MEASUREMENTS OF RAIL/TIE DEFLECTIONS AND FASTENER CLIP STRAINS

FAST Facility for Accelerated Service Testing

TRANSPORTATION TEST CENTER
PUEBLO, COLORADO 81001

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16. Abstract

Measurements of rail-to-tie deflections and fastener clip strain were made on both concrete and wood tie track at the Facility for Accelerated Service Testing (FAST) in October 1980. These measurements were made to provide a data base for duplicating, if possible, these deflections and strains in a laboratory. The laboratory tests would serve as the basis for evaluating the performance of various wood and concrete tie fasteners.

The results demonstrated that rail-to-tie deflections are a reasonable way to characterize the fastening load environment. However, because of the complexity of fastener deflection, better results would have been obtained by direct measurement. The rail-to-tie deflections measurement did provide enough data to develop appropriate laboratory fastener performance tests.

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PREFACE

This work was sponsored by the Improved Track Structures Research Division of the Federal Railroad Administration (FRA). Mr. Howard Moody of the FRA was the Contracting Officer's Technical Representative. Test planning and coordination at the Transportation Test Center (TTC) were completed by Larry Daniels, FAST Experiment Monitor. Members of the dynamic data collection group at TTC provided the data recording equipment and assisted in the placement of the test fixtures on ties. The contribution of all of these people is greatly appreciated.

ACRONYMS

BCL	Battelle-Columbus Laboratories
DCDT	direct-coupled differential transformer
FAST	Facility for Accelerated Service Testing
FRA	Federal Railroad Administration
IF	inside rail, field position
IG	inside rail, gage position
OF	outside rail, field position
OG	outside rail, gage position
TTC	Transportation Test Center

ABBREVIATIONS AND METRIC EQUIVALENTS

o	degree	$= \{(^{o}F-32)5/9\}^{o}$ C
", in	inch	= 2.54 cm
kΩ	kilohm	
μin	microinch	$= 2.54 \times 10^{-8}$ m
%	percent	
lb	pound	= 0.45359 kg
sec	second	
V	volt	

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EXECUTIVE SUMMARY

During October 1980, measurements of dynamic rail-to-tie deflections and fastener clip strains were made on four selected subsections of the Facility for Accelerated Service Testing (FAST) track, Pueblo, Colorado. Test locations were in 5^0 curves of wood and concrete tie track where elastic clip fastener systems are installed. Rail-to-tie deflections were measured in the four subsections, and fastener clip strains were measured in a concrete and a wood tie subsection that used a common clip. The measurements were to provide the data for laboratory simulation of severe loading environments for the fasteners. Laboratory tests of fastener clip strain vs. vertical clip deflection were made to compare with the field data.

The major results of this measurement program were:

- An approximate correspondence was found between the strain-deflection results from the track data and the results produced by a laboratory method in which the vertical loading was applied through a rail segment. In another laboratory method, the vertical loading was applied directly to the clip. This method required much greater clip deflection to produce similar levels of clip strain.
- The maximum levels of clip strain found on concrete tie track exceeded the fatigue limit identified by the manufacturer in load-deflection tests similar to those first tried for this test. This result was established by a comparison of clip strain-deflection data found in the field with the strain-deflection results of the two laboratory tests and with the manufacturer's load-deflection data.
- Nonsymmetrical rocking of the tie about its longitudinal axis was found in most measurements on concrete tie track.
- In contrast to the expected result, maximum rail-to-tie deflections for concrete tie track were found in a subsection containing stiff rail pads rather than in a neighboring subsection containing resilient pads.
- For one type of elastic clip wood tie fastener, much of the vertical rail/tie deflection occurred through tie plate bending rather than through flexing of the clip.

The major conclusions of this study are:

- The basic approach was adequate to define loading environments for planned fastener fatigue tests. However, the measurement sites were limited in number, and data reductions had to be performed by hand calculations. In spite of the limitations, it is reasonable to assume that any response found during this program will occur repeatedly during normal operations on the FAST track.

- Fastener clips installed in track receive strain from sources independent of vertical deflection. The laboratory tests indicate that a significant additional strain component is produced by lateral loading. Other possible sources include the longitudinal rail/tie motion and the shift of the clip support point at its flattened toe due to tie rocking and rail rollover.

INTRODUCTION

During October 1980, measurements of rail-to-tie deflections and fastener clip strains were made on four selected subsections of the Facility for Accelerated Service Testing (FAST) track at the Transportation Test Center (TTC), in Pueblo, Colorado. Additional laboratory tests of fastener clip strain vs. vertical clip deflection were made to compare with the field data.

The measurement program provided the data for laboratory simulation of severe loading environments encountered by representative wood and concrete tie fastener systems. This report summarizes the data and defines levels of rail-to-tie deflections and clip strains to be used in fastener fatigue tests. The effort is part of a study to define improved fastener performance specifications.[1]

FAST was selected as a test site because it provides an easily accessible track and a severe fastener loading environment. Fastener performance problems have occurred in the 5^{o} curves of both wood and concrete tie track. These include the fallout and failure of fastener components on both types of track, tie movement on concrete tie track, and dynamic gage widening on wood tie track.

Measurement sites consisted of two subsections in the concrete tie Section 17 (5^{o} curve, 2% grade) and two subsections in the wood tie Section 07 (5^{o} curve, essentially no grade). All subsections contained "improved" fastener systems with elastic clips. The six rail-to-tie deflection measurements consisted of three vertical deflections at the rail base, one lateral at the rail base, one lateral at the rail head, and one longitudinal at the rail base. Clip strain was also measured in one subsection of both wood and concrete tie track, where a common clip was installed.

The clip strain vs. deflection relationship was measured in the laboratory by two methods: by vertical loading of individual clips in a special test fixture, and by loading through a rail segment to simulate approximately the lateral and vertical load components experienced in track.

Track loading was provided by a special test train of two locomotives and 20 loaded 100-ton hopper cars.

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[1] Dean, F.E., Research Plan for the Development of Improved Rail Fastener Performance Requirements, report by Battelle-Columbus Laboratories to the Federal Railroad Administration, Contract DOT-FR-1962, April 1980.

TEST PROCEDURE

APPROACH

The service loading environment of a fastener is difficult to measure in terms of the forces to which a fastener is subjected. Fastener load paths are complex, and space to install transducers is usually very limited. Measurement of wheel/rail loads would not suffice because these loads are distributed to several adjacent ties, and it is desirable to restrict laboratory fixtures to a single fastener system. The simplest method by which the fastener loading environment can be defined is to measure rail/tie deflections and, where practical, strains in fastener components. These can be reproduced in the laboratory to determine the forces that simulate the fastener loading environment. This method was adopted for the field measurements at FAST.

The transducer locations shown in figure 1 were selected to provide measurements of all significant modes of rail-to-tie movement. The locations were:

- Vertical deflection at the "field side left" position,
- Vertical deflection at the "field side right" position,
- Vertical deflection at the "gage side left" position,
- Lateral deflection at the rail head,
- Lateral deflection at the rail base, and
- Longitudinal deflection at the field side base.

The three vertical deflections can be combined to define clip deflections, rail/tie rollover and rail/tie rocking. The difference of lateral deflections at the rail head and rail base can also define rail rollover. The only component that was neglected was rail/tie yaw. This could only be produced as the difference of very small linear deflections in the lateral or longitudinal directions at the rail base.

MEASUREMENT LOCATIONS

Measurements were made in the 5° curves of concrete tie Section 17 and wood tie Section 07. The following subsections were selected for testing:

Tie Type	Fastener Type	Tie Number
Concrete	Type B Clip and Synthetic Rubber Pad (Soft)	0550, 0560, 0576
Concrete	Type A Clip and Polyethylene Pad (Hard)	0390, 0405, 0415
Wood	Type A Clip and Screw Spikes	0154, 0165, 0181
Wood	Elastic Clip-Spikes and Cut Spikes	0339, 0351, 0363

To the extent that time allowed, data were collected on both rail seats of each tie and for clockwise and counterclockwise train directions. (Only the clockwise direction was obtained for wood tie track.) Tie locations were

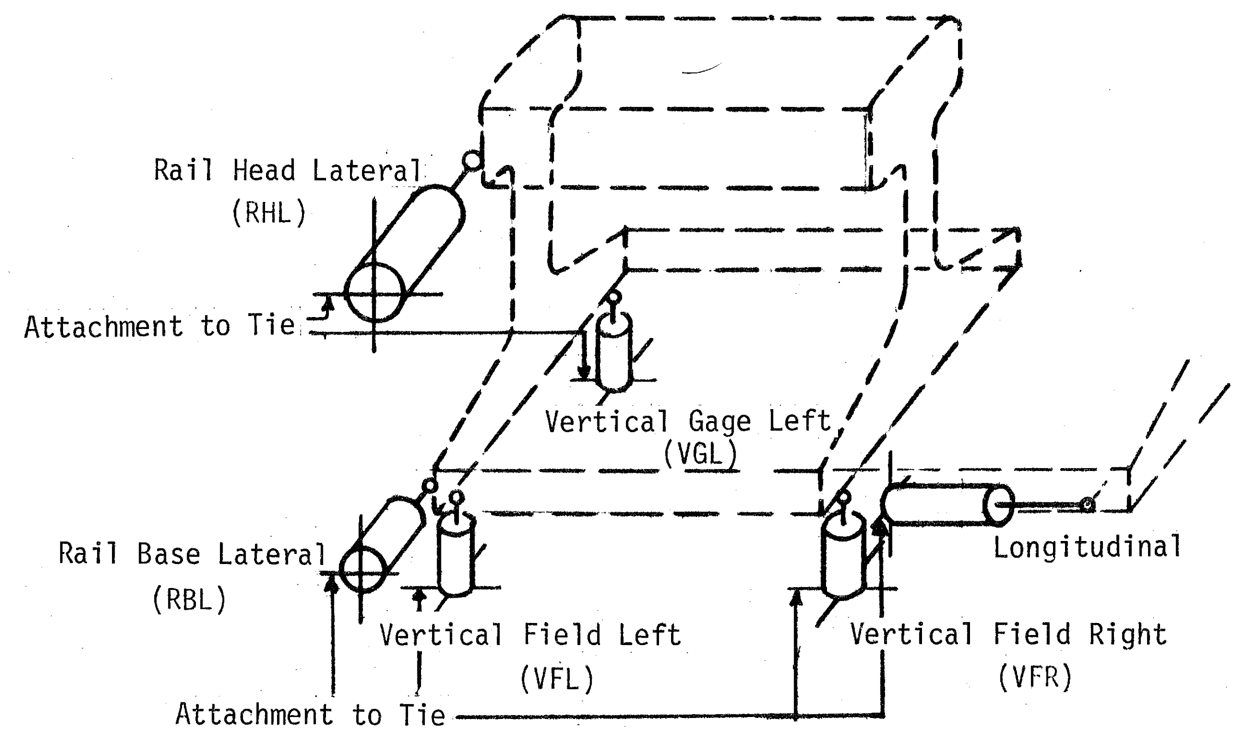

FIGURE 1. POSITIONS OF DISPLACEMENT TRANSDUCERS.

selected to be independent of each other, within the subsection by at least 10 ties, and to offer convenient fixture mounting. The concrete tie test segments were selected because they offered tie pads with widely differing stiffnesses. In the pad load range between 4,000 lb and 20,000 lb, the stiffness of the polyethylene pad is 4.6 million pounds per inch, while that of the synthetic rubber pad is 1.5 million pounds per inch. Tie pad stiffness controls rail/tie deflections more than any other parameter.

INSTRUMENTATION

All deflection transducers were standard, direct-coupled differential transformers (DCDT's). Except for the longitudinal transducer, all were fitted with preload springs to eliminate the need for positive attachment to the rail. The longitudinal DCDT required a target that was clamped to the rail base. Ranges of the transducers were:

- All verticals: ±0.10"
- Two laterals and the longitudinal: ±0.5"

The vertical transducers were selected principally for their limited physical length of about 3.5", which minimized ballast disturbance. The limit in frequency response of the DCDT's with preload springs was about 50 Hz.

To further minimize the time required for setup, a transducer mounting fixture was constructed. Fixture placement is illustrated in figure 2. The fixture made it possible to transfer the instrumentation array from one rail seat to another within 20 minutes.

Strain-gaged Type A clips were available from an earlier study of the structural performance of these clips.[2] As shown in appendix A, a four-arm resistance bridge consisted of a biaxial pair of strain gages and two completion resistors. The location for placement of the gages on the clips was selected for convenience of strain definition and is not the location where maximum strains can be expected. The clips were used in these tests to provide a direct indication of the loading environment of the clip, as opposed to the loading environment of the fastener system that was provided by the deflection measurements.

CALIBRATION

All transducer signals received supply voltage (5V) and amplification from amplifiers. The signals were fed to an 8-channel strip chart recorder in the TTC data van. Final gain settings were adjusted at the recorder.

All displacements were calibrated by deflecting the transducer rod by a known amount and adjusting the recorder pen to a desired scale position.

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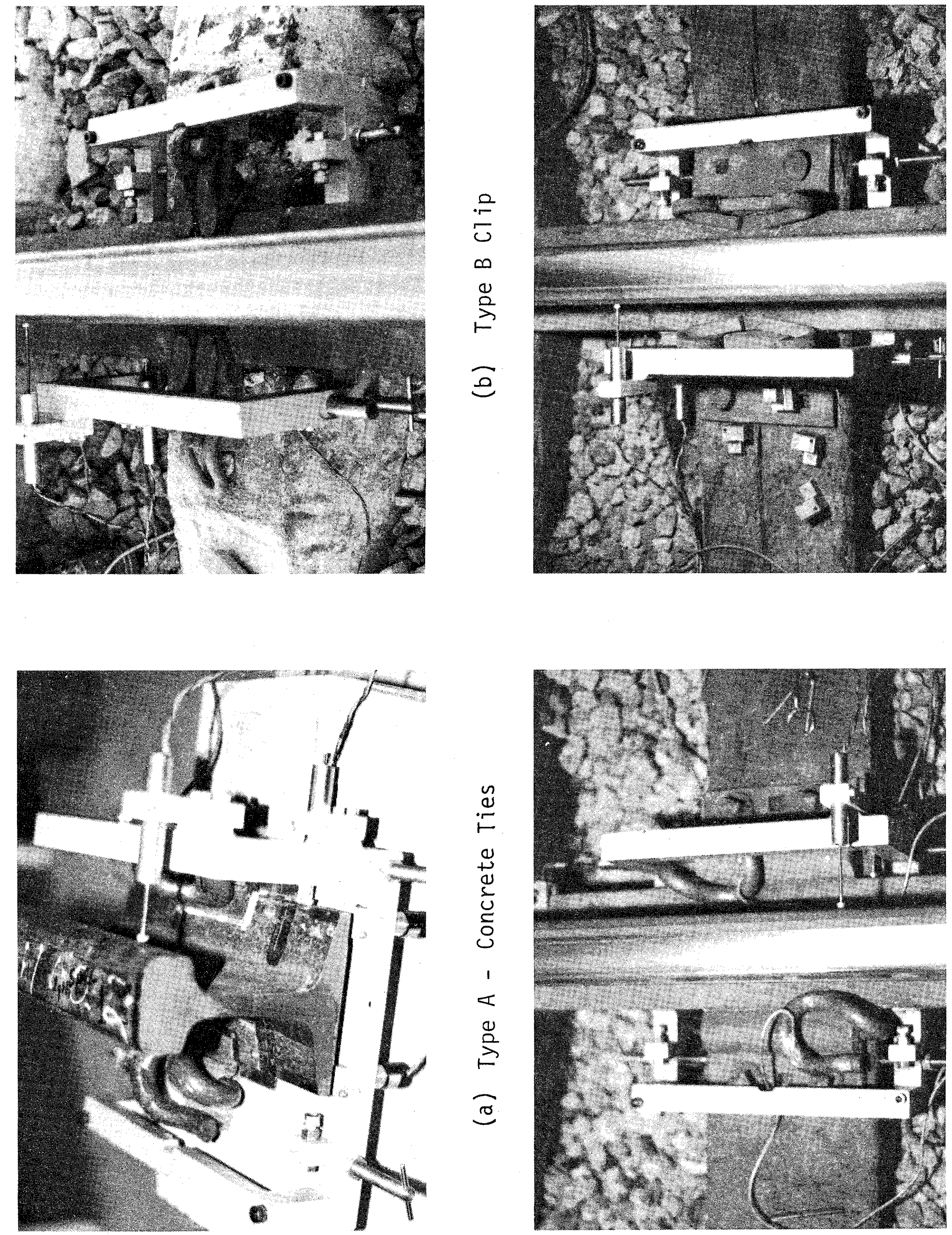
[2] Hadden, J.H., et al., Tests for the Structural Evaluation of Pandrol Rail Fasteners in Section 17 and FAST, report by Battelle-Columbus Laboratories to the Federal Railroad Administration, Contract DOT-TSC-1595, March 1980.



(a) Type A - Concrete Ties

(b) Type B Clip

(c) Type A - Wood Ties

(d) Elastic Clip-Spike

FIGURE 2. PLACEMENT OF TRANSDUCERS ON THE FOUR TYPES OF FASTENERS.

Transducers were calibrated for the following maximum physical deflections:

- Vertical and rail head lateral deflections: ±0.10"
- Rail base lateral and longitudinal deflections: ±0.05"

The instrumented clips were calibrated by shunt resistances placed across two opposite arms of the 4-arm bridge. Independent calibrations were performed for measurement of static strain due to clip installation and for dynamic strain due to train passage. This was desirable because the dynamic strain was normally only a small fraction of the installation strain. The shunt resistances, resultant bridge offset voltages, and equivalent values of linear clip strain at the gage location were:

	Shunt Resistance Across Each of 2 Arms	Bridge Response Voltage	Equivalent Clip Strain
Installation Strain	24.9 kΩ	5V	3,330 μin/in
Dynamic Strain	100 kΩ	5V	830 μin/in

A derivation of the clip strain-voltage relationships is given in appendix A.

TEST RESULTS

CLIP STRAIN DUE TO INSTALLATION

To illustrate the general level of dynamic clip strain as compared to installation strain, measurements of installation strain were made at each designated site in the Type A Clip subsections prior to the start of dynamic measurements. Table 1 presents the results of the installation strain measurements. Average levels are later compared with dynamic measurements.

TABLE 1. TYPE A CLIP INSTALLATION STRAINS.

Clip Location	Clip Type	Mean* (V)	Mean* (μin/in)	Range (% - and +)
Concrete ties, low rail	Field clip	6.47	4,310	-5, +4
	Gage clip	5.78	3,850	-9, +3
Concrete ties, high rail	Field clip	5.43	3,620	-19, +13
	Gage clip	6.00	4,000	-4 +6
Wood ties, low rail	Field clip	3.89	2,590	-9 +13
	Gage clip	3.50	2,330	-5, +5
Wood ties, high rail	Field clip	4.53	3,020	-5, +9
	Gage clip	3.42	2,280	-13, +23

*Three to five measurements were made at each tie location (IG, IF, OG, OF) within a subsection.

Note: The relationship between linear strain at the gage location and transducer voltage is $\varepsilon = 666e$, where ε = linear strain and e = transducer voltage (see appendix A). Mean linear installation strains for the two types of track were:
Concrete ties: 3,940 μin/in
Wood ties: 2,560 μin/in

DYNAMIC MEASUREMENTS

Dynamic measurements were collected during two nights of operations for at least one train run at each designated site. The test train consisted of two locomotives and twenty 100-ton cars. There were three designated tie locations per subsection. In the concrete tie section, measurements were taken on inside and outside rails for both clockwise and counterclockwise train directions. Lack of time restricted the wood tie measurements to the clockwise train direction. Excerpts from some of the more interesting results can be seen in figures 3 through 9.

Maximum clip strains and rail/tie deflections on concrete ties occurred on the low rail during counterclockwise travel (up the 2% grade) in the subsection with the hard pad. Figure 3 shows the effect of train direction; figure 4 shows typical differences between high and low rail; and figure 5 compares maximum results found on hard and soft pads. The larger deflections occurred

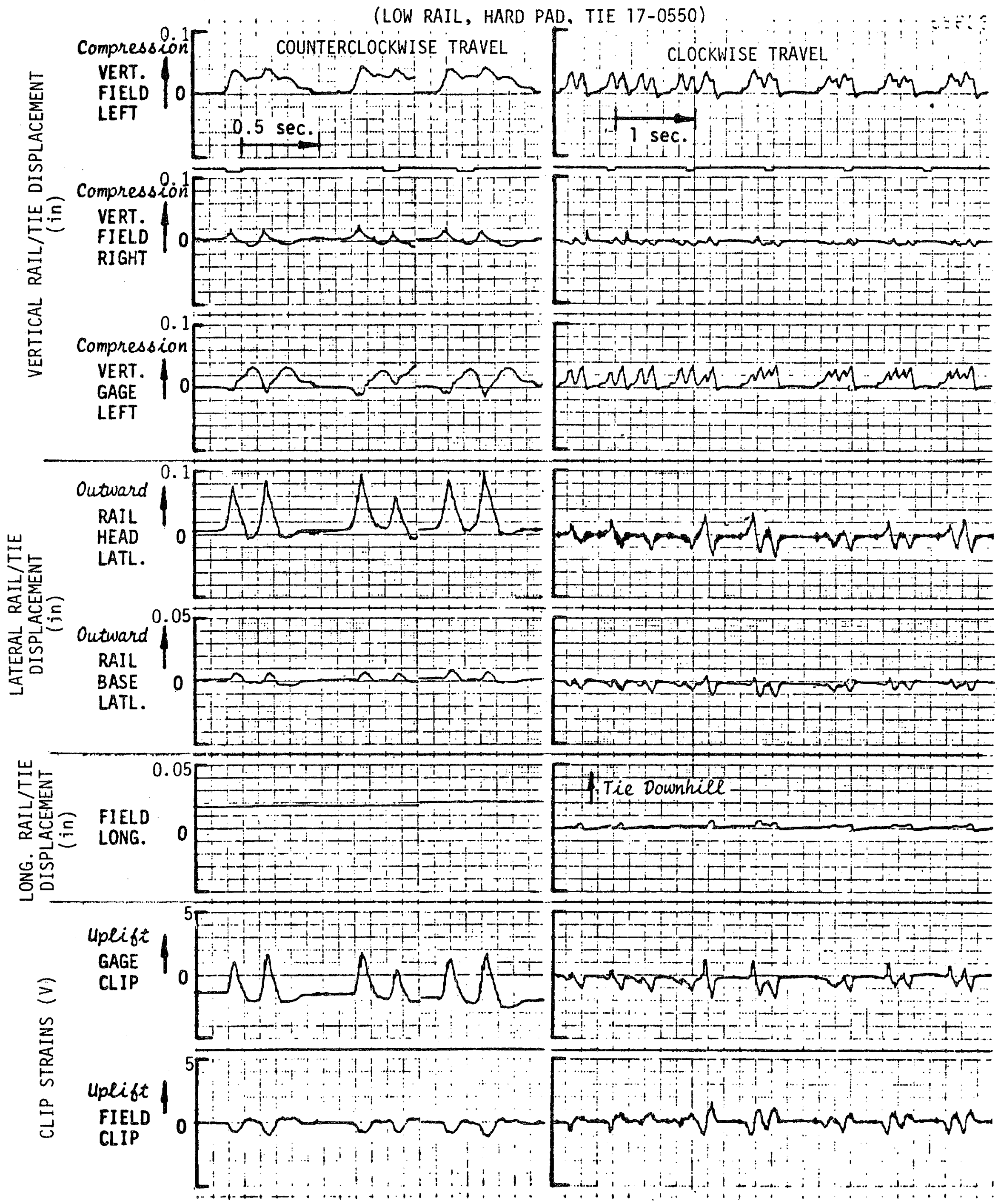


FIGURE 3. EFFECT OF CHANGE IN TRAIN DIRECTION ON MAXIMUM RAIL/TIE DEFLECTIONS FOR CONCRETE TIE TRACK.

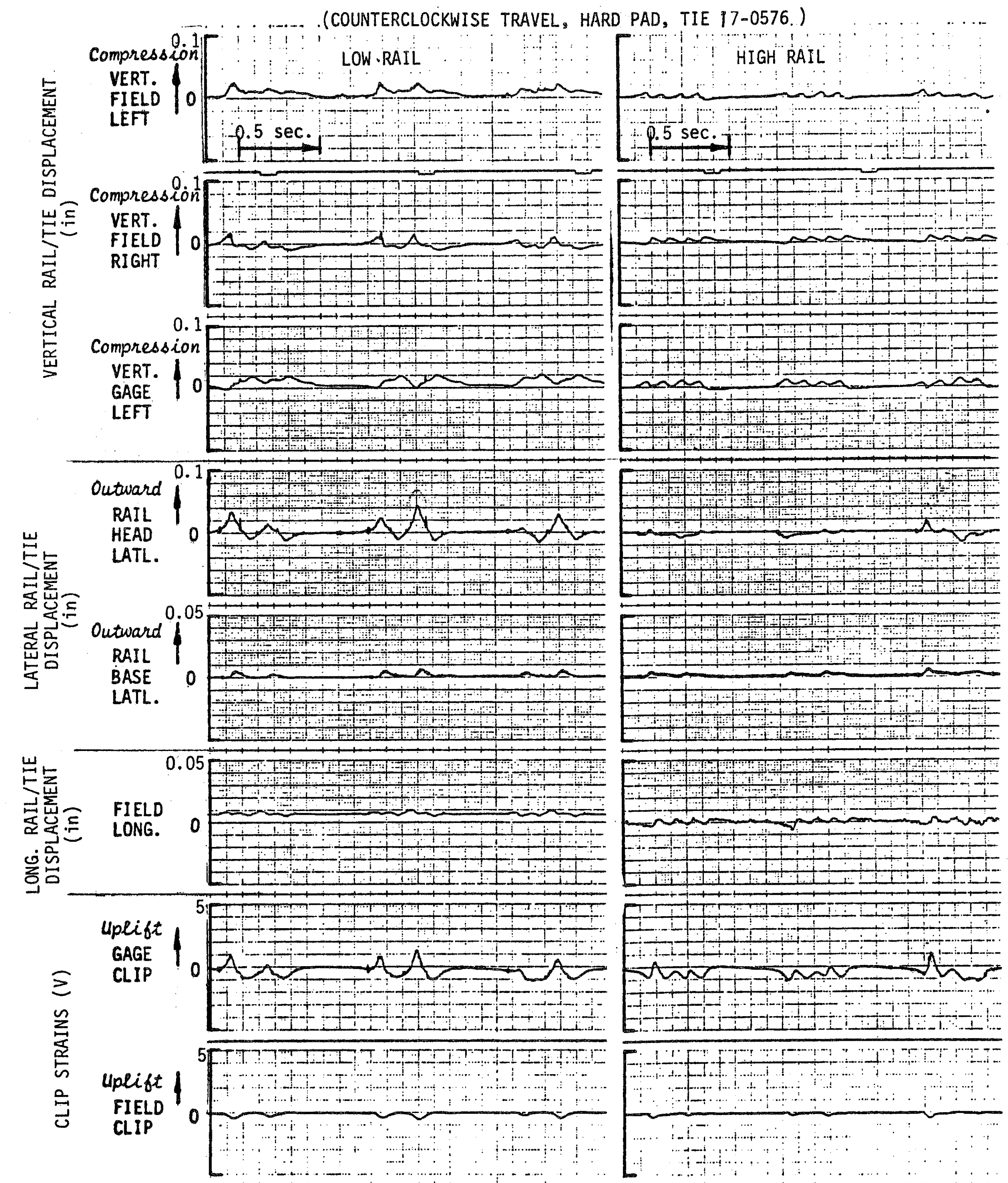


FIGURE 4. COMPARISON OF TYPICAL RESULTS FOR HIGH AND LOW RAIL ON CONCRETE TIE TRACK.

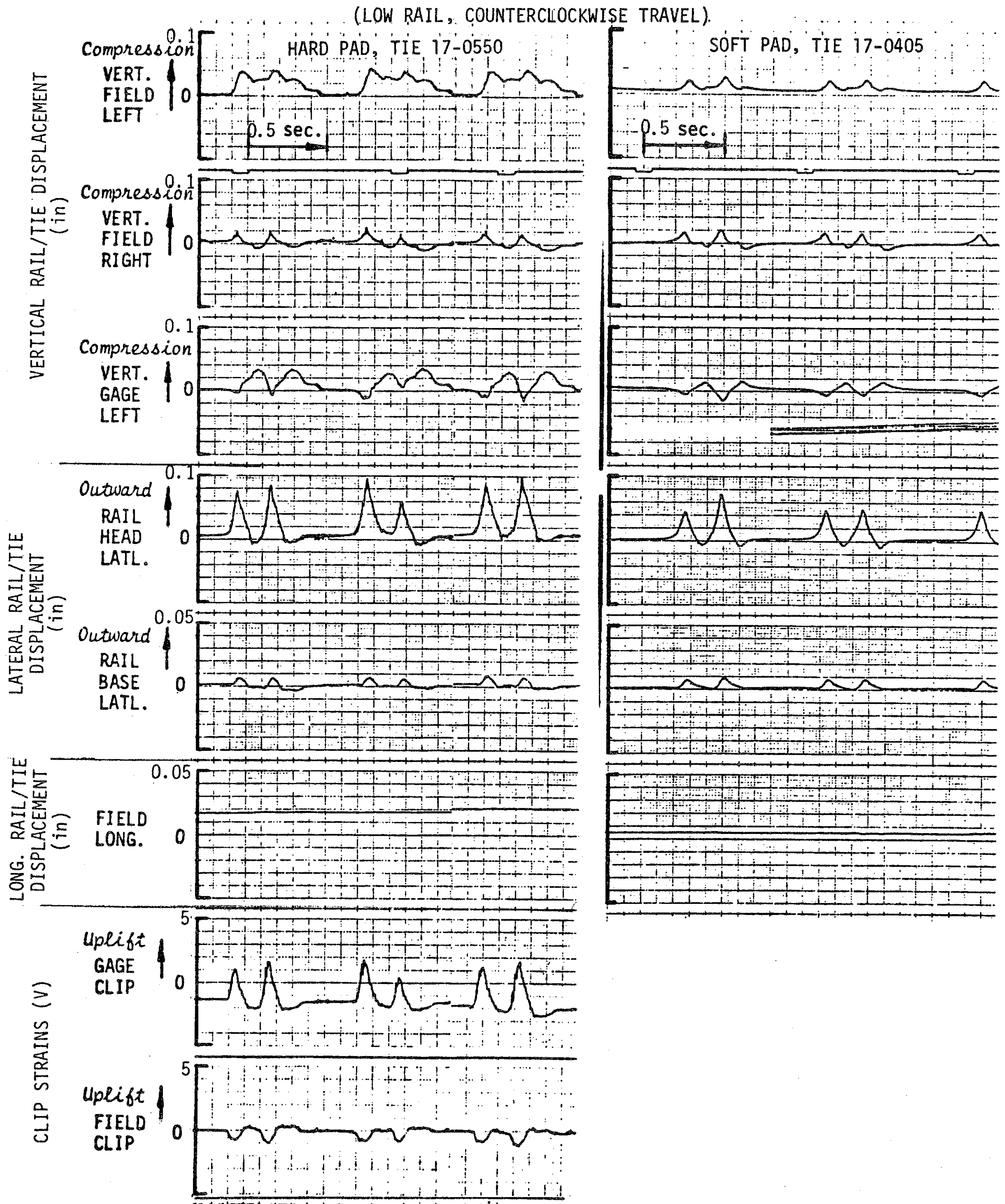


FIGURE 5. MAXIMUM RESULTS FROM HARD AND SOFT PADS ON CONCRETE TIE TRACK.

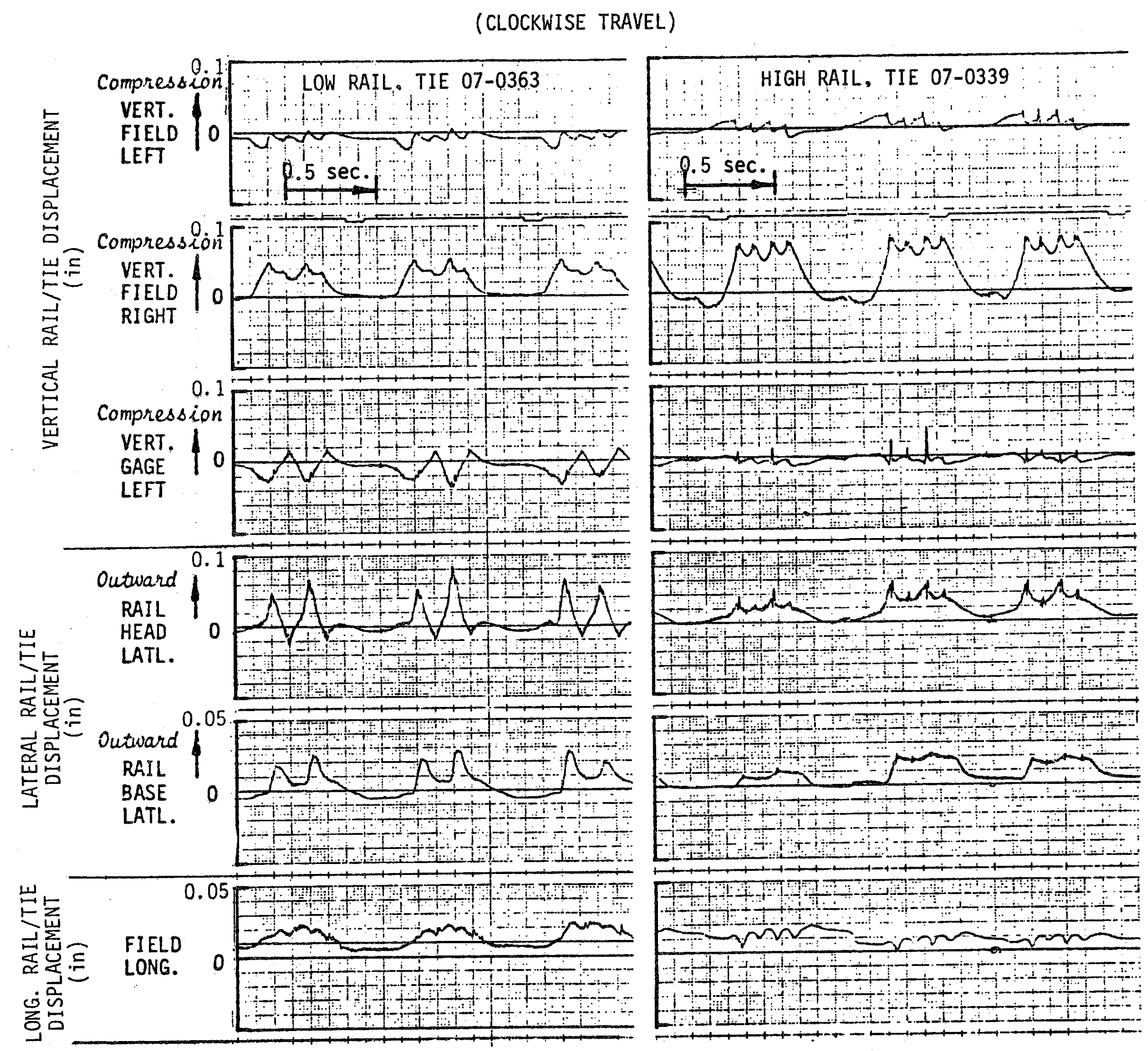


FIGURE 6. MAXIMUM RESULTS FROM MEASUREMENTS ON WOOD TIES WITH DOUBLE-SHANK ELASTIC CLIP-SPIKE.

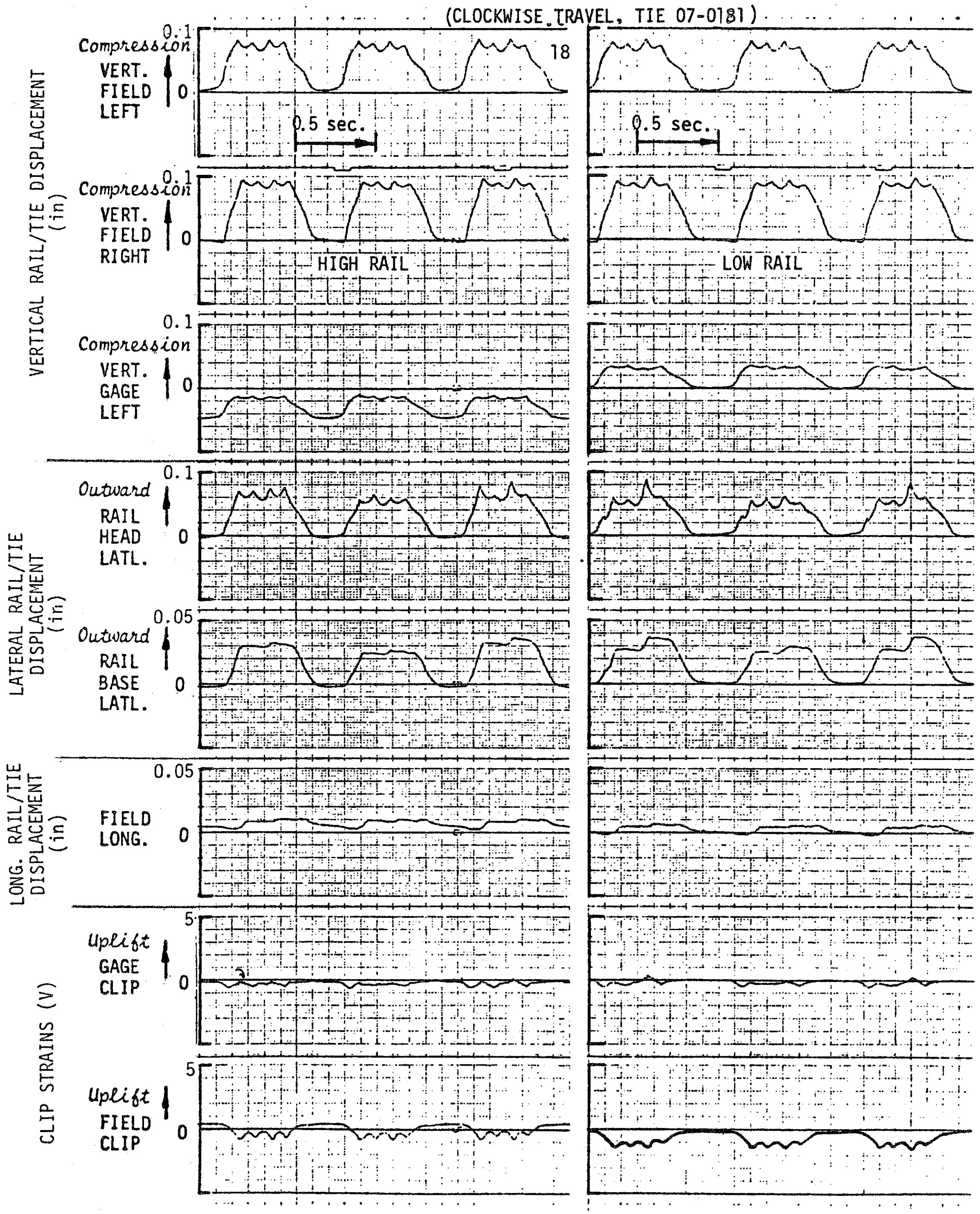


FIGURE 7. COMPARISON OF RESULTS FOR HIGH AND LOW RAILS ON WOOD TIES WITH TYPE A CLIPS.

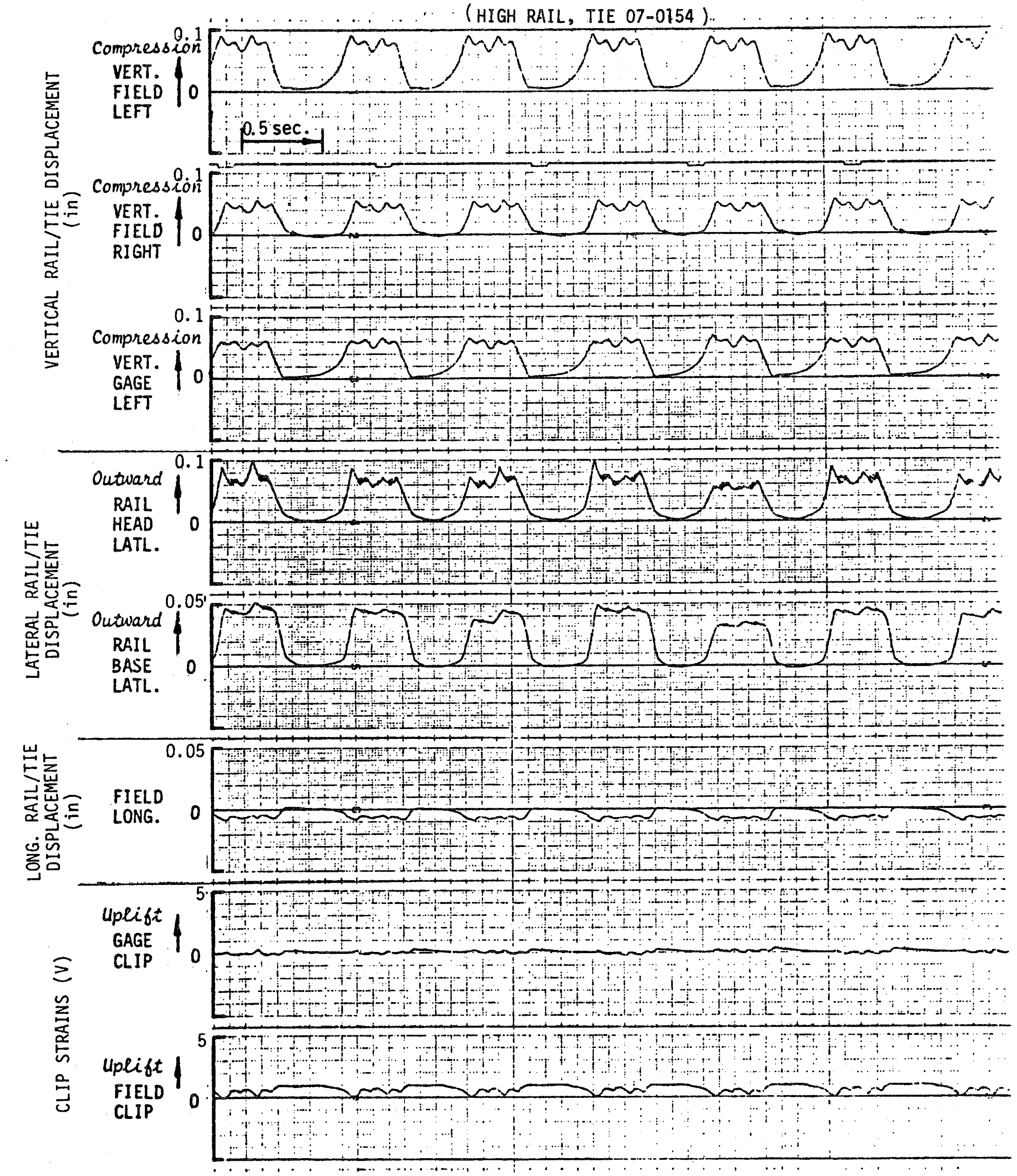


FIGURE 8. MAXIMUM RAIL/TIE DEFLECTIONS FOR WOOD TIES WITH TYPE A CLIPS.

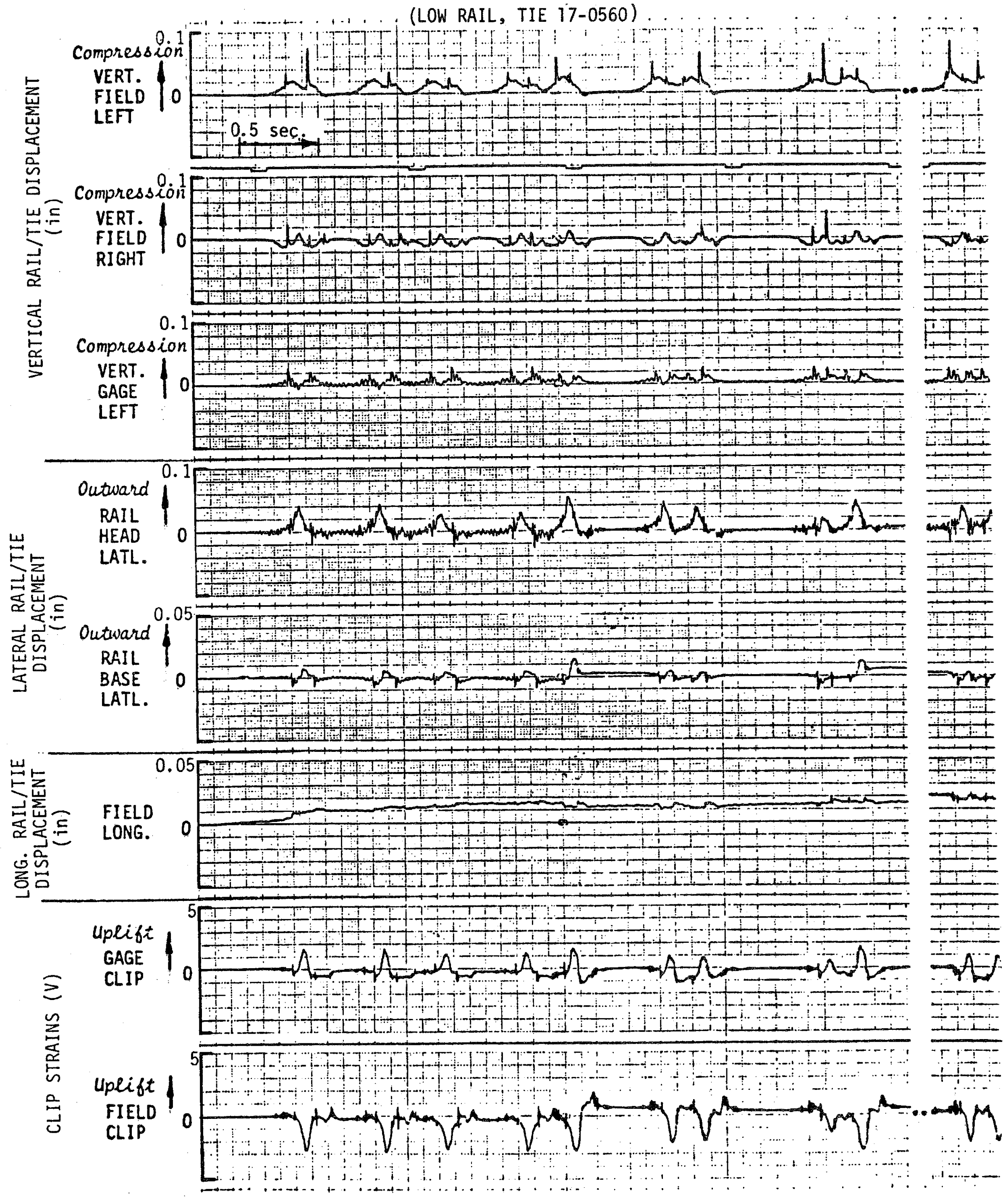


FIGURE 9. EFFECT OF BATTERED WELD ON SPRING-LOADED DISPLACEMENT TRANSDUCER.

with the hard pads. However, the latter comparison cannot be taken as an indication of the effect of pad stiffness, since so few measurements were taken in both locations. Variations in load due to position on track apparently outweighed the differences due to pad stiffness.

In most cases there was only one complete loading cycle per truck, although small blips caused by the passage of individual wheels can occasionally be seen in the vertical deflection measurements.

Figure 3 shows that, for that particular subsection and pad, in comparison to the clockwise train run, the counterclockwise run produced:

- Much higher levels of rail head lateral deflection,
- Much higher levels of gage clip strain,
- Approximately equal levels of vertical deflection, and
- Very small and approximately equal levels of rail base lateral deflection.

Therefore, most of the rail head lateral deflection took place through rail rollover.

At first glance, the data indicate an anomaly, because larger rollover/lateral deflection and gage clip strain should be accompanied by larger vertical gage deflection. The anomaly is explained by examination of the phasing of simultaneous field and gage vertical deflections. These deflections are nearly "out-of-phase" for the counterclockwise train run, and more nearly "in-phase" for the clockwise train run. Calculated clip deflections presented in the next section show an approximate correspondence between clip strain and deflection.

Unsymmetrical tie rocking, or rotation about the longitudinal axis of the tie, was prevalent during the concrete tie measurements. This is made evident by large differences in the field side vertical deflections measured at the left and right faces of the tie (figure 3). As a consequence of this rotation, the calculated clip deflections generally fall below the vertical deflections measured at the three positions shown in figure 1.

Measurements on wood ties with the double-shank elastic clip-spikes (figure 6) show high vertical rail/tie deflections at one transducer location and much lower levels at the other two locations. In both examples of figure 6, this is caused by tie rocking. In addition, the low rail example shows high rail head lateral displacement with rail rollover, and the high rail example shows lateral displacement with almost no rollover.

Levels of vertical deflection measured on wood ties with Type A clips exceeded the levels measured on concrete ties with the same fastener by about a factor of two (figures 7 and 8). In contrast, the clip strains were much lower on wood ties. This is possible because much of the vertical rail/tie deflection takes place through tie plate bending. Flexing of the tie plate, as it conforms to the irregular surface of the wood tie under compression, can be observed as the wheel passes over the tie. Plate bending was much lower with the elastic spikes, which are anchored to the tie.

Figure 9 shows data taken on the low rail of the subsection with hard pads, near a battered rail weld. The "spring-mass" frequency response of the spring-loaded vertical displacement transducers is exceeded, producing apparent deflections up to 0.080". Actual deflections were probably about 0.040".

DATA REDUCTION

The purpose of this field measurement program is to define representative, severe fastener loading environments that can be simulated in laboratory tests. The translation from field to laboratory measurements is made simple by the fact that the same deflection fixture and instrumented clips, calibrated identically, can be used in both cases. Upon verification of the data, it is only necessary to select appropriate levels of the measured variables to be reproduced under laboratory loading.

Verification of the data was undertaken by two methods:

- The rail head lateral deflection was calculated from rail base lateral deflection and the rollover obtained from field and gage vertical deflections.
- The vertical deflections at the clips were calculated from the three measured vertical deflections. Some correspondence between clip strain and deflection was expected.

Figure 10 illustrates the positive directions assumed for the measured variables and the rotations requiring calculation. For a small number of maximum response cases selected from the concrete tie data, the following calculations were performed:

Rail Rollover Angle

$$\theta x = \frac{v_{fl} - v_{gl}}{5.25}$$

Rail Head Lateral Deflection

$$l_h = l_b + 6.12\theta_x$$

Gage Clip Deflection

$$v_{gc} = v_{gl} + 0.5\ (v_{fr} - v_{fl})$$

Field Clip Deflection

$$v_{fc} = 0.5\ (v_{fl} + v_{fr})$$

Figure 11 plots measured vs. calculated rail head lateral deflection. A systematic error of about 20% can be seen, as the calculated deflections consistently underestimate the measured deflections. There are several possibilities for this error: riding up of the transducer pointer on the rail head, rotation of the displacement fixture due to tie bending, or a slight misalinement of the recorder pens. The latter would produce nonsimultaneous values in the data sets that were read from the records, and might lead to underestimation of the clip deflections. Given these possibilities for error, the degree of correlation shown in figure 11 can be judged acceptable for defining deflections and strains for laboratory tests.

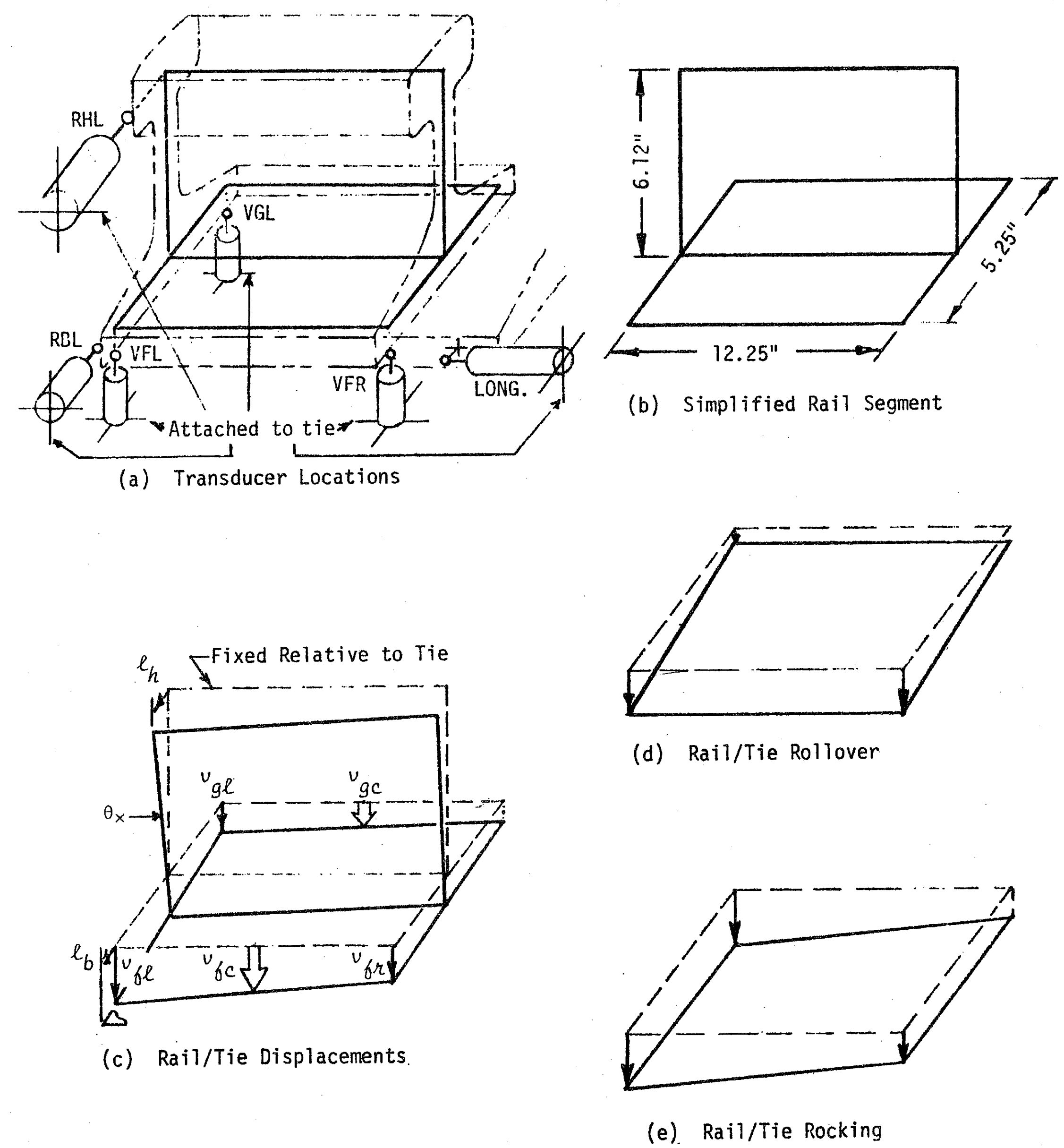


FIGURE 10. TRANSDUCER ARRANGEMENT AND RAIL/TIE DISPLACEMENTS.

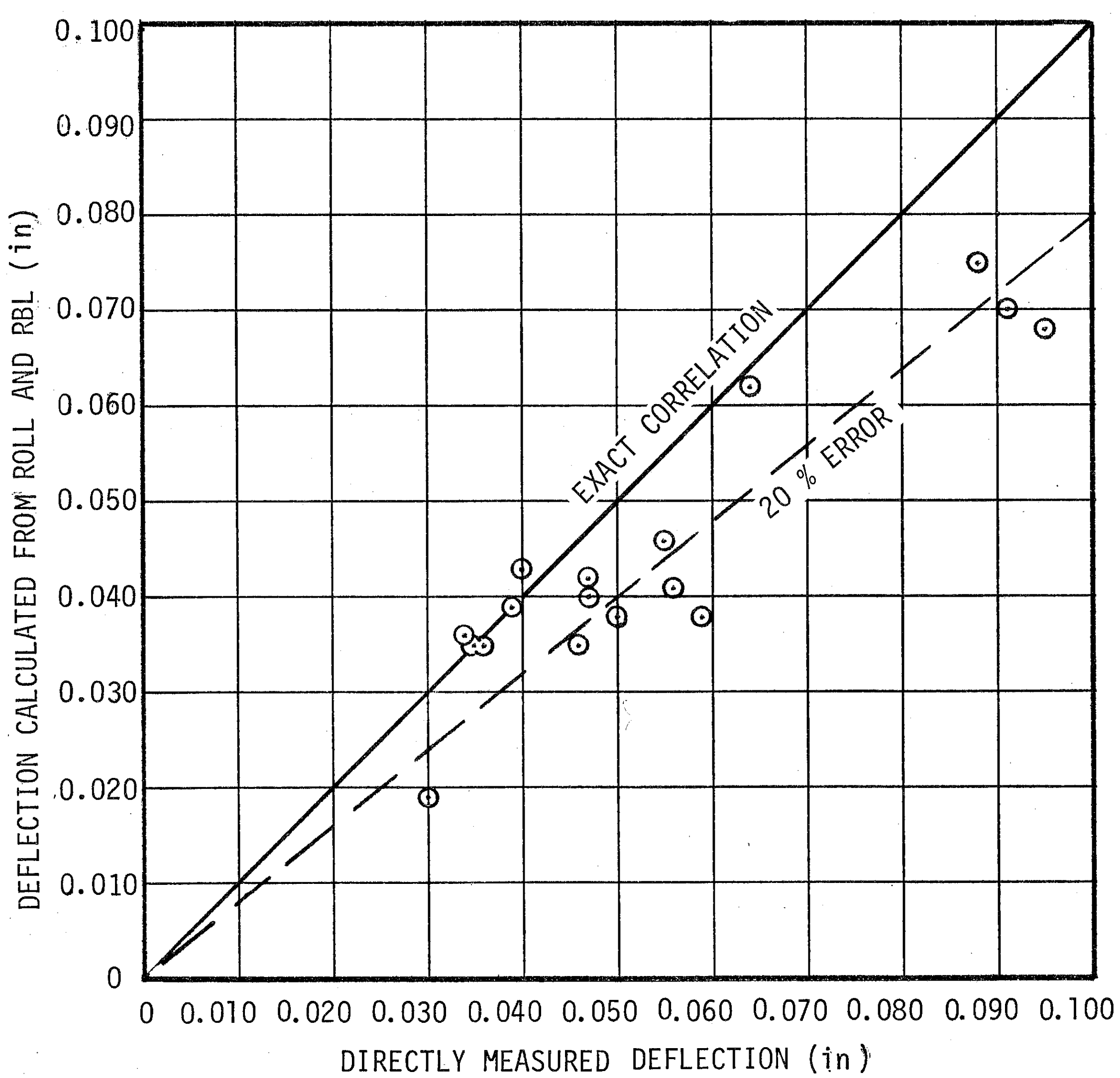


FIGURE 11. CORRELATION OF MEASURED AND CALCULATED RAIL HEAD LATERAL DEFLECTION.

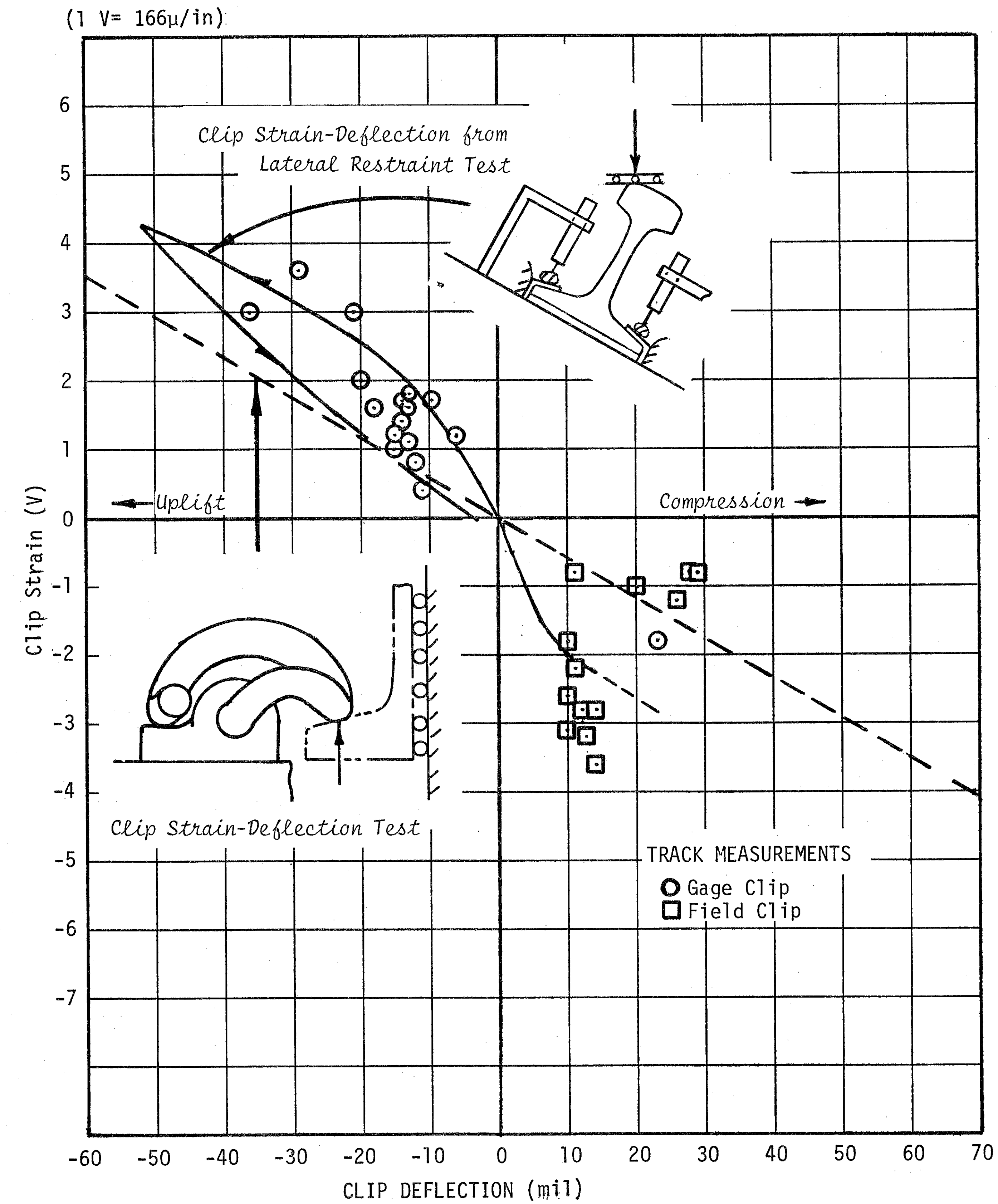


FIGURE 12. VERTICAL CLIP DEFLECTION VS CLIP STRAIN FROM TRACK MEASUREMENTS AND TWO LABORATORY TESTS.

Figure 12 plots the calculated clip deflections vs. clip strain expressed in volts of strain gage bridge output. The equivalences of strain and voltage are stated on the figure and derived in appendix A. Also shown on the figure are the strain-deflection characteristics obtained in the following two laboratory tests:

- Vertical clip strain-deflection. Each clip was inserted individually into a special fixture and subjected only to vertical load. Beginning with a static load of 1,700 lb, the clip was cycled between 1,400 and 2,000 lb. The result was a linear and repeatable strain-deflection characteristic that does not agree well with the field results.

- Simulated track loading. A rail segment and fastener system were subjected to vertical loading with the test specimen mounted at lateral/vertical angles from 25° to 30°. A reasonably complete strain-deflection cycle was obtained for the gage clip, and the results were much closer to the track data than the results from the vertical load test were. A complete characteristic was not obtained for the field clip within a vertical load of 40,000 lb. However, the portion of the characteristic obtained indicates approximately the same strain-deflection behavior as that for the gage clip.

The lack of correspondence of the vertical clip strain-deflection test with either the field data or the simulated track loading indicates that the clips in track receive strain from sources independent of vertical deflection. Possible sources of additional clip strain include longitudinal rail/tie deflection, climbing of the clip on the rail base from lateral deflection and rail rollover, and shift of the clip support point at its flattened toe. The latter could be caused by tie rocking and rail rollover.

The levels of strain found in the field exceed the clip fatigue limit identified by the manufacturer.[2] In tests under vertical load only, the clips did not fail under dynamic deflections of 0.050" (over nominal static load), but failed in less than 1 million cycles with dynamic deflections of 0.060". Therefore, a clip fatigue limit exists at strain levels produced by purely vertical deflections between 0.050" and 0.060". To reproduce the strain levels found in the track, vertical deflections up to 0.062" were required in the laboratory fixture.

Many of the Type A clips have failed in the concrete tie 5° curve of the FAST track. Most of the failures have occurred at the inside-gage location on the tie, and at either of two positions on the clip, as shown in figure 13. The position marked "S" is the approximate location of maximum strain, while the position marked "L" is the location used for the field measurements. The peak dynamic strain, the range of strain (+ to -), and the mean strain due to installation at position "L" can be compared as follows:

	Fastener Clip Strains, μin/in		
	Peak Dynamic Strain	Dynamic Strain Range, + to -	Mean Installation Strain
Concrete Ties	600	650	3,940
Wood Ties	250	280	2,560

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2 Hadden, et al., op. cit.

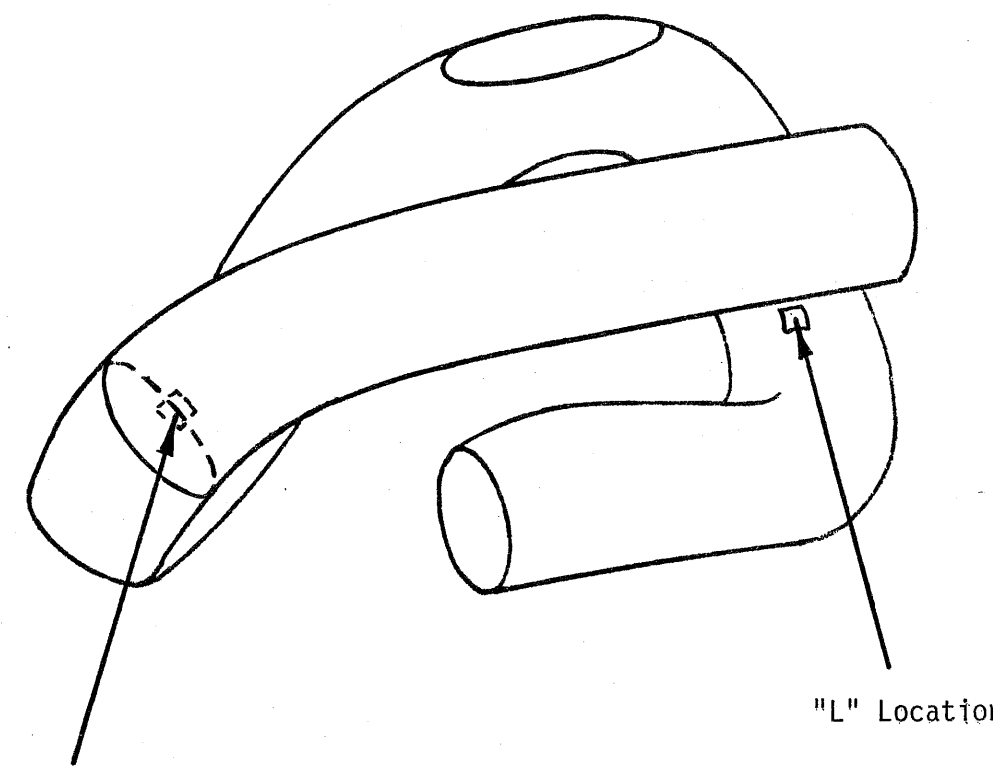

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FIGURE 13. APPROXIMATE LOCATIONS OF BIAXIAL STRAIN GAGE PAIRS ON INSTRUMENTED CLIPS.

DEFLECTION AND STRAINS FOR LABORATORY TEST

The final products of this measurement program are sets of deflections and strains that will subject the fastener systems to realistic loading environments when applied in the laboratory. To define appropriate levels, it is necessary to recognize the limitations under which these measurements were made. Perhaps the most important limitation was the shortness of the test train (2 locomotives, 20 cars). The full FAST consist produces high draft loads in the 5^{o} curve and 2% grade of the concrete tie Section 17. There is evidence from earlier fastener measurements[2] that a short consist does not produce equivalent draft loads in this segment of combined curve and grade.

In spite of the limitations of the measurement program, it is reasonable to assume that any level of deflection or strain found in these measurements will occur often under normal FAST operations. Therefore, the levels defined in table 2 represent envelopes over the maximum values found in the measurements. Separate envelopes are defined for the wood and concrete tie fastener systems, and they apply only to fasteners with elastic clips. The deflections and strains defined in table 2 will be reproduced in laboratory fixtures to define fastener fatigue loads.

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2 Hadden, et al., op. cit.

TABLE 2. DEFLECTIONS AND STRAINS FOR LABORATORY TESTS OF FASTENERS WITH ELASTIC CLIPS.

Rail Tie Deflections	Concrete Tie Fasteners (in)	Wood Tie Fasteners (in)
Vertical deflections at clips (field side compression or gage side uplift)	0.040	*
Nonsymmetrical vertical deflections		
Left side of tie** (field compression or gage uplift)	0.020	0.050
Right side of tie (field compression or gage uplift)	0.060	0.100
Rail head lateral deflection	0.10 outward	0.10 outward
Rail base lateral deflection (after initial load cycle)	0 - 0.02 outward	0.10 outward
Longitudinal deflection	0.005	0.01
Type A Clip Strain* **	(V)	(V)
Peak strains		
Gage clip (uplift)	3.6 (600 $\mu\varepsilon$)	1.5 (250 $\mu\varepsilon$)
Field clip (compression)	3.6 (600 $\mu\varepsilon$)	1.5 (250 $\mu\varepsilon$)
Range of strains		
Gage clip (+ to -)	3.9 (650 $\mu\varepsilon$)	1.7 (280 $\mu\varepsilon$)
Field clip (+ to -)	3.9 (650 $\mu\varepsilon$)	1.7 (280 $\mu\varepsilon$)

* Clip deflections were not definable from the tests due to plate bending. Clip strain data will be used instead.

** The designations left and right are interchangeable.

*** At position "L", figure 13.

SUMMARY OF RESULTS

Fastener clip strain-deflection relationships were obtained from field measurements and from two laboratory test methods. The second laboratory method showed an approximate correspondence with the field data, but the first method did not. To produce the maximum levels of clip strain found in the field, the following vertical rail/tie deflections were required.

	Vertical Deflection At Maximum Clip Strain (in)
Field Measurements	0.029 - 0.037
Lab Method 1 (vertical clip loading)	0.062
Lab Method 2 (simulated track loading)	0.038

Dynamic clip strains were measured at one of the two locations on the clip where fractures have occurred in service. This was not the location of maximum clip strain. Maximum values found at the measurement location were about 600 in/in for either uplift of the gage clip or compression of the field clip on the low rail in the concrete tie section.

The maximum dynamic clip strains found in the track data exceeded the fatigue limit identified by the clip manufacturer. This fatigue limit occurred at dynamic vertical clip deflections between 0.050" and 0.060" in tests similar to the first method discussed previously. The reproduction of maximum dynamic strains found in the field required 0.062" of deflection in the laboratory test by this method.

Rail head-to-tie lateral deflections approached, but did not exceed, 0.10" on both wood and concrete tie track.

Nonsymmetrical rocking of the tie about its longitudinal axis could be observed in a majority of the measurements on concrete tie track. Vertical rail/tie deflections measured at opposite faces of the tie were, in many cases, very large at one face (up to 0.058") and very small at the other face, often within ±0.006".

Small but consistent longitudinal rail-to-tie deflections up to 0.005" were measured.

In contrast to the expected result, maximum rail-to-tie deflections for concrete tie track were found in a subsection containing hard pads rather than in a subsection containing soft pads. Maximum deflections on the hard pads exceeded those on the soft pads by about 30%. However, much of this difference may have been caused by variations in loading due to location on the track.

Measurements on wood tie fasteners showed evidence of tie plate bending. Where the clip was anchored to the tie plate, most of the vertical rail/tie deflection occurred through plate bending rather than through flexing of the clips. Although the clip of the second wood tie fastener was anchored to the tie, bending under compression could be observed in both systems as the tie plates conformed to the irregular tie surfaces.

CONCLUSIONS

This approach to measurement of rail-to-tie deflections and fastener clip strains is adequate for defining the fastener loading environment. However, several factors limited the effectiveness of the effort:

- Measurement accuracy would have been improved by direct measurement of clip deflections rather than by the indirect method used.
- The test sites and train directions were severely limited in number by reducing the nights of testing from four to two.
- The 20-car test train probably produced lower loads on the 5^0 curve and 2% grade of Section 17 than the full FAST train consist produces.

Fastener loading environments are characterized separately for wood and concrete tie track by the definition of conservative envelopes over the maximum deflections and strains found in track. In spite of the limitations of the test program, it is reasonable to assume that any response found during this test program will occur repeatedly in normal operations. Therefore, the definition of conservative envelopes is appropriate.

Fastener clips installed in track receive strain from sources independent of vertical deflection. The simple vertical flexure of a clip in a laboratory fixture requires about 50% greater deflection to reproduce the levels of strain found at maximum deflections in the field or in a laboratory fixture that simulates field loading. The laboratory tests indicate that a significant component of the clip strain is produced by lateral loading. Other possible sources of additional strain include longitudinal rail/tie motions and the shift of the clip support point at its flattened toe due to tie rocking and rail rollover.

APPENDIX A

STRAIN-VOLTAGE RELATIONSHIP OF INSTRUMENTED CLIPS

Figure A-1 shows the schematic of the 4-arm bridge containing two active gages and two completion resistors. Changes in resistance of the active gages produce response voltage e_o according to the equation,

$$\frac{e_o}{e} = \frac{1}{4}\ \frac{\Delta R_1^*}{R} - \frac{\Delta R_2}{R} \qquad \text{(A-1)}$$

where,

e_o = output voltage
e = input voltage
R = resistance.

The linear strain at each gage is related to the fractional change in resistance of the gage by,

$$\frac{\Delta R_1}{R} = GF\ \ 1,\ \frac{\Delta R_2}{R} = GF\ \varepsilon_2 \qquad \text{(A-2)}$$

where,

ε_1 = linear strain at Gage 1
ε_2 = linear strain at Gage 2.

A ratio between ε_1 and ε_2 was established in laboratory tests conducted in preparation for the field measurements described by Hadden, et al.[1] For biaxial gages placed at the position indicated in figure A-1, it was consistently found that,

$$\varepsilon_2 = -0.44\ \varepsilon_1. \qquad \text{(A-3)}$$

Thus an effective Poisson ratio of 0.44 was found. Substitution of equations A-2 and A-3 into equation A-1 yields,

$$\frac{e_o}{e} = \frac{GF}{4}\ (1.44)\ \varepsilon_1. \qquad \text{(A-4)}$$

Shunt resistance, R_c, placed across two opposite arms of the bridge will produce the following ratio of response to excitation voltage:

$$\frac{e_o}{e} = \frac{1}{2}\ \frac{R}{R + R_c}.$$

-----

* R = 120Ω, nominal for all arms of bridge.

[1] Hadden, J.H., et al., Tests for the Structural Evaluation of Pandrol Rail Fasteners in Section 17 and FAST, Report by Battelle-Columbus Laboratories to the Federal Railroad Administration, Contract DOT-TSC-1595, March 1980.

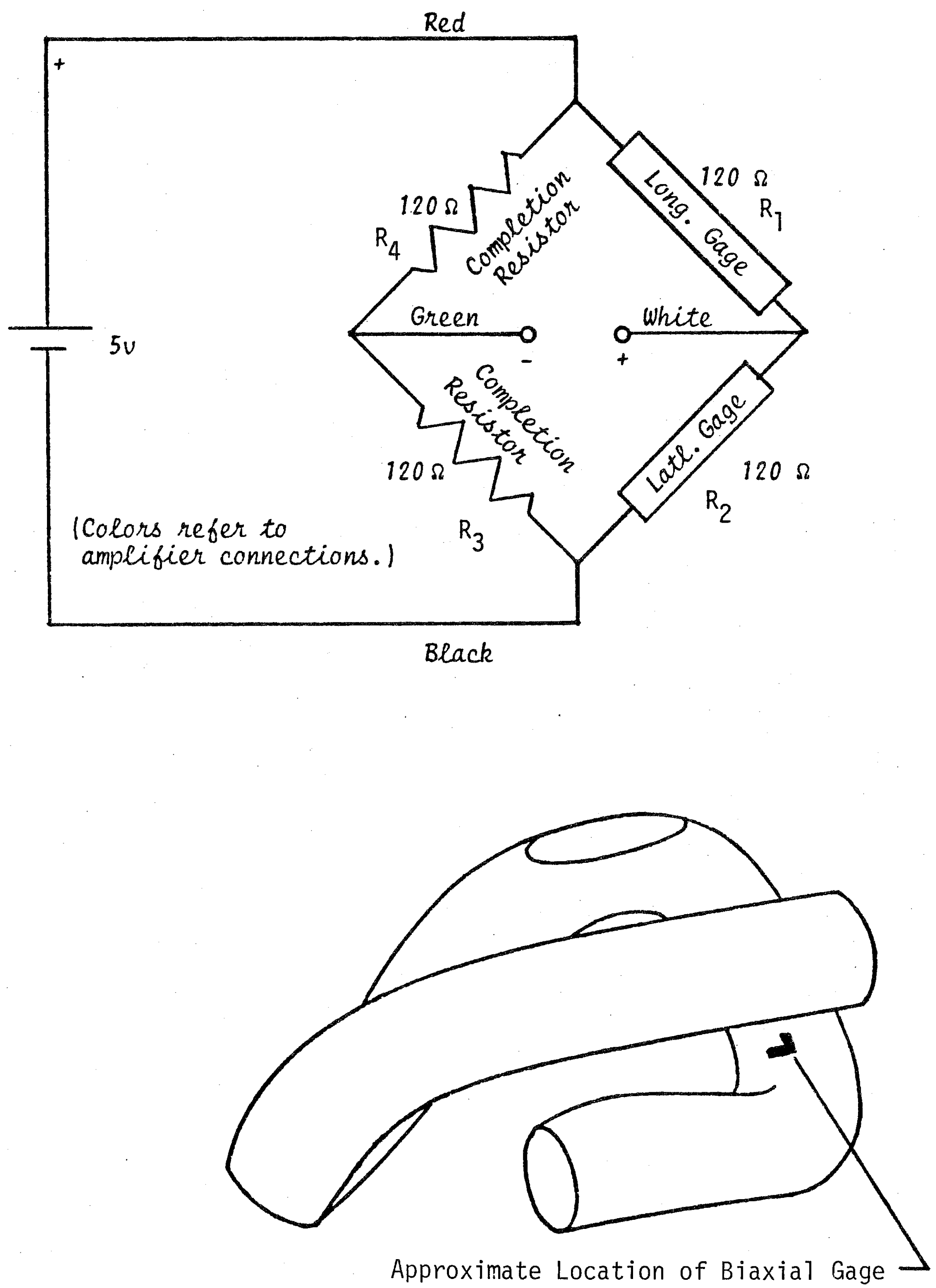

FIGURE A-1. SCHEMATIC OF TYPE A CLIP INSTRUMENTATION.

Amplification of e_o yields,

$$\frac{E_o}{e} = K \frac{e_o}{e} = \frac{K}{2} \frac{R}{R + R_c} \qquad \text{(A-5)}$$

where,

E_o = amplified output
K = gain factor.

Because the installation strain and dynamic strain were of such different magnitudes, two separate shunt resistances were used. To determine K in each case, the amplification was adjusted so that,

$$\frac{E_o}{e} = \frac{5}{5} = 1.$$

Then the two amplification factors were determined as follows:

a. Installation Strain: R_c = 24,900

$$K_{inst.} = \frac{2(120 + 24,900)}{120} = 417.$$

b. Dynamic Strain: R_c = 100,000

$$K_{dyn} = \frac{2(120 + 100,000)}{120} = 1,670.$$

Finally, the linear strain at Gage 1 can be expressed in terms of output voltage as,

$$\varepsilon_1 = \frac{4}{K\ GF\ (1.44)\ e} E_o$$

a. Installation Strain:

$$\varepsilon_1 = \frac{4}{(417)(2)(1.44)(5)} E_o = 0.000666\ E_o\ \text{(in/in)}$$
$$= 666\ E_o\ (\mu\text{in/in}).$$

b. Dynamic Strain:

$$\varepsilon_1 = \frac{4}{(1,670)(2)(1.44)(5)} E_o = 0.000166\ E_o\ \text{(in/in)}$$
$$= 166\ E_o\ (\mu\text{in/in}).$$

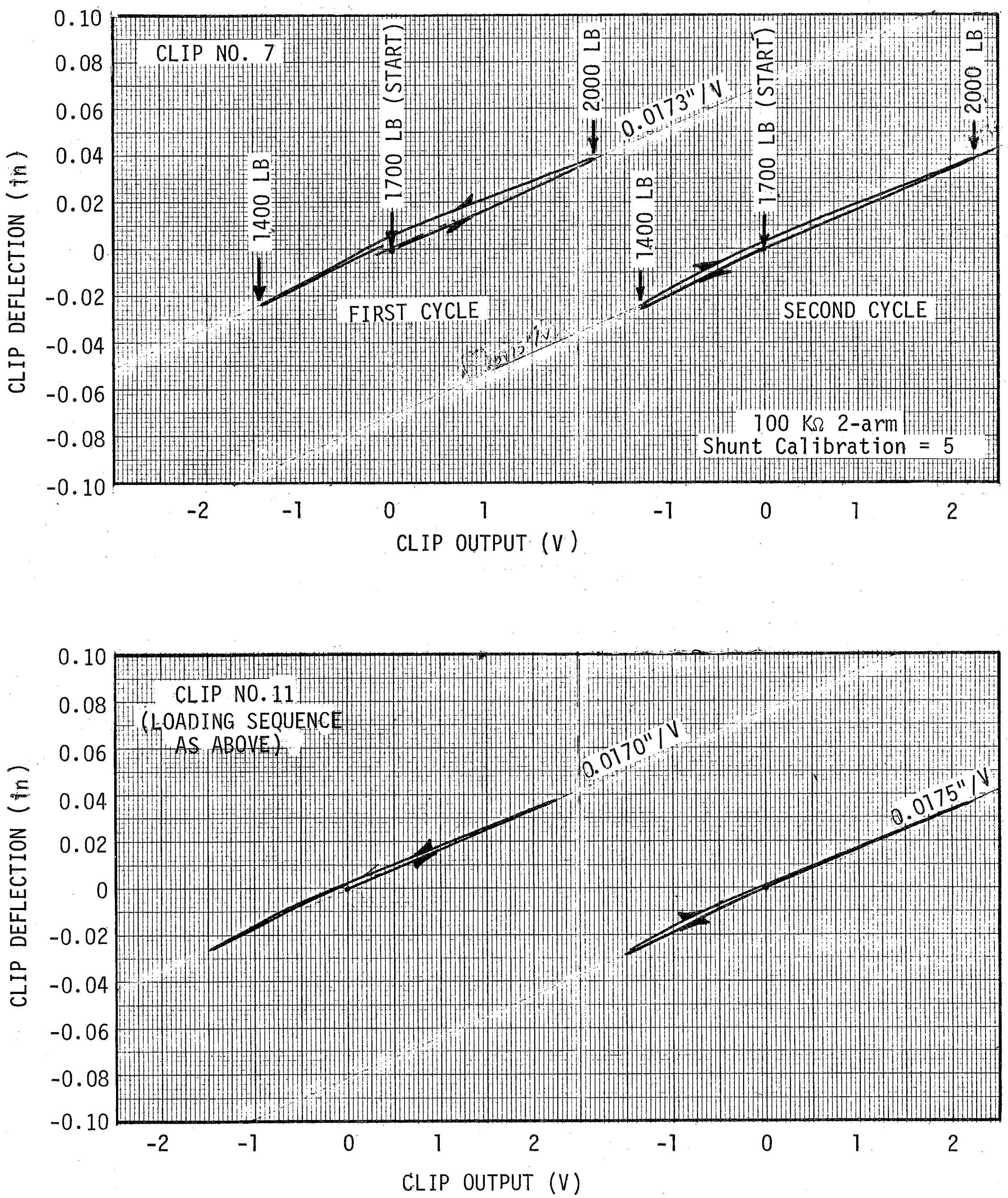

FIGURE A-2. MEASUREMENT OF CLIP RESPONSE VOLTAGE VS. DEFLECTION IN LABORATORY FIXTURE.

To determine the relationship between strain gage bridge output and vertical clip deflection, the clips were subjected to the laboratory tests illustrated in figure A-2. An arbitrary strain "zero" was established with a vertical clip load of 1,700 lb. The load was then cycled between 1,400 lb and 2,000 lb. The slope of the curve of strain (V) vs. deflection (in) was reasonably linear and very consistent, as shown in the figure. The mean slope of the two clips illustrated is 0.0173", when the clips are given shunt calibrations equivalent to those applied for dynamic measurements in the field.