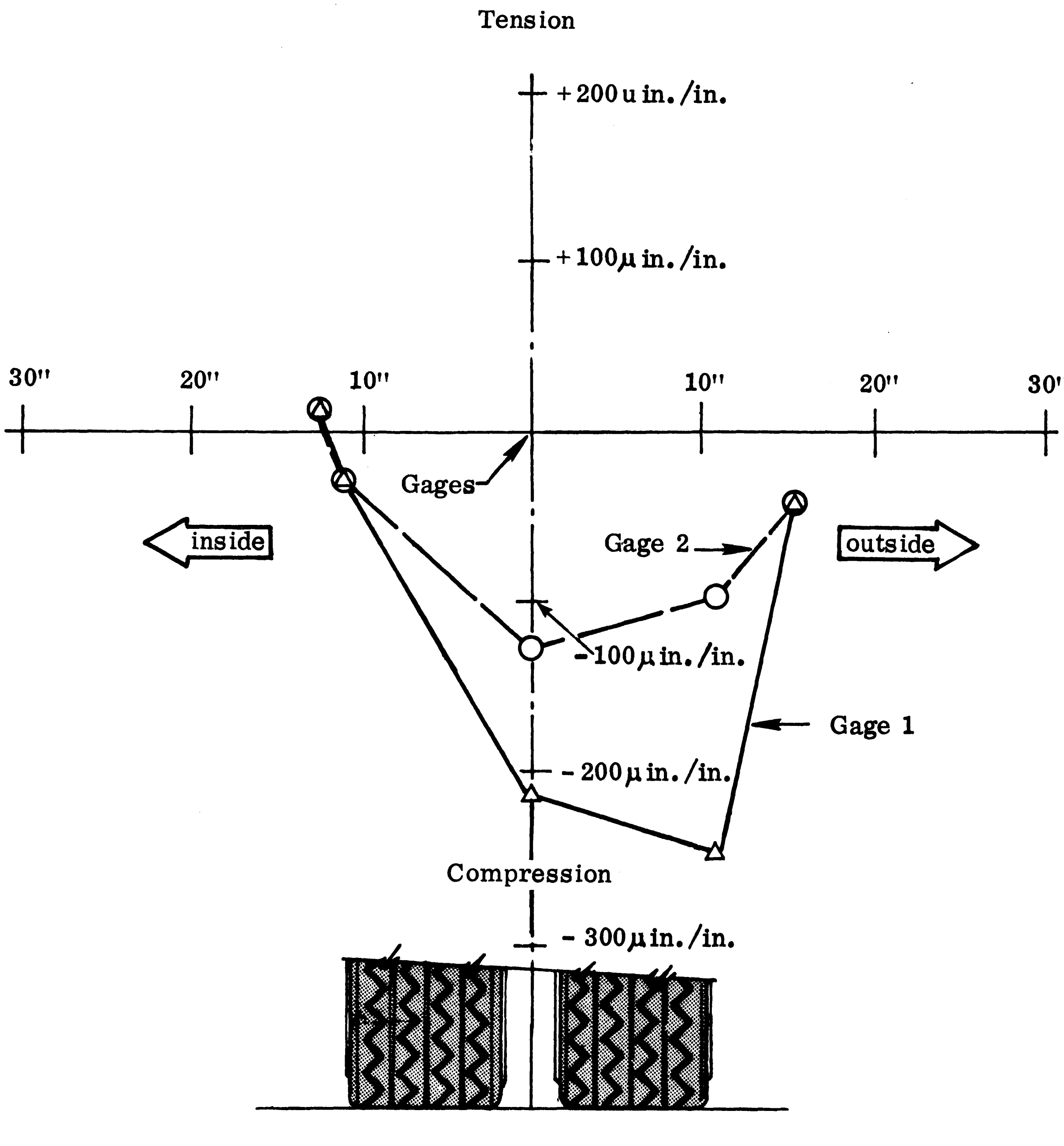


Figure A-2. Influence diagram for surface strain at ℄ of established wheelpath — Route 250.

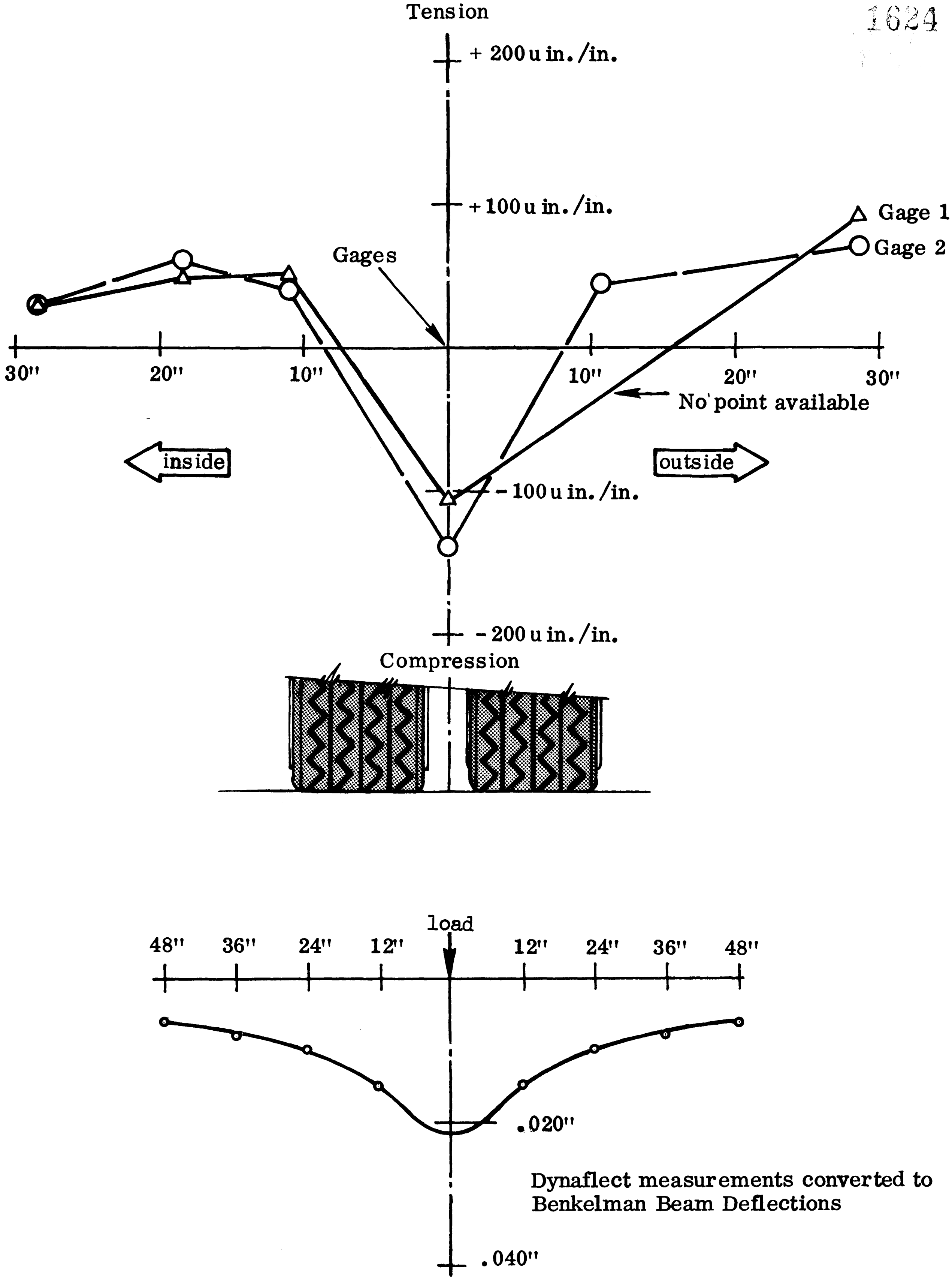
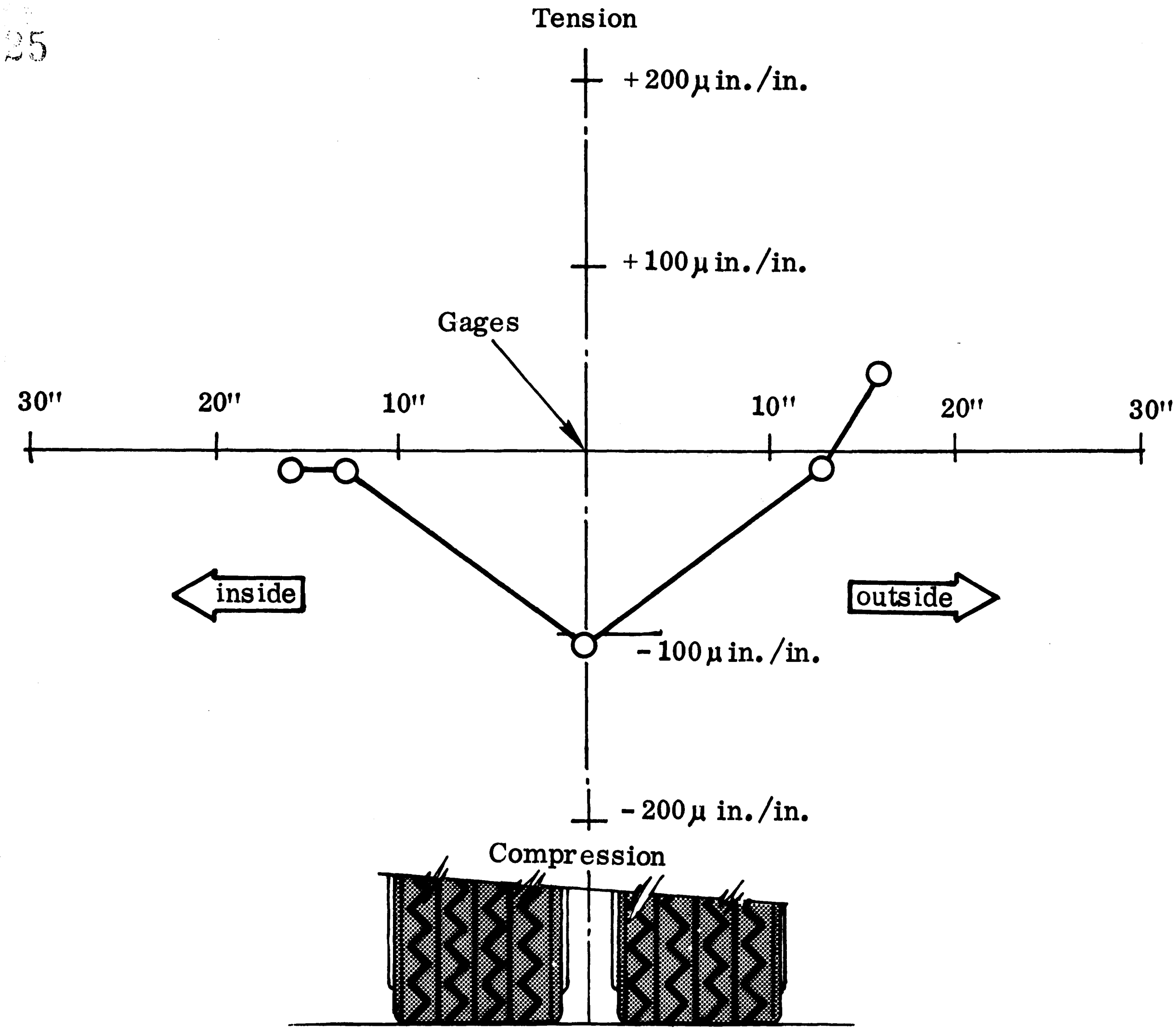


Figure A-3. Influence diagram for surface strain at ℄ of established wheelpath and dynaflect measurements — Route 151.



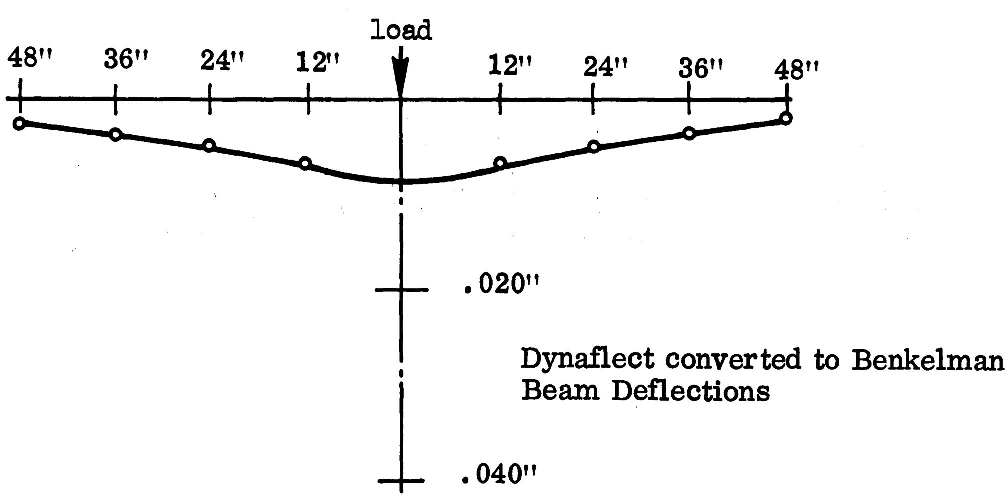


Figure A-4. Influence diagram for surface strain at ℄ of established wheelpath — and dynaflect measurements — Route 6.