Engineering

FAST INSTRUMENTED CROSSTIES

Background

1. In the spring of 1976 the Department of Transportation (DOT) Federal Railway Administration (FRA) was engaged in final planning for a major field test at the Transportation Test Center (TTC) near Pueblo, Colorado. The test program will be carried out on the TTC Facility for Accelerated Service Testing (FAST), a 4.8 mile loop comprised of various conventional track support systems. During each day of operations, approximately 1.0 million gross tons (MGT) of captive train traffic will be applied to the FAST. Test items will include a variety of track support equipment and hardware; performance of the various test items will be monitored at specified intervals in the testing cycle. This effort may be of up to one year duration.

2. The DOT/FRA requested Waterways Experiment Station (WES) support for one phase of the test program in June 1976. This support, which initially involved only tie instrumentation, was later expanded to include calibration of ten concrete crossties to be installed in the FAST system. Time limitations were a paramount WES concern, since the FAST testing was scheduled to commence in August 1976.

Purpose

3. The WES instrumented and calibrated ties were to be used to determine crosstie response to train loadings on both curved and tangent track sections. Specifically, the DOT/FRA desired to determine the maximum bending moments occuring at the center and railseats of the Conforce Costain type 244-C ties. These measurements are critical since premature tie failure could result if service stresses exceed design limits.

Scope

4. The WES was requested to instrument and calibrate ten Conforce Constain concrete crossties to specifications furnished by the MITRE Corp., McLean, Virginia, who was designated as the DOT/FRA project manager. Data acquisition and reduction would be accomplished by others. This report will detail the WES design, fabrication and calibration procedures developed for this special application.

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tie but on opposite vertical faces, provide a temperature compensated full bridge using four active gages. Signal output from this arrangement is (nominally) proportional to strain in a horizontal plane through the two horizontal gages on opposite faces of the tie. All horizontal and vertical gages were of 2-in. gage length except in the center of the tie. Because of space limitations at the center of tie, gage arrays at that location were installed using 1-in.-long vertical gages. Gage length is always an important consideration, and is particularly so in this instance because concrete is a relatively nonhomogeneous material and aggregate size is a primary factor in determining adequate gage length. While 2-in.-long gages were preferred for this application, no adverse effects were detected from substituting gages (vertical, center of tie) of 1-in. gage length. This determination was based on direct comparisons of signal output from 1- and 2-in. length gages mounted on the same tie.

9. MITRE specifications for laboratory load calibration of the ties required that WES apply pure bending moments at the gage locations. Hence, stress-strain relationships derived in this way could only be accurate for pure bending conditions. However, the WES was concerned that these results could not be directly related to results obtained in the field since field loadings would be applied through the rail seat whereas laboratory load test geometry would be entirely different. WES concerns in this matter were discussed with MITRE prior to and during calibration testing and were later transmitted in an informal note to the DOT on 22 October 1976. Prior to gaging the ties, it was concluded that field loading would produce stress gradients under the rail seat which might drastically affect the response of gage arrays located just beneath the rail seat. To minimize this effect, it was agreed by all parties that the vertical gages of the Poisson gage pairs would be offset to the inside of the tie, and would be located just inside a line drawn at a 45 deg angle from the inside of the rail seat to the bottom of the tie. In this way, it was hoped to avoid most of the influence of the stress gradients believed to occur under the rail seat. Lacking time for further analysis and/or testing, the first eight (replicate) ties were gaged and tested with the results described in Incl 1. At the time the first eight ties were completed, the WES recommended that a further series of tests be conducted to define, if possible, the actual relationship between field and laboratory test results. In this way the FAST data acquisition phase could proceed as planned but the final results could be refined during the data reduction phase to follow. A reconciliation of field and laboratory test results is included in the analysis section of this report.

10. The problem of protecting the gage arrays and wiring for long periods of time, in a hostile environment, was also addressed. A number of protective measures, i.e., tubing, protective metal shields, etc., were considered but were discarded for various reasons. A viable approach was finally developed from WES experience in protecting strain gages applied to steel piles, which were later hammer driven to depths of 60 or more feet. In this earlier WES study, epoxy protected gages survived for several years of vibratory testing with no problems of any sort. After

successful preliminary tests on small concrete cylinders, epoxy protection was adapted for use on the FAST crossties. A cross section through a typical as built gage installation is shown in Figure 1. Leadout wires from the gage arrays were brought out to epoxy protected terminal strips atop the ties; wiring runs from the ties to the cable tunnels beside the track were also protected with heavy sleeving and a one foot depth of burial in the ballast, upon installation in the FAST track.

11. The application of strain gages to the concrete ties posed one problem whose magnitude had not been expected. It had been assumed that the ties would have some surface defects which would require filling before gages could be installed. As it turned out, this was a classic understatement of the actual fact since a myraid of small voids, and some rather extensive voids, were encountered at each gage location. An illustration of this problem is shown in the photograph in Figure 2. Each gage location had to be tapped lightly with a small hammer to break down the surface voids so they could be filled. After the tie surface was filled and sanded, to facilitate gage bonding and to prevent mositure seepage from the tie to the gage, the gage was cemented in place. A heavy coat of moisture sealer was next applied over the gages and wiring terminals, and a 1/4-in.-thick protective coat of Colma Dur epoxy was then poured within a small cofferdam to encapsulate the gages and wiring. This completed the typical gage installation, as shown in Figure 1.

12. As mentioned previously, the eight replicate ties were prepared and delivered to the FAST in September 1976; the remaining two (MITRE multi-gage) ties were specially instrumented and tested under MITRE supervision. These ties were delivered and installed in the FAST in October 1976. Details of the gage installations and calibration test results for these two ties are shown in Incl 2.

13. After installation of the ten instrumented ties at FAST, the DOT requested further WES testing. Originally, twelve ties had been shipped to WES so two spare ties (one of which had been broken) were available for testing. The DOT and WES agreed that the final loading tests should be devised to simulate field conditions. Accordingly, two simulated service loading tests on the intact tie, as well as other tests on the broken tie to determine the physical properties of the concrete, were conducted at WES. Results of this testing are shown in Incl 3.

Analysis of Tie Response

Initial calibrations

14. Results of the WES calibration tests have already been summarized by MITRE and, in the interest of brevity, will not be reproduced herein. However, it is known that minor irregularities in the WES calibration test geometry did affect some of the rail seat strain measurements on the eight replicate ties. The typical load geometry used for rail seat testing on the replicate ties was as shown;

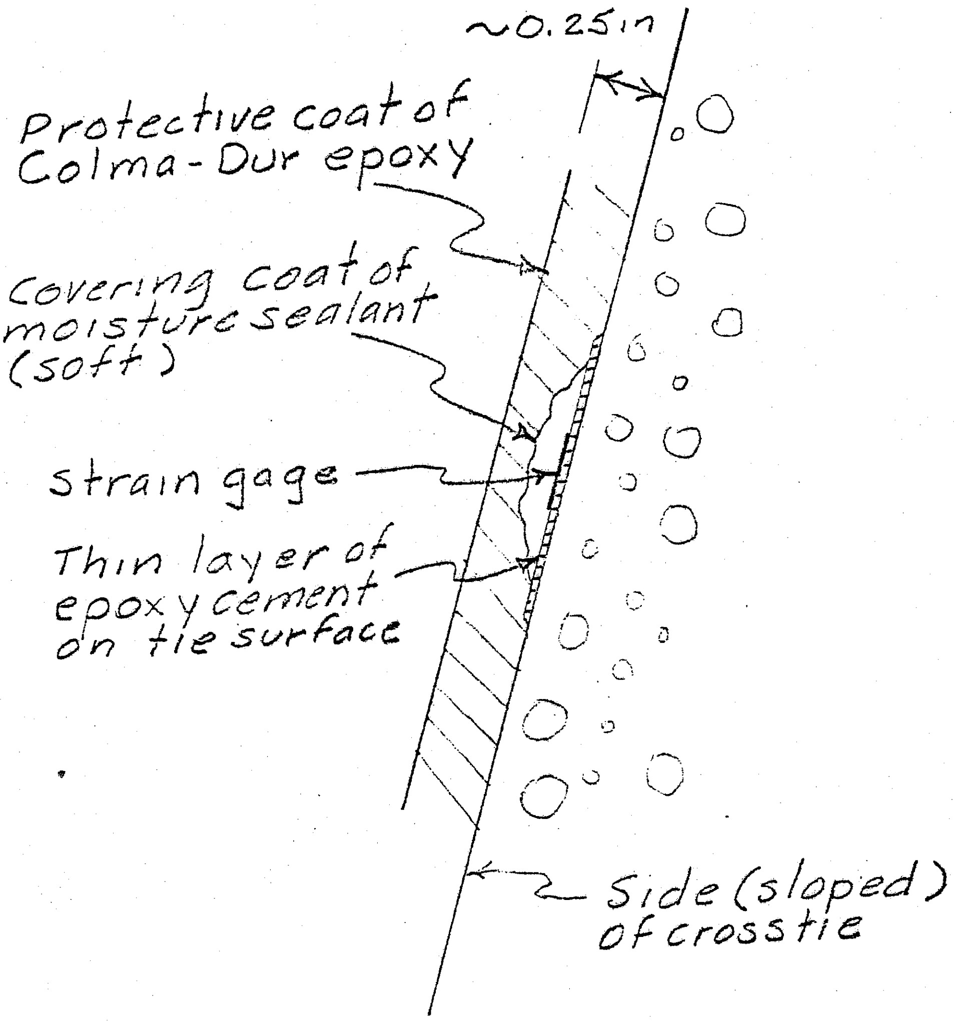


Fig. 1. Vertical section through typical WES gage installation

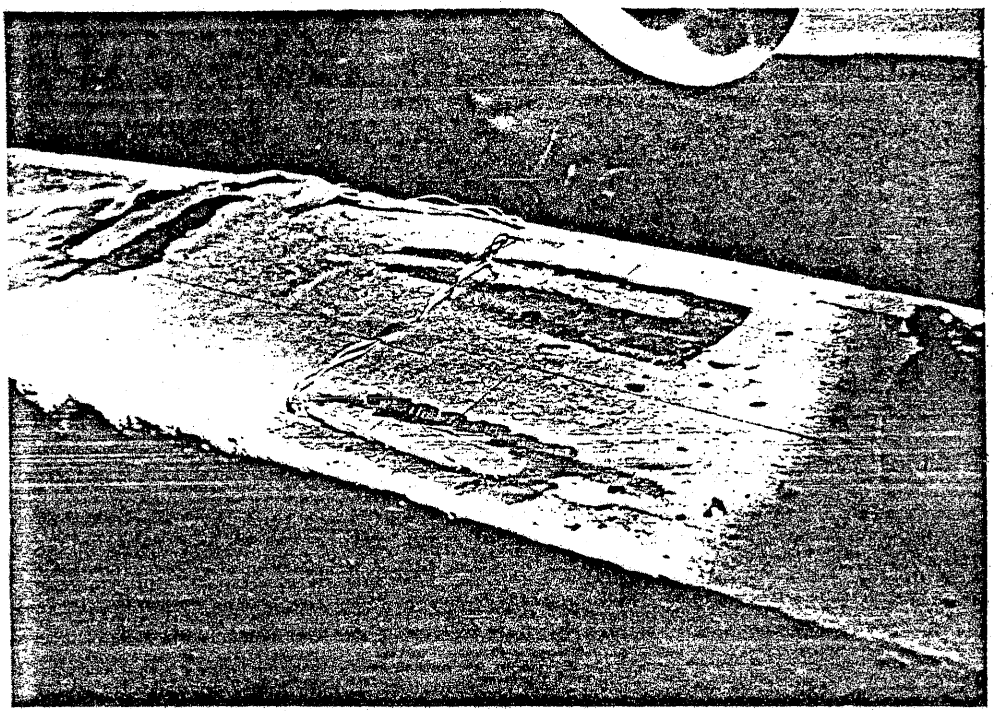
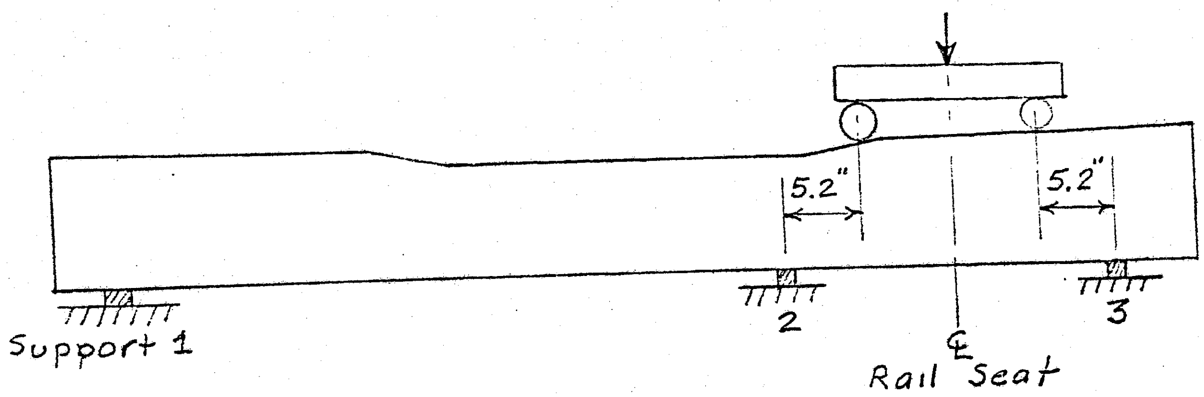


Fig. 2. Surface voids encountered at various gage locations.



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Support(s) 1, 2, and 3 were 1-in.-high by 2-in.-wide by 1-ft-long rubber pads.

15. In order to test the tie, the free end had to be supported at location 1 prior to loading. Load was applied through a bridge plate and rollers to the top of the tie; the load was to be reacted at supports 2 and 3. It was noted, however, that the largest strain values measured coincided with partial load transfer to support 1. Selected retesting, minimizing undesireable load transfer to support location 1 during the test, verified the existence of the problem as well as its effect on measured strain values. Results of the rail seat testing, together with the corrections applied to data to account for the load transfer effects, are shown in Table 1.

16. It is important to note that horizontal strain was measured from individual gages during all of the calibration testing; gages were later wired together to form full bridges having four active gages. In this way, full bridge output under laboratory test conditions could be calculated easily, but, the individual strain gage readings also provided a means for correcting bridge output to conform with a different load geometry. This approach was adopted because of suspected differences in field and laboratory loading conditions, the effects of which had yet to be documented at the time of calibration testing. Failure to consider these differences can lead to erroneous determinations of bending moments in the field, as will later be explained.

17. Results of calibration tests on the rail seats of the first eight, or replicate, ties are shown in Figure 3. The plot in Figure 3 shows the average distribution of horizontal strain on the vertical face of a typical tie. From the plot, the neutral axis of the member is found to be 3.05 in. above the bottom gage location. The measured (uncorrected) strain data have also been used to determine the location of the neutral axis, with virtually the same result.

TABLE 1

Summary of Rail Seat Strain Data, Replicate Ties

At P_{max} = 50 kips, M = 129,500 inch pounds

Tie	Horizontal Strain Under "A" Rail Seat, μin./in.						Horizontal Strain Under "B" Rail Seat, μin./in.			
	2.5 in. below centroid		at centroid		2.5 in. above centroid		2.5 in. below centroid		2.5 in. above centroid	
No.	Measured	Corrected	Measured	Corrected	Measured	Corrected	Measured	Corrected	Measured	Corrected
0103	*210	164	*80	62.4	*-155	-120.90	--	--	--	--
0134	*225(175)	175	*35(27)	27.3	*-160(-125)	-124.80	--	--	--	--
089	--	--	--	--	--	--	*195	152	*-120	-93.6
0152	*190	148	*40	31.2	*-130	-101.40	180	180	-117	-117.0
088	*195	152	*35	27.3	*-150	-117.00	123(140)	123	-90	-90.0
0106	*195	152	*40	31.2	*-100	-78.00	*220	172	*-140	-109.2
0122	*210	164	*35	27.3	*-125	-97.50	140	140	-90	-90.0
096	*215	168	*30	23.4	*-130	-101.40	170(165)	170	-135	-135.0
Averages	205.7	160.4	42.1	32.9	-135.7	-106.0	171.3	157.0	-115.3	-106.0

* Denotes data affected by undesireable load transfer to third support during calibration load test. This problem had been identified and corrected before testing "B" rail seat of ties 088 and 096; retesting showed these values to be accurate within reasonable limits (140 vs. 123 μin., 165 vs. 170 μin., respectively). Due to time limitations all ties could not be tested, and only one retest of "A" end data could be performed. This retest was done on tie 0134, with results shown in parentheses. The retest values were (uniformly) 78 percent of original values; the other data denoted with an asterisk were corrected accordingly.

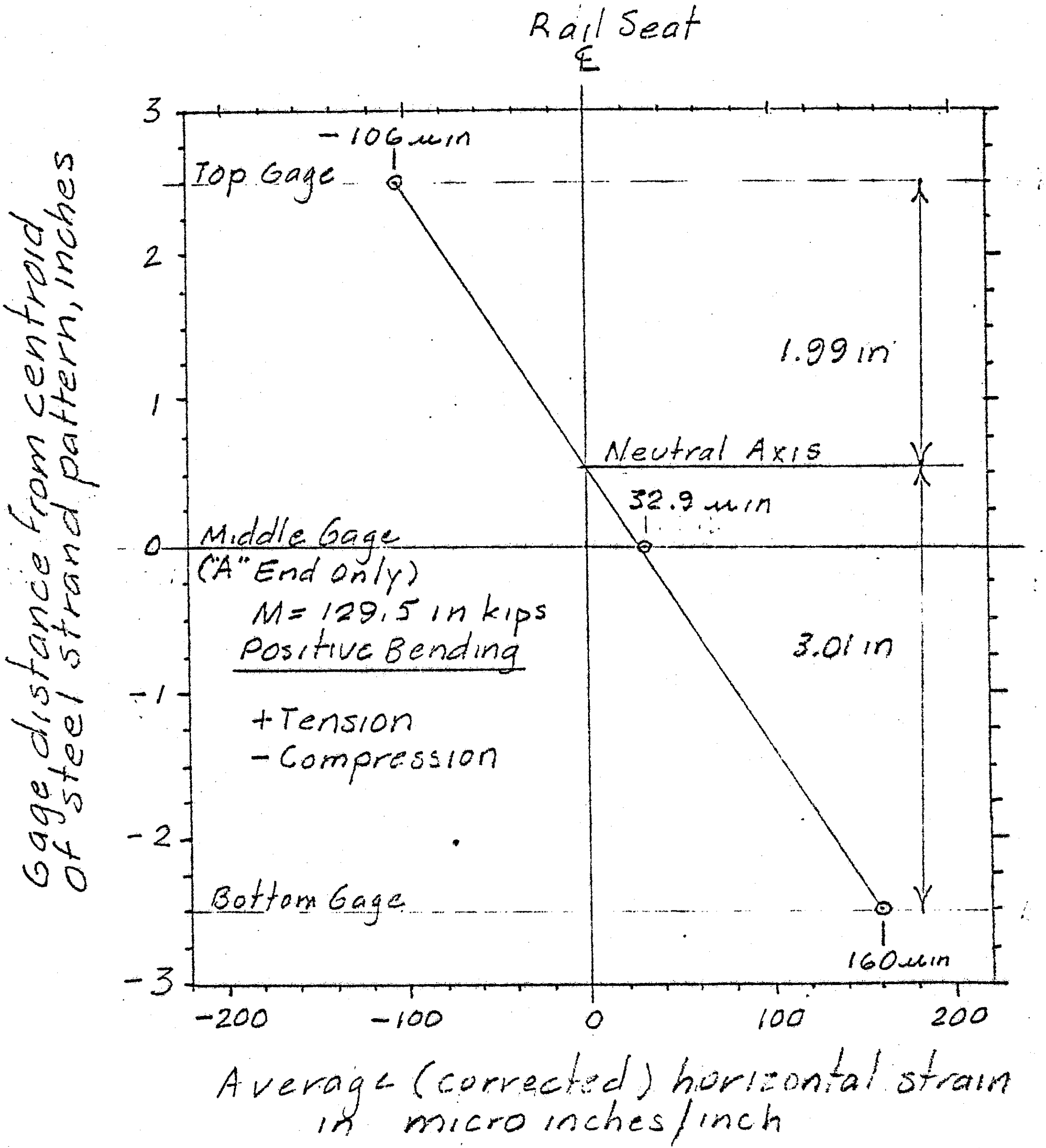


Fig. 3. Strain distribution under rail seat in calibration testing (replicate ties)

18. Similarly, horizontal strain measurements in the center of the tie yield the following results:

Center Section Strain Results
At P = 35 kips, M = 90,500 in. lb
Horizontal Strain, µin./in.

Tie No.	1.75 inches Above Centroid	1.75 inches Below Centroid
0152	105.0	-90.0
088	100.0	-80.0
0106	110.0	-87.5
0122	105.0	-102.5
096	107.5	-82.5
Average	105.5	-88.5

These values were used to derive the strain distribution plot shown in Figure 4.

19. Field and laboratory measurements on the center of the ties may be directly compared, i.e., no compressive loads are input to the center of the tie under normal circumstances. It is instructive to examine the effective Youngs E modulus values for the center and rail seat areas of the tie. These may be calculated from elastic theory, as follows:

$$\sigma_H = \frac{Mc}{I} = E\varepsilon_H$$

$$E = \frac{Mc}{I\varepsilon_H}$$

where:

$$I_{center} = 277.2 \text{ in.}^4$$

$$I_{rail\ seat} = 482.1 \text{ in.}^4$$

$$E_{center} = \frac{90{,}500\ (1.6)}{277.2\ (0.0000885)} = 5.9 \times 10^6 \text{ lb/in.}^2$$

$$E_{rail\ seat} = \frac{129{,}500\ (3.01)}{482.1\ (0.00016)} = 5.05 \times 10^6 \text{ lb/in.}^2$$

The variation in apparent E moduli is explained by the higher proportion of steel present in the center section (where the tie dimensions are reduced). The actual modulus of the concrete material used in the ties is 3.59×10^6, from Incl 3.

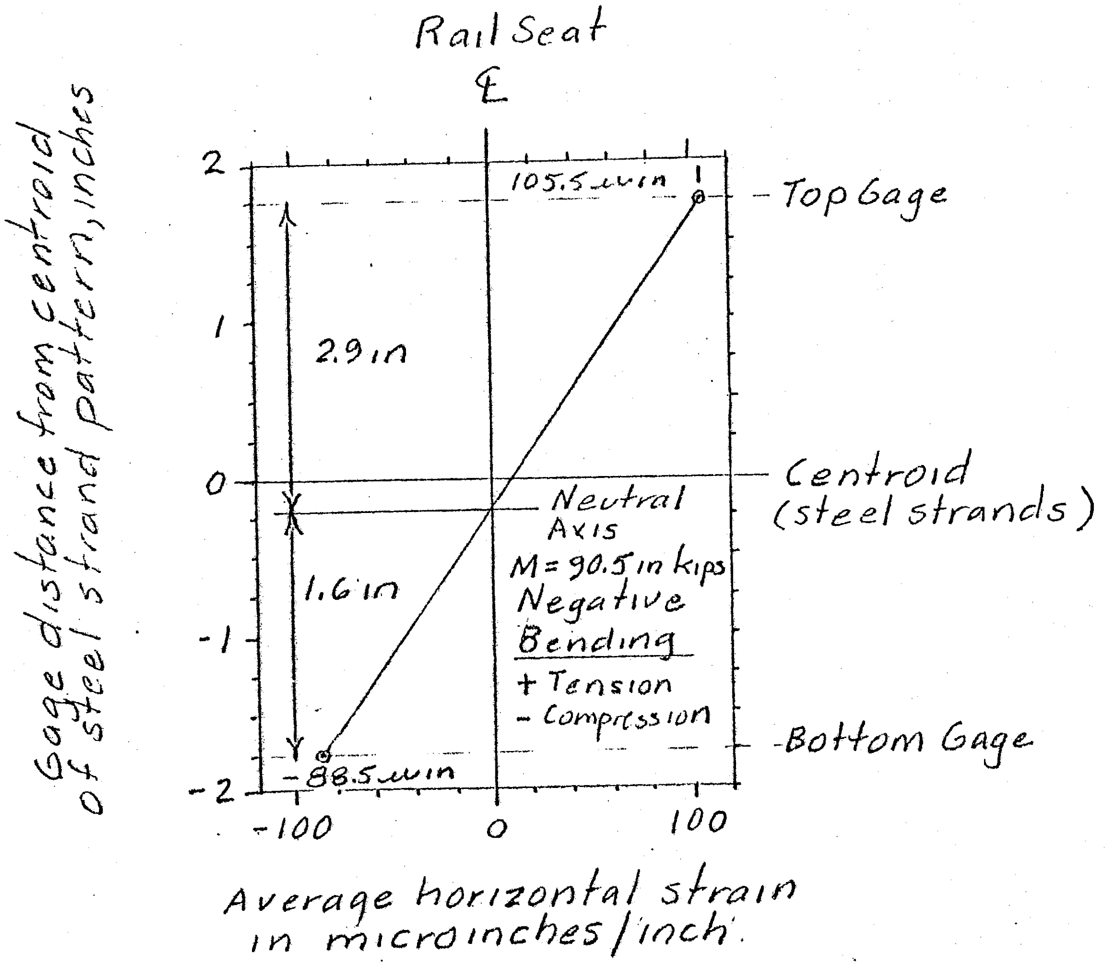


Fig. 4. Strain distribution in center of tie in calibration testing (replicate ties)

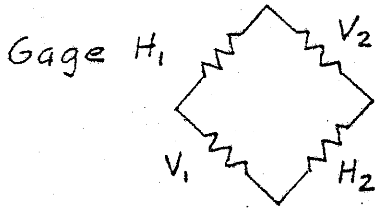
20. When determining initial calibration values (Incl 1), the average strain output of the full bridges, versus bending moment applied, was used. Of course, certain assumptions were implicit to this approach, as follows:

A. The calibrations were valid only for pure bending conditions, as existed in laboratory calibration. The effects of different loading geometry, as in the rail seat area under actual traffic, would have to be determined by further testing.

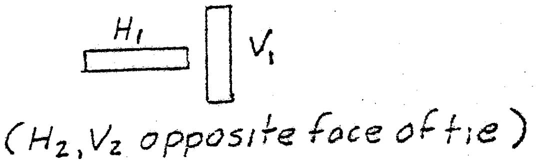
B. Poissons ratio ν for the concrete tie was determined to be about 0.18 from calibration test results, and this ratio was used in computing calibration values.

The circuitry for the four active gage full bridges was as shown below;

Circuitry



Location



In this arrangement, the bridge output is:

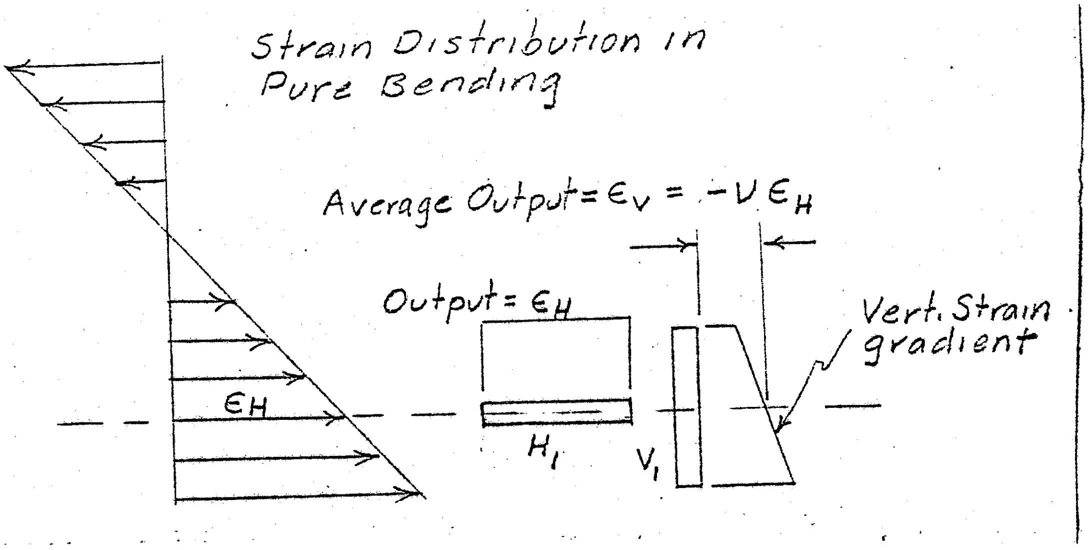
$$\text{Apparent strain } \varepsilon_t = (\varepsilon_{H_1} - \varepsilon_{V_1}) + (\varepsilon_{H_2} - \varepsilon_{V_2})$$

with Poissons ratio $\nu = 0.18$, $\varepsilon_V = -0.18\ \varepsilon_H$, and if pure bending occurs only in the horizontal plane we have:

$$\text{Apparent strain } \varepsilon_T = 2\ \ \varepsilon_H - (-0.18\varepsilon_V)$$

$$\text{or, } \varepsilon_T = 2.36\ \varepsilon_H\ .$$

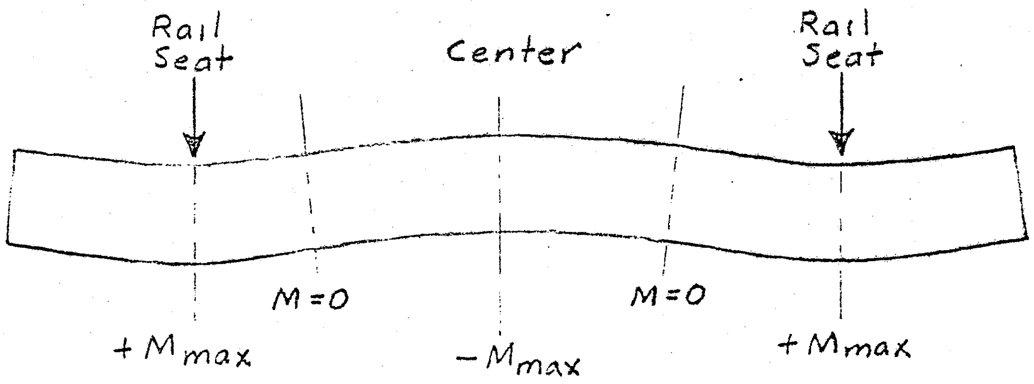
Actually, this gage arrangement cancels any lateral bending effects, and also compensates for temperature effects. The foregoing, however, is based on the assumptions previously noted. The rationale for a Poisson gage array located on a flexural member is as follows:



Comparison of Laboratory and Field Conditions

21. Preliminary results from the eight replicate ties installed in the FAST indicated that WES reservations about the behavior in the field were well founded. These early results indicated average rail seat bending moments of approximately 25 in. kips at the top gages and approximately 75 in. kips at the bottom gages (positive bending mode). Obviously, if uniform bending in the rail seat had occured in the field then the calibration values should yield approximately equal moment values, but such was not the case. On the other hand, moment values derived from strains recorded in the center section of the ties were more reasonable and consistent, as expected. Accordingly, the service simulation tests performed later, and described in Incl 3, were primarily designed to determine behavior in the rail seat area of the tie.

22. The principal mode of bending in a tie loaded by rail traffic is as shown:



In this bending mode, described by Hetenyi, and shown in a modified form by the deflected curves in Incl 3, maximum positive bending moments occur under the rail seats and the maximum negative bending moment occurs at the center of the tie. The deflection curve obtained from simulated service test No. 2, Incl 3, was used to calculate the maximum positive moments applied at the rail seats and the maximum negative moment applied to the center section of the tie, in the simulated service test, from:

$$M = \frac{EI}{r}$$

where:

$E = 5.05 \times 10^6$ lb/in^2 (rail seat), 5.9×10^6 lb/in^2 (center)

I = moment of inertia of section (277.2 in^4 for center, 482.1 in^4 for rail seat)

$r = 2.25 \times 10^4$ in (rail seat), 5.2×10^4 (center)

At the maximum applied rail seat load of $P = 30{,}000$ lb, this calculation yields:

$$\text{Rail Seat } M_{max} = 108 \text{ in-kips (positive)}$$

$$\text{Center } M_{max} = 31 \text{ in-kips (negative)}$$

Equally interesting are the inflection points between the rail seat and the center of the tie where the curvature reverses (transition from positive to negative bending). At this transition point there is no curvature, r is infinitely large, and $M = 0$. This fact has an important impact on the discussions to follow. It should be noted that the WES deflection curves from the service simulation tests in Incl 3 clearly illustrate this behavior, and that these curves show that zero moment occurs at a distance of about 9.5 in. inside either rail seat, with the loading geometry described. Figure 5, derived from the strain data in Incl 3, also illustrates this behavior. Of course, ballast support conditions in the field will vary from the ideal, however, the deflected shape of a tie as well maintained roadbed will generally follow the classic pattern. It is assumed that FAST conditions generally satisfy this description.

23. This existance of a biaxial stress field in the rail seat is clearly illustrated by Figure 6. The strain data used in Figure 6 were obtained from the results of service simulation test No. 2 described in Incl 3. Figure 6 shows the horizontal and vertical strains measured at

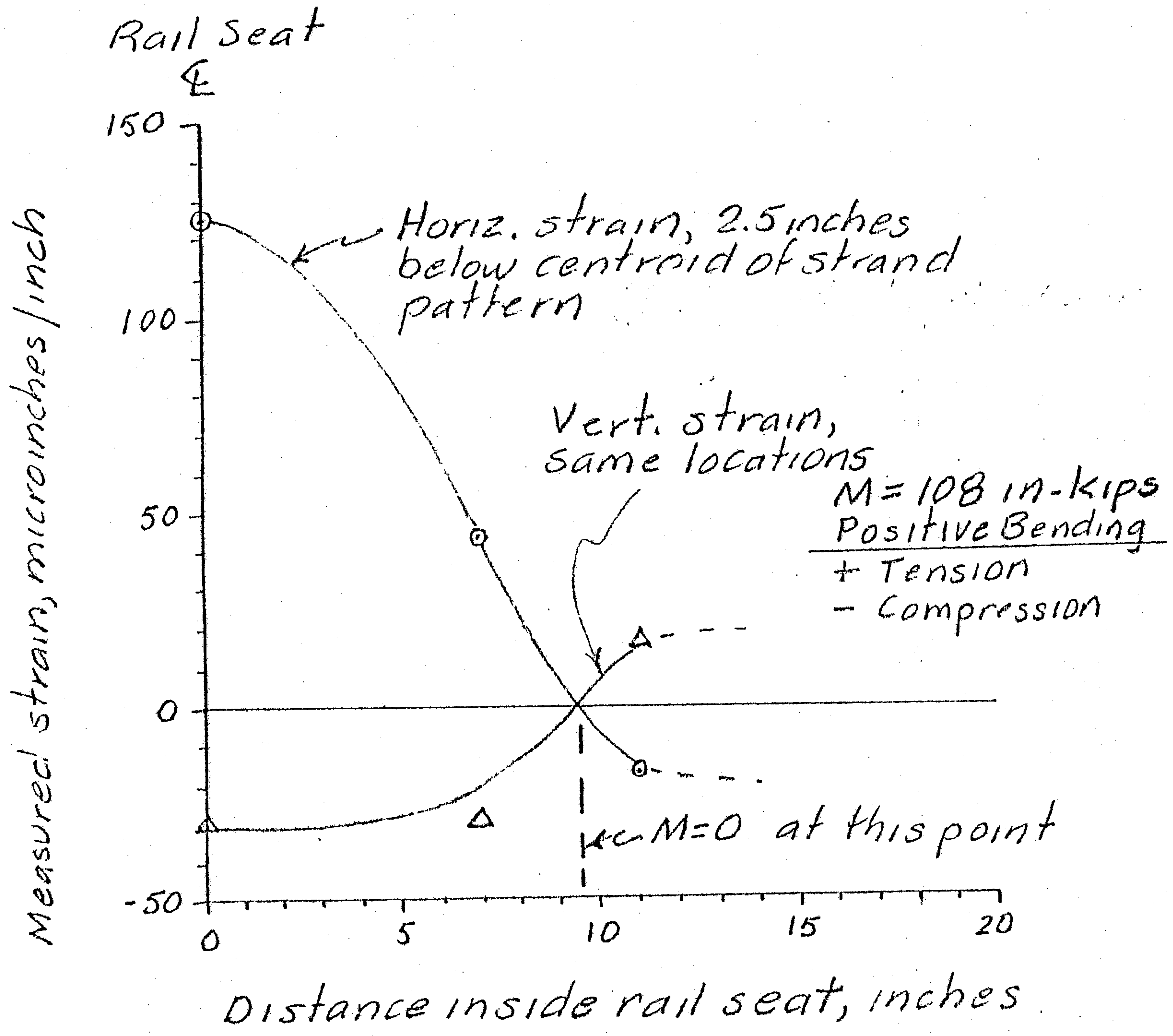


Fig. 5. Strain distribution near bottom of tie, in service simulation test #2, incl 3

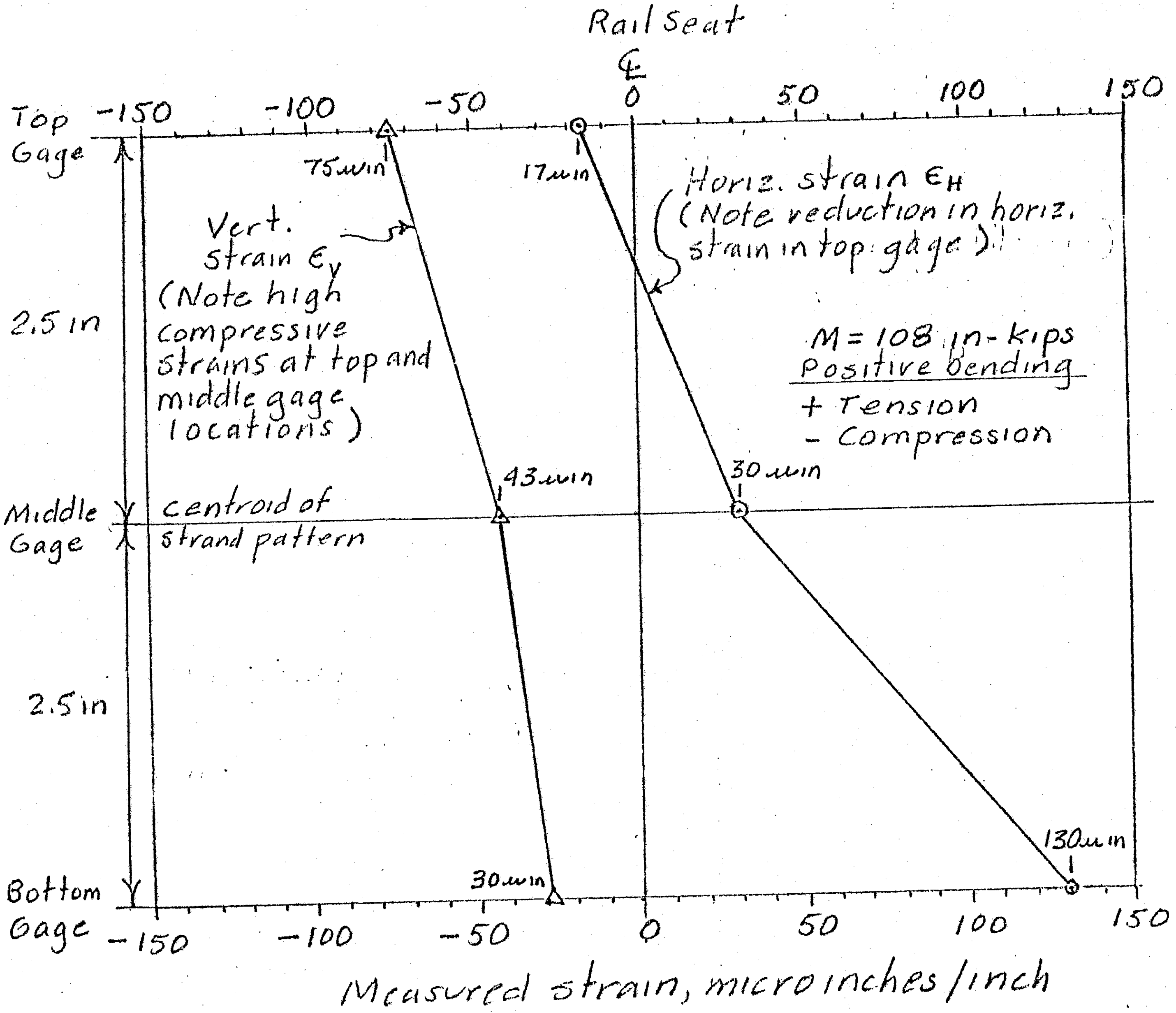


Fig. 6. Strain distribution under rail seat in service simulation test #2, incl 3

three locations beneath the rail seat, which coincide with horizontal gage locations used on the eight replicate ties. The vertical strain pattern reflects the relatively high compressive stresses occuring at the top and middle gage locations; concomitant reductions in measured horizontal strains are also evident. This explains the responses noted in early FAST field measurements of moment values under the rail seat, i.e., the top gages showed much lower moment values than the bottom gages (where vertical stresses are much reduced).

24. The influence of rail seat traffic loads, based on the service simulation test results in Incl 3, may be calculated from the following relationships:

$$E_H = \frac{1}{E} (\sigma_H - \nu \sigma_V)$$

$$E_V = \frac{1}{E} (\sigma_V - \nu \sigma_H)$$

where:

σ_H = horizontal stress, psi

σ_V = vertical stress, psi

E_H = 130 μin./in.

E_V = -30 μin./in. (test No. 2, Incl 3)

E = effective Youngs modulus = 5.05×10^6 lb/in.^{2}

ν = Poissons ratio = 0.21 (Incl 3)

Using these values, for the bottom gage location in the rail seat (2.5 in. below the centroid of the strand pattern), and under the simulated service test conditions described in Incl 3, the results are:

σ_H = 640 psi (tensile)

σ_V = 19.8 psi (compressive)

and,

$$\nu = \frac{30\ \mu\text{in.}}{130\ \mu\text{in.}} = 0.23\text{, versus 0.21 assumed}$$

It is clear that at the location of the bottom horizontal gages a condition closely approximating pure bending exists. And, with a suitable correction for the comparison vertical gage (because this gage of the Poisson pair is in a different stress field which is located 11 in. inside the rail seat of the tie) a meaningful and accurate calibration value can be derived for field conditions. From Figure 5, it is determined that when the bottom horizontal gage registers 130 μin./in., its companion vertical gage in the Poisson pair (located 11 in. inside the rail seat) should register 17 μin./in. Hence, the actual output value for the replicate tie full bridge AB or BB becomes:

$$\varepsilon_{\text{total}} = (\varepsilon_{H_1} - \varepsilon_{V_1}) + (\varepsilon_{H_2} - \varepsilon_{V_2})$$

$$\varepsilon_T = (130 - 17) + (130 - 17)$$

$$\varepsilon_T = 113 + 113 = 226 \ \mu\text{in./in. (For } M = 108 \text{ in. kips)}$$

(ε_H and ε_V values obtained from Incl 3.)

Note that the algebraic convention for this calculation does not result in an additive relationship between ε_H and ε_V, contrary to the theory used to derive the original calibration values. This is because the vertical gage, whose output is ε_V, is located in a different stress field (on the opposite side of the vertical plane at 9.5 in. inside the rail seat, where M = 0). Fortunately, the total output of the vertical gages accounts for only 20 percent of the total bridge output ($\varepsilon_V = 0.21\ \varepsilon_H$) so that even a 50 percent error in predicting ε_V will result in only a 10 percent error in the final strain and/or moment determination. Finally, the average horizontal strain derived in the original calibration testing may be compared with the horizontal strain recorded in service simulation test No. 2 (from the bottom horizontal gage beneath the rail seat) as follows:

Average horizontal strain at M = 108 in kips from calibration testing	= 133 μin./in.
Average horizontal strain at M = 108 in kips from simulated service test No. 2 Incl 3	= 130 μin./in.

These values, derived by different means, are in excellent agreement. It is concluded that the relationship between the original calibration tests, the simulated service tests conducted at WES, and the field measurements is clearly and accurately established.

25. It should be noted that results obtained from the bottom gage arrays (designated as full bridges AB and BB on the eight replicate ties) will provide the most accurate measurements of rail seat bending moments, simply because these arrays are not influenced appreciably by vertical stresses existing beneath the rail seat in service. Revised calibration values for most of the gage arrays will be offered in the following section.

Revisions to Original Calibration Values

26. Revisions to the rail seat calibration values for the eight replicate ties will be considered first. In simulated service test No. 2 the output of the AB and BB full bridges was determined to be 216 μin./in. for M = 108 in.-kips. This was based on a horizontal strain of 130 μin./in. in the horizontal gages of the AB and BB bridges (Incl 3). Using the original calibration values, the AB and BB full bridges should indicate 314 μin./in. strain at M = 108 in. kips. The necessary moment correction factor to be applied is then:

$$M_{actual} = \frac{314}{226} M_{calibration} = 1.39\ M_{calibration}$$

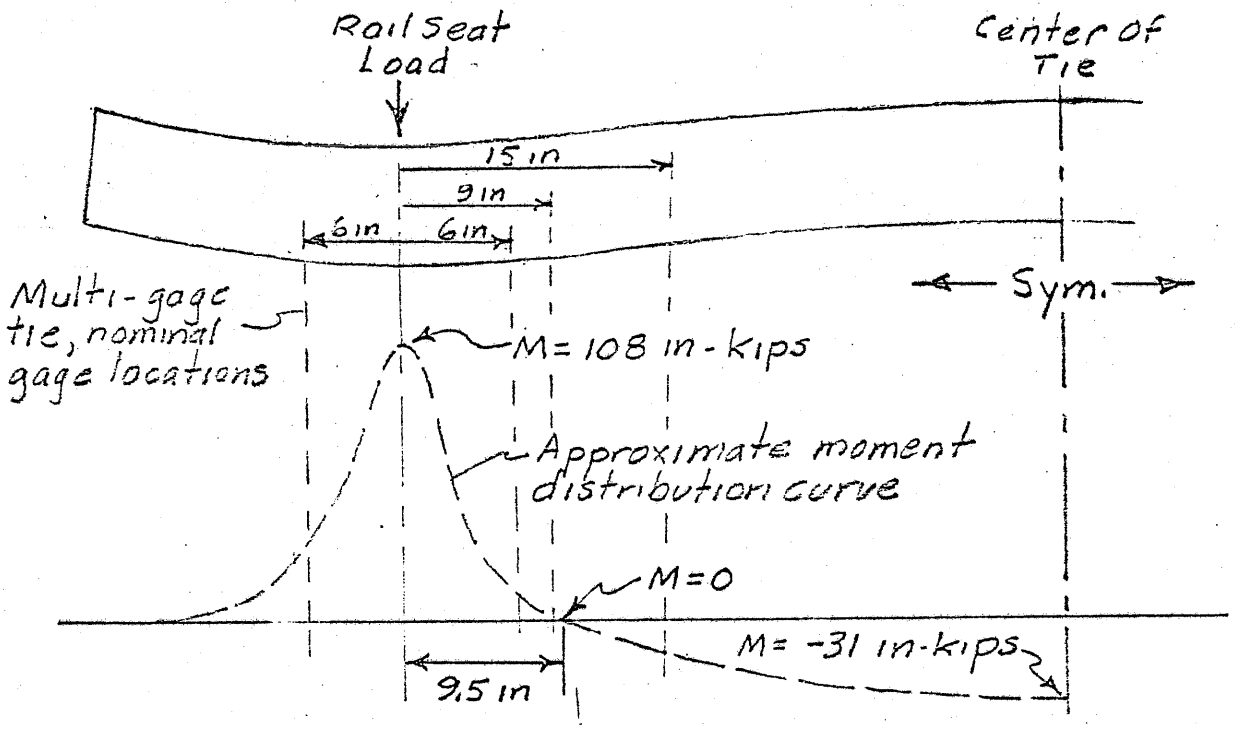
Similar calculations were performed for the other gage locations beneath the rail seats of the replicate ties; results of the calculations are summarized below:

Rail Seat Full Bridge Designation (Replicate Ties)	Plane of Measurement	Moment Correction Factor
AB, BB	2.5 in. below centroid	$1.39 \times M_{cal}$
AM	At centroid	$0.77 \times M_{cal}$
AT, BT	2.5 in. above centroid	$4.95 \times M_{cal}$

These correction factors apply to ties 0103, 0134, 089, 0152, 088, 0106, 0122, and 096.

Ideally, with these corrections, all strainbridges under one rail seat should indicate the same moment value under a given field (rail traffic) loading. However, it should be remembered that the AT and BT bridges operate in a biaxial stress field which is characterized by sharp gradients, i.e., results are susceptible to error. When in doubt, it is good practice to rely on the moment values derived from the AB and/or BB bridges, since they will typically provide the most accurate results.

27. There is a basic problem in attempting to revise the calibration values originally derived for the MITRE multi-gage ties. This is best illustrated by comparing the as-built gage locations with the classic tie deflection pattern from the simulated service test results in Incl 3, as shown below:



By inspection, it is apparent that most of the gage arrays outside the rail seat fall at locations where moment values will be of small magnitude (approximately 20 percent M_{max}, or less). This condition, together with any small shifts in the moment curve which might occur as a result of support variations, virtually prohibits a meaningful calibration and/or moment determination. In view of these conditions, it is not considered to be worthwhile to revise the original multi-gage tie calibrations for gages near but outside the railseat. Results obtained to date with these ties seem to support this conclusion, i.e., little or no measurable output has been recorded for gages near (but not beneath) the rail seat. One calibration value for the milti-gage ties does warrant revision and this gage array is located under the "A" rail seat of multi-gage ties 0128 and 0146. The gage configuration used is similar to that used by Battelle in a research study conducted at the DOT Florida East Coast test site. For this gage array, WES designation A1-BH and TH, 1/2 bridge, the original calibration value gives a full bridge output of 170 μin./in. at M = 108 in. kips. From Figure 6, based on results of the service simulation tests described in Incl 3, output under field conditions at M = 108 in. kips should be:

$$\varepsilon_T = 130\ \mu\text{in./in.} - (-17\ \mu\text{in./in.})\quad \text{or}\ 147\ \mu\text{in./in.}$$

The moment correction value for 1/2 bridge A1-BH and TH is, then:

$$\begin{array}{l}\text{Moment correction value for}\\ \text{multi-gage ties 0128, 0146,}\\ \text{1/2 bridge A1-BH and TH}\end{array} = \frac{170}{147} = 1.16 \times M_{cal}$$

Note that this correction does not directly equate to Battelle results in the earlier study, since the calibration procedures used in that study were significantly different from WES procedures; however, it is clear that loading geometry during rail seat calibration tests should closely approximate field conditions or erroneous field measurements will result, irrespective of the gage configuration used.

Summary

28. Eight Conforce Costain crossties, instrumented with strain gages and load calibrated by WES, were installed in the DOT-FAST in September of 1976. These ties have been designated as "replicate" ties by MITRE, who, under DOT direction, specified the instrumentation and calibration procedures to be used by WES. MITRE also specified and supervised the fabrication and testing of two "multi-gage" ties which were installed at FAST in October 1976. The total complement of ten ties has since undergone approximately 100 MGT of rail traffic. The response of these ties has been periodically monitored by the TTC to determine bending moments occuring at locations of interest (principally in the rail seat and tie center sections).

29. Since the ties were originally calibrated under conditions of pure bending, and since different stress conditions were believed to exist in the rail seat area when the ties were subjected to rail traffic, the WES recommended further study of the stress state existing in the rail seat area under service loadings. With DOT approval, the WES conducted two static "simulated service tests" to better define rail seat behavior under simulated field loading conditions. Results of these tests have led to revision of the rail seat calibration values originally derived for the eight "replicate" ties; the final result will be a much more

accurate determination of bending moments in the rail seat areas of these ties. The WES recommended correction factors for gages in the rail seats of the "replicate" ties are as follows:

Replicate Tie Strain Bridge Designation	Appropriate Correction Factor
AB, BB	1.39 x original calibration value for M
AM	0.77 x original calibration value for M
AT, BT	4.95 x original calibration value for M

Refers to ties 0103, 0134, 089, 0152, 088, 0106, 0122, 096.

Revisions to the original calibration values derived for gages near the rail seats of the "multi-gage" ties proved to be impractical, primarily due to the gage locations specified and the relatively low output signals which result. However, one calibration revision is proposed for the 1/2 bridge designated by WES as A1-BH and TH, which is located beneath the rail seat at the "A" end of ties 0128 and 0146 (multi-gaged ties). This gage configuration is similar to that used by Battelle at the DOT Florida East Coast Test Site, and gage output should be corrected as follows:

Multi-Gage Tie Strain Bridge Designation	Appropriate Correction Factor
A1-BH and TH	1.16 x original calibration value for M

Refers to ties 0128 and 0146.

Note that the above calibration factor does not directly relate to results obtained in the earlier study by Battelle, since the WES and Battelle calibration procedures were significantly different.

30. Among the most interesting technical challenges to WES was the arrangement and protection of the various strain gage arrays. Apparently, the gage locations selected for the "replicate" were generally satisfactory, and the epoxy gage protection method seems to have given reasonably good results to date (after 100 MGT of rail traffic), although a final determination of gage survivability is still pending.

CONCLUSIONS AND RECOMMENDATIONS

31. In the analysis section of this report a meaningful and accurate relationship between field and laboratory test results has been established. The end result of this effort will be a more accurate determination of bending moments occuring in the FAST Conforce Costain crossties.

32. The insight into tie behavior provided by the WES service simulation tests may be used to good advantage in any future programs involving similar strain gage measurements. Several important conclusions may be drawn, as follows:

A. When possible, strain gaging should be done using four active gage full bridges so as to secure the benefits of enhanced signal output and temperature compensation.

B. Preliminary testing on a representative number of sample ties should be performed, both to define calibration parameters of interest and to aid in selecting suitable gage locations. Experience indicates that, in the rail seat area, the preferred locale for gaging is beneath the rail seat and as near as practicable to the bottom of the tie (where strain gradients are likely to be much less severe than just under the rail seat). Strain readings made just beneath the rail seat may be subject to large errors, unless calibrations are carefully performed under conditions which simulate field loadings.

C. It is concluded that the epoxy gage protection method adopted by WES has generally performed well; however, full consideration should be given to alternative methods and/or permutations of the WES method for any future programs of this type, and particularly if long term gage survivability is not a paramount concern.

33. The thrust of this study has been to determine the magnitude of traffic induced bending moments in the Conforce crossties. However, an opportunity also exists to determine how load repititions affect tie performance, and with only minimal additional effort. Since the FAST traffic history is being recorded, and bending moment measurements at various cumulative traffic totals are being made, a logical and cost effective extension of this program is a post test assessment of tie condition (hence performance). A comparison of pre- and post test responses would provide a index of performance under actual (and very well documented) traffic conditions. If during the course of the test cycle a tie(s) should fail, then retesting could be done immediately to secure intermediate data of, possibly, considerable signifigance.

34. WES recommendations, then, are:

A. To calculate rail seat moment values using the corrections provided herein.

B. To carefully control calibration testing for any similar future programs so that calibration and field measurements can be accurately compared.

C. To extend the current study to include post traffic testing; this effort should yield a better understanding of the effects of repetitive loading on tie performance.

3 Incl
as

S. S. COOPER
Geophysicist
Geodynamics Branch
Soils and Pavements Laboratory

INCLOSURE 3

Results of Simulated Service Tests

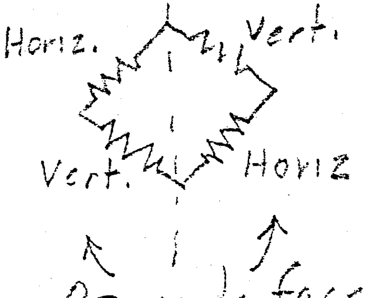
SUBJECT:	COMPUTED BY:	DATE:	FILE NO.
	CHECKED BY:	DATE:	SHEET NO.

In order to relate the data in incl 3 to the full bridge gage arrays on the replicate ties, the following equivalence key is provided;

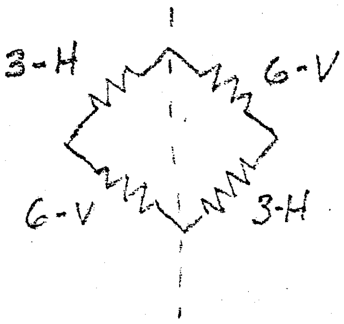
Replicate Tie Full Bridge Designation	Equivalent Locations in Simulated Service Loading Test	
	Horizontal Gage Location	Vertical Gage Location
AB, BB	3-H	6-V
AM	2-H	None
AT, BT	1-H	4-V

Note that each full bridge is composed of four active gages; hence an equivalent set from the simulated service loading test would relate as follows

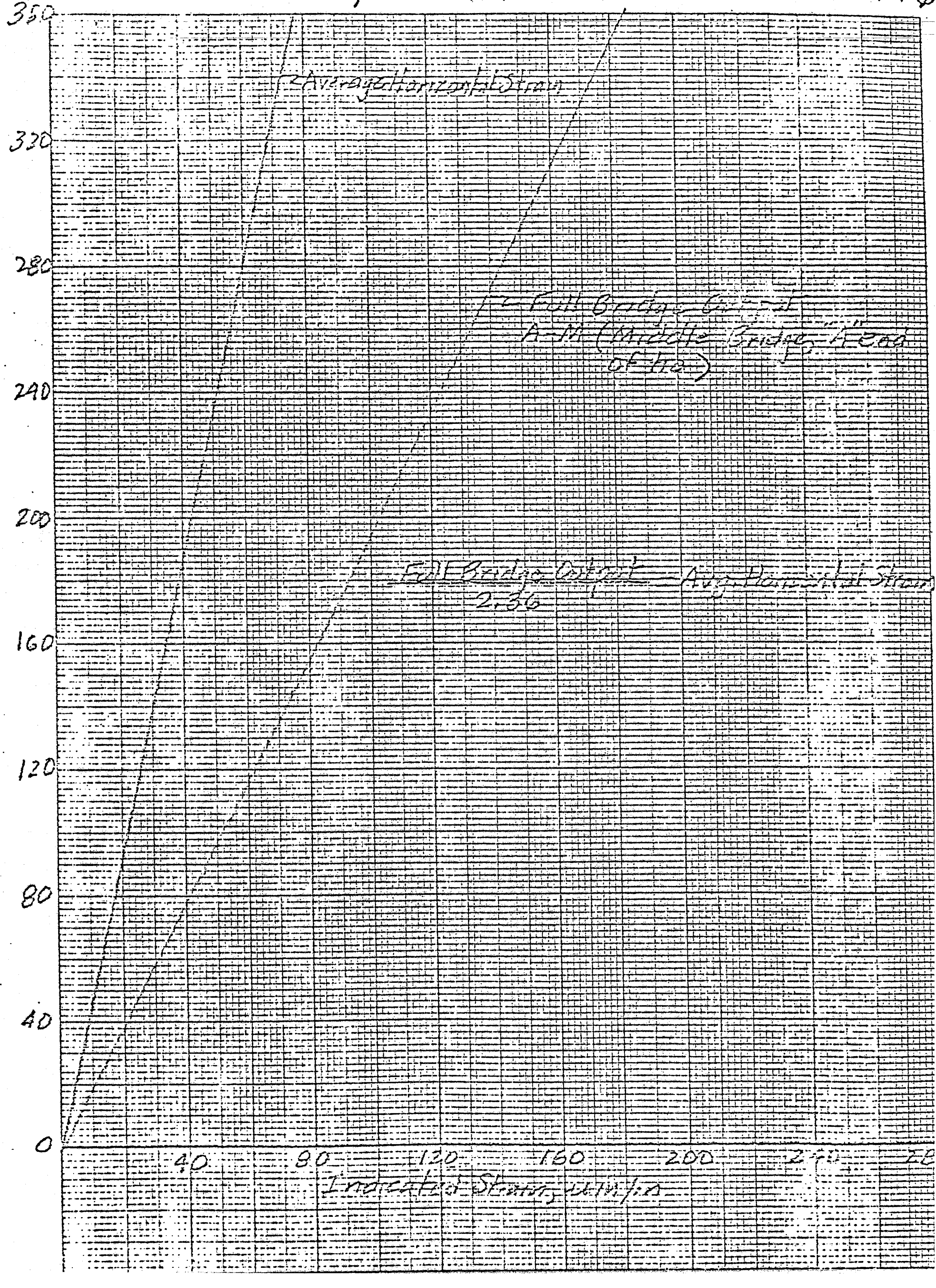
AB or BB bridge



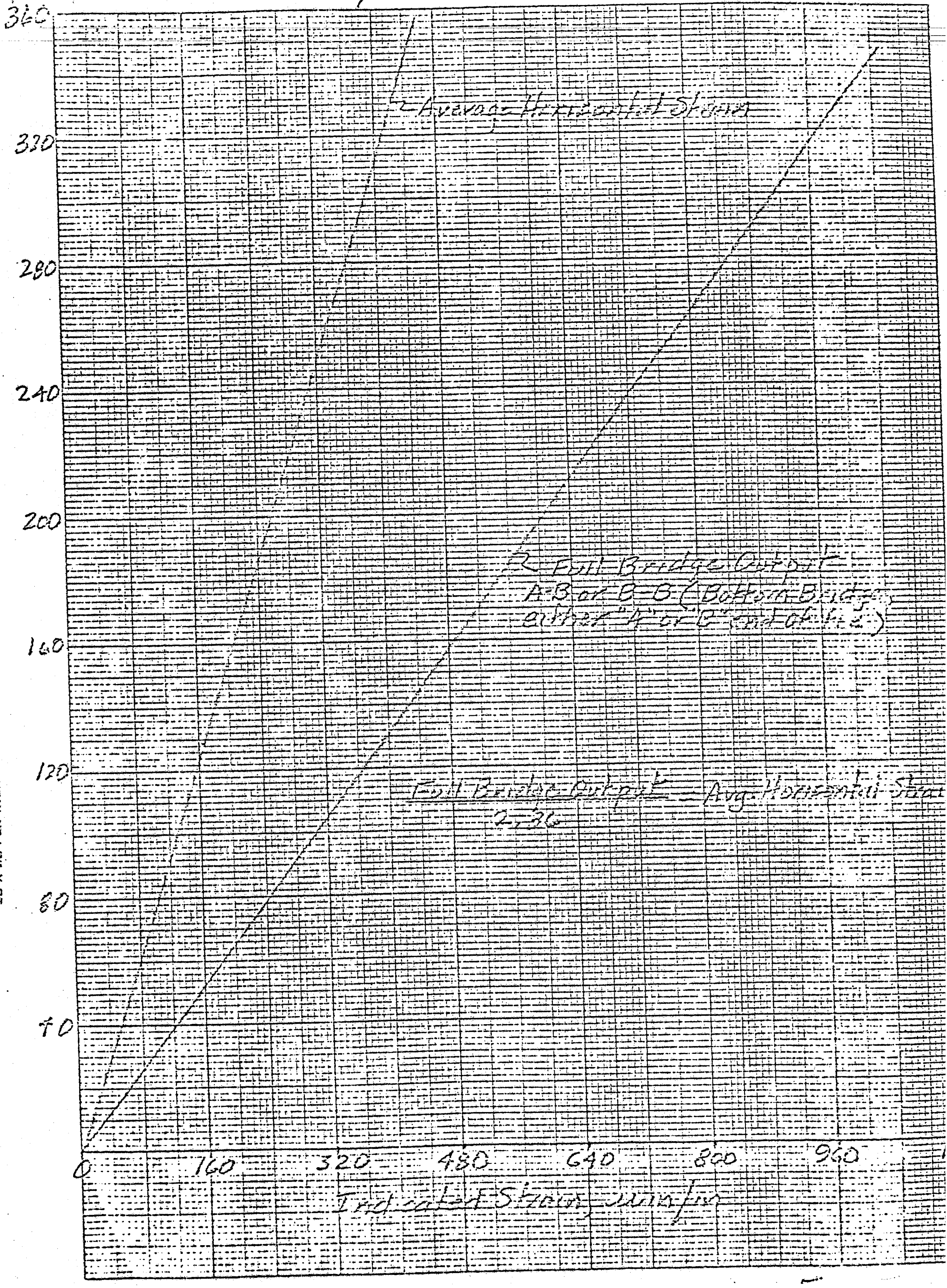
Opposite faces of tie.



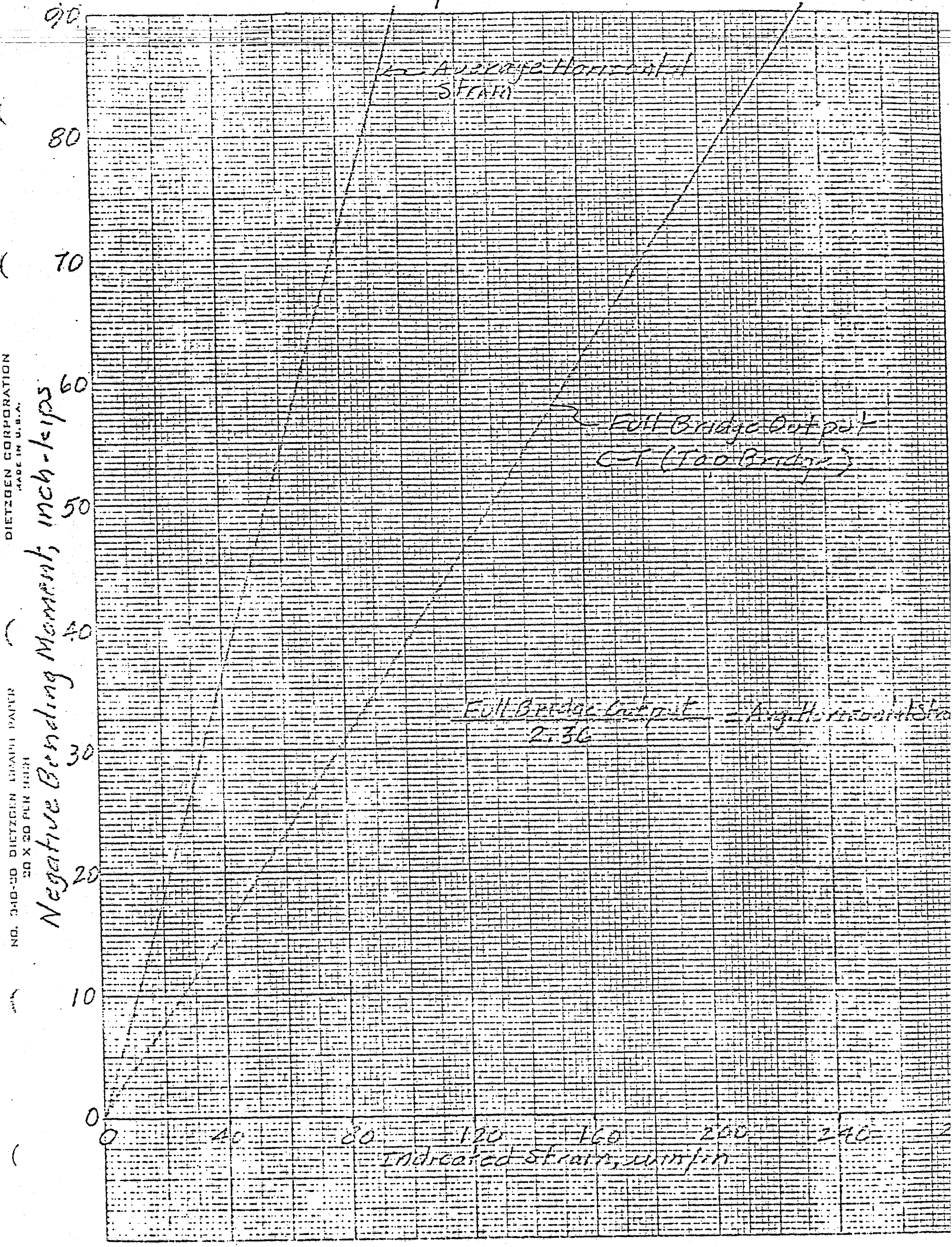
WES Preliminary Calibration Curves – FAST 9-14-76



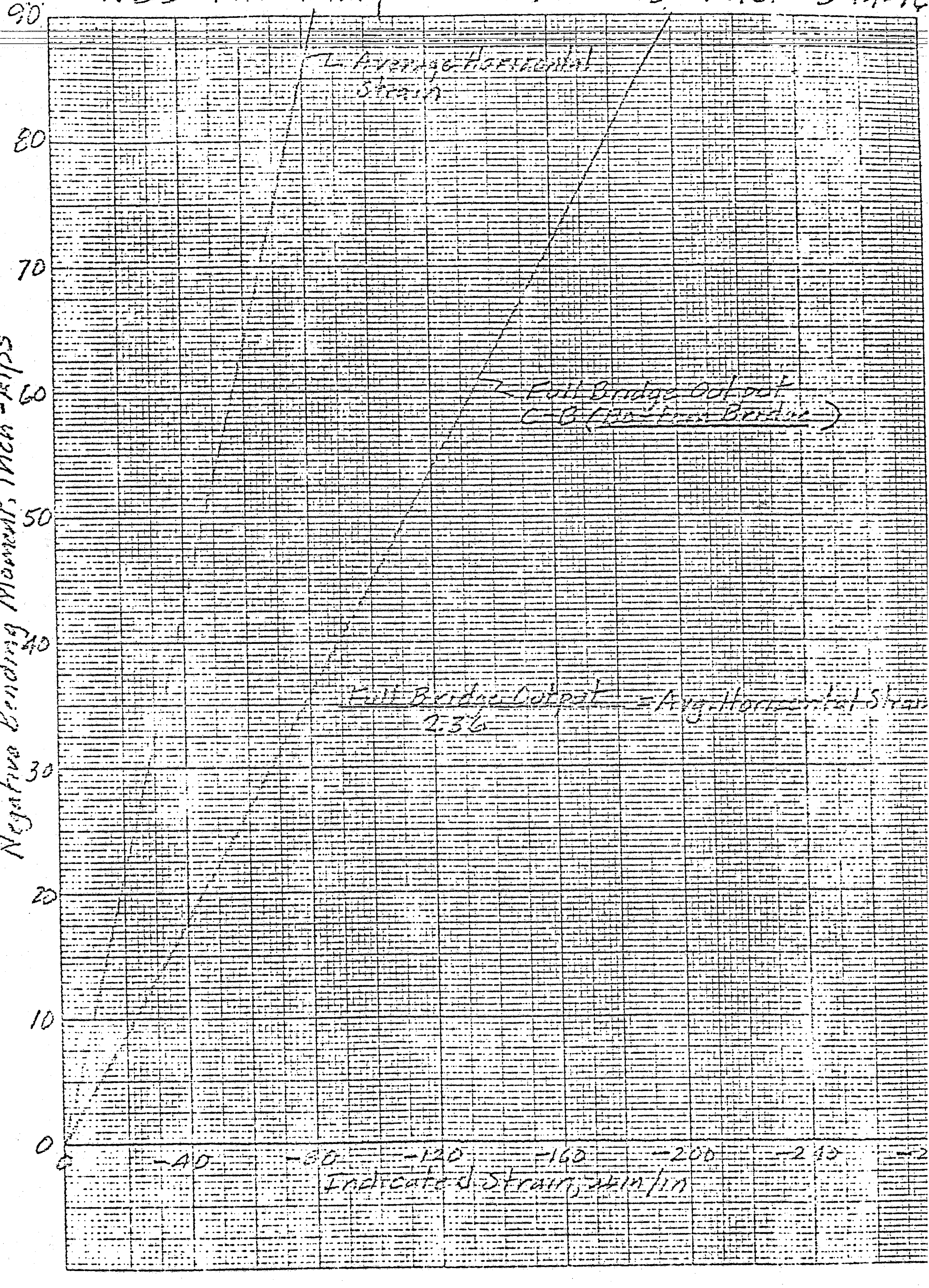
WES - Preliminary Calibration Curves - FAST 9-14-76



WES - Preliminary Calibration Curves - FAST 9-14-7



WES- Preliminary Calibration Curves - FAST 9-14-76

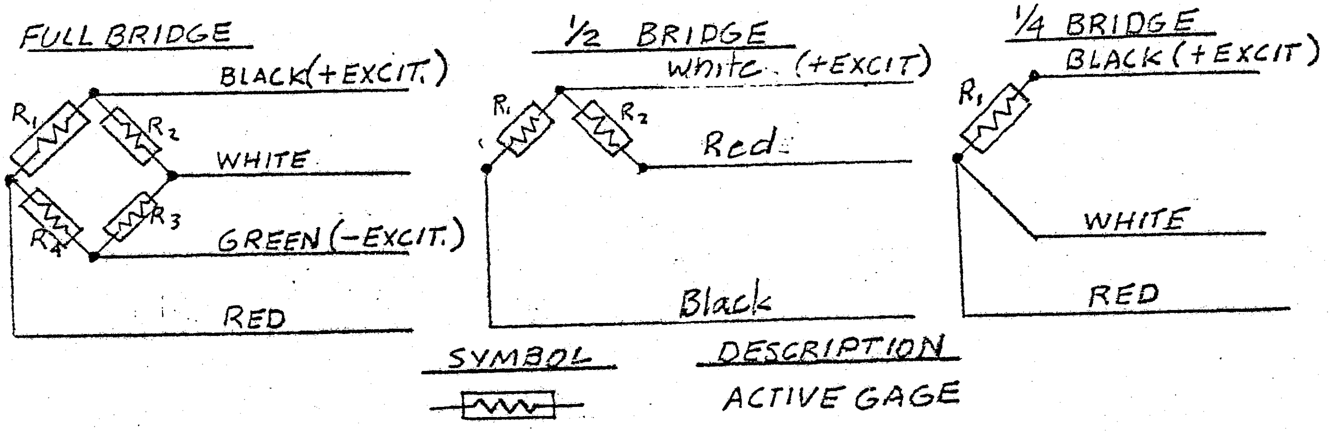


INCLOSURE 2

Calibration Test Results
On Multi-Gage Ties

SUBJECT: WES INSTRUMENTED TIES	COMPUTED BY:	DATE: 16 Nov 76	FILE NO. 1
ATTN: MR. MEL LEVINE MR. GERRY MATTHEWS	CHECKED BY:	DATE:	SHEET NO.

TYPICAL WIRING DIAGRAM
WES TIES 0146, 0128



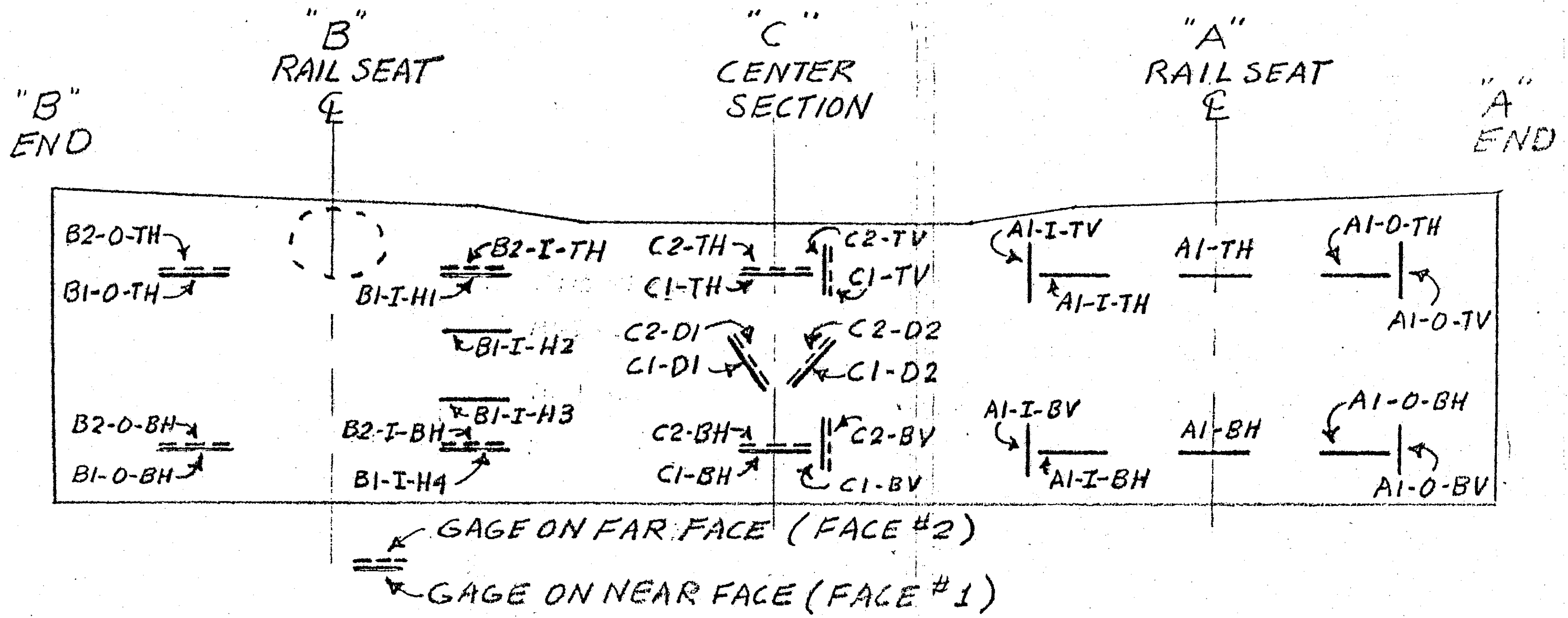
WIRING SUMMARY

GAGES IN BRIDGE	BRIDGE LOCATION	CALIBRATION PARAMETER(S)
* R_1 = A1-O-TH } ½ BRIDGE R_2 = A1-O-TV } R_3 = 120Ω RESISTOR R_4 = 120Ω "	"A" END, OUTSIDE RAIL SEAT (TOP)	MOMENT, STRAIN @ 2.5" ABOVE STRAND CENTROID
* R_1 = A1-O-BH } ½ BRIDGE R_2 = A1-O-BV } R_3 = 120Ω RESISTOR R_4 = 120Ω "	"A" END, OUTSIDE RAIL SEAT (BOTTOM)	MOMENT, STRAIN @ 2.5" BELOW STRAND CENTROID
* R_1 = A1-TH } ½ BRIDGE R_2 = A1-BH } R_3 = 120Ω RESISTOR R_4 = 120Ω "	"A" END, UNDER RAIL SEAT	MOMENT
* R_1 = A1-I-TH } ½ BRIDGE R_2 = A1-I-TV } R_3 = 120Ω RESISTOR R_4 = 120Ω "	"A" END, INSIDE RAIL SEAT (TOP)	MOMENT, STRAIN @ 2.5" ABOVE STRAND CENTROID
* R_1 = A1-I-BH } ½ BRIDGE R_2 = A1-I-BV } R_3 = 120Ω RESISTOR R_4 = 120Ω "	"A" END, INSIDE RAIL SEAT (BOTTOM)	MOMENT, STRAIN @ 2.5" BELOW STRAND CENTROID

(CONT'D)

TYPICAL GAGE LOCATIONS, WES TIES #0146, #0128
(VIEW SHOWN IS FACE #1 OF TIE #0128)

17 Nov 76



IDENTIFICATION CODE

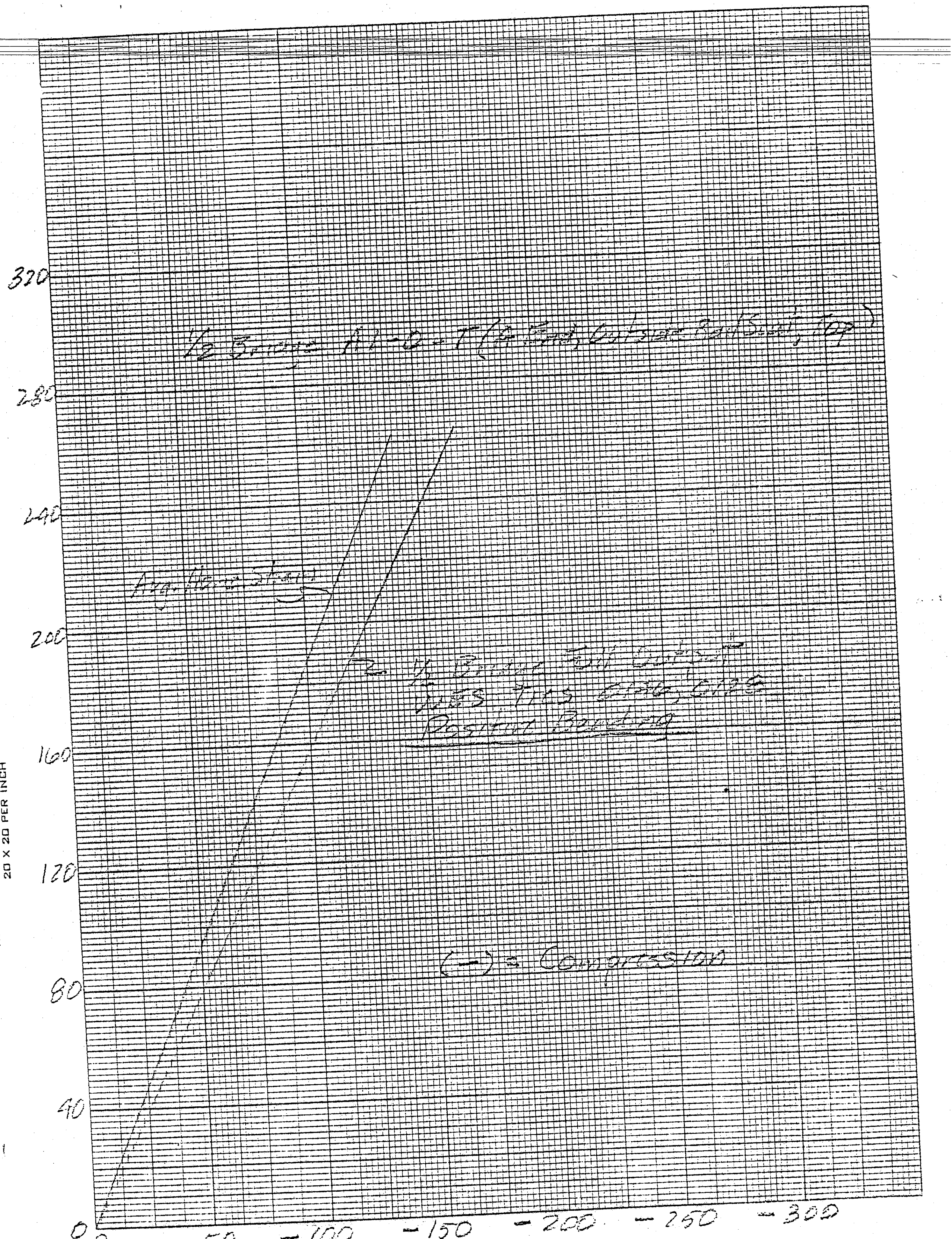
A1-O-BH
- A: "A" END (OR "B" END)
- 1: FACE #1 (OR FACE #2)
- O: OUTSIDE RAIL SEAT (OR INSIDE, OMITTED UNDER RAIL SEAT OR CENTER)
- B: BOTTOM (OR TOP)
- H: HORIZONTAL GAGE (OR VERTICAL)

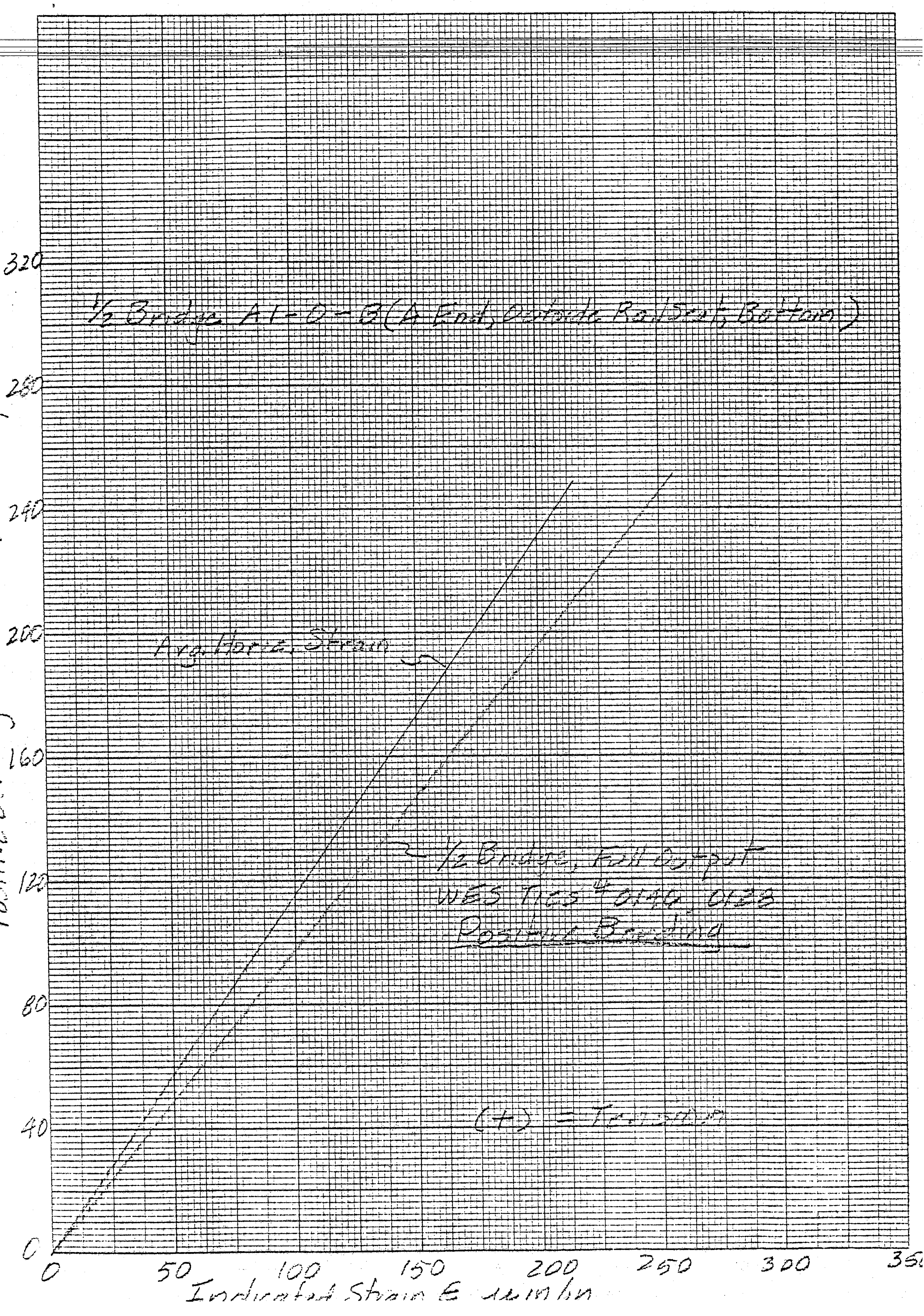
LAST TWO SYMBOLS BECOME H1 (HORIZONTAL, GAGE 1) ETC., FOR STACKED GAGES INSIDE "B" RAIL SEAT

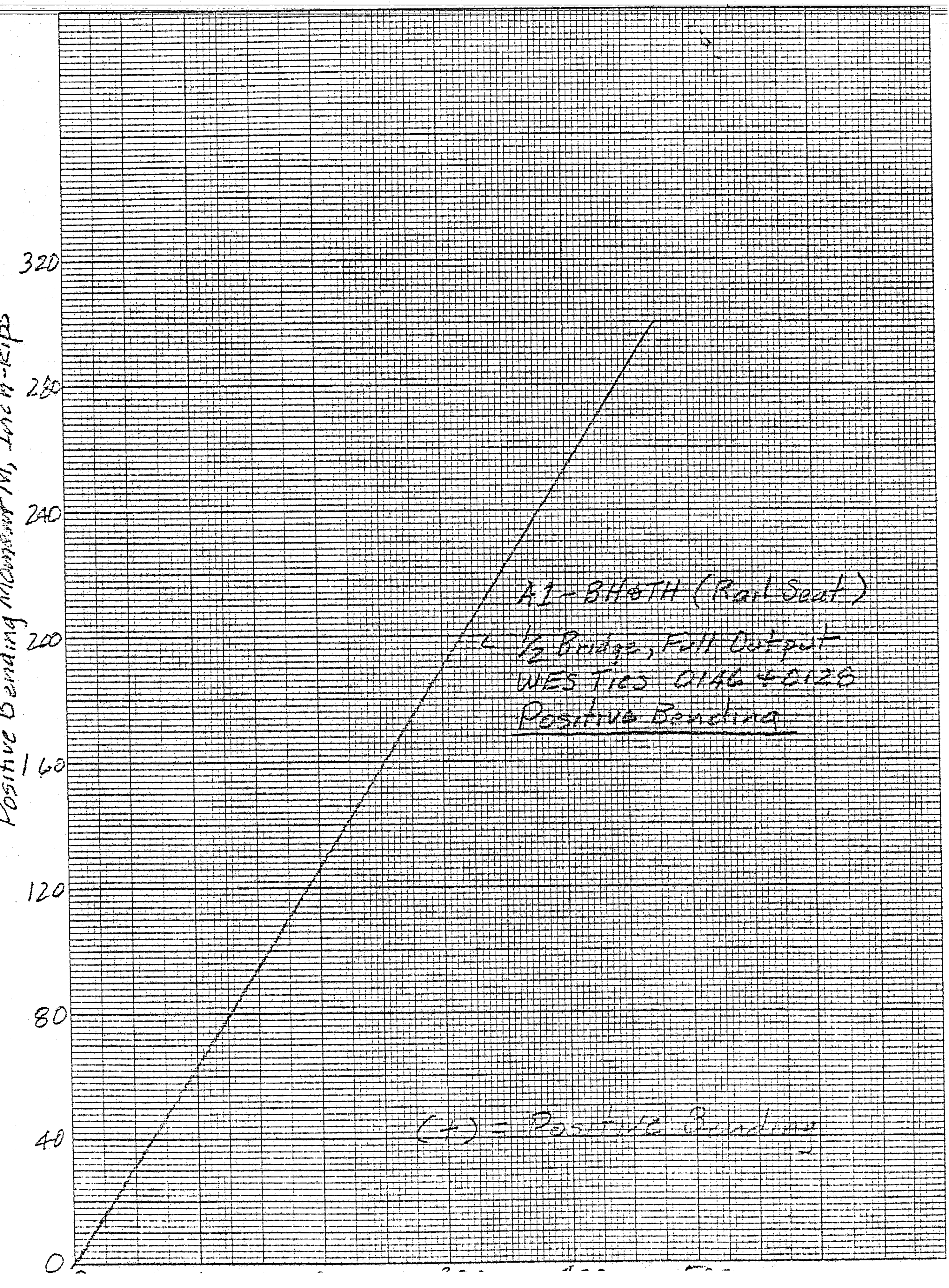
◌ SEE DETAIL DRAWING OF SPECIAL GAGE ARRAY BENEATH "B" RAIL SEAT OF TIE #0146

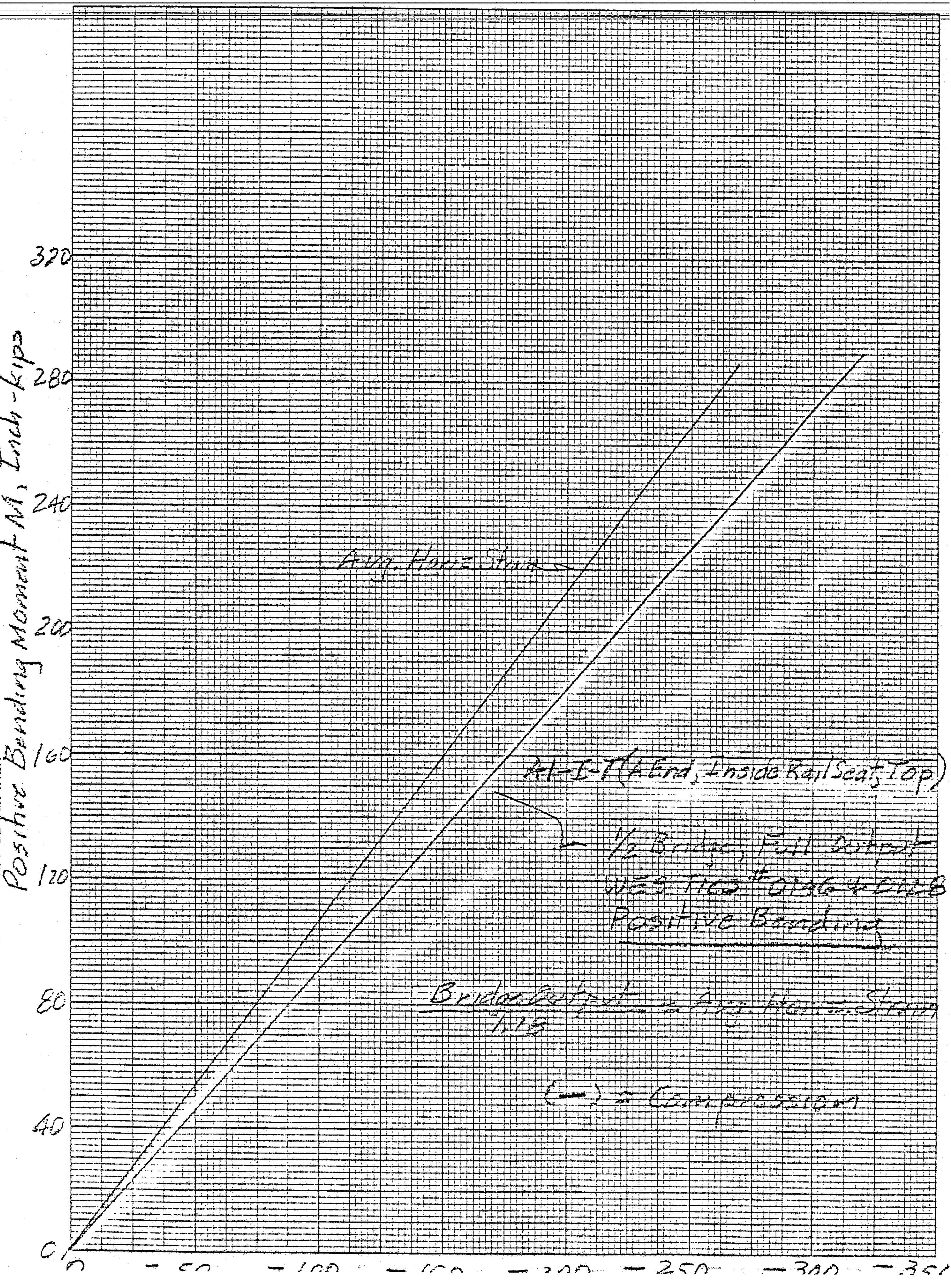
SUBJECT: WES Crossties ATTN: MEL LEVINE GERRY MATTHEWS	COMPUTED BY:	DATE:	FILE NO. 3
	CHECKED BY:	DATE:	SHEET NO.

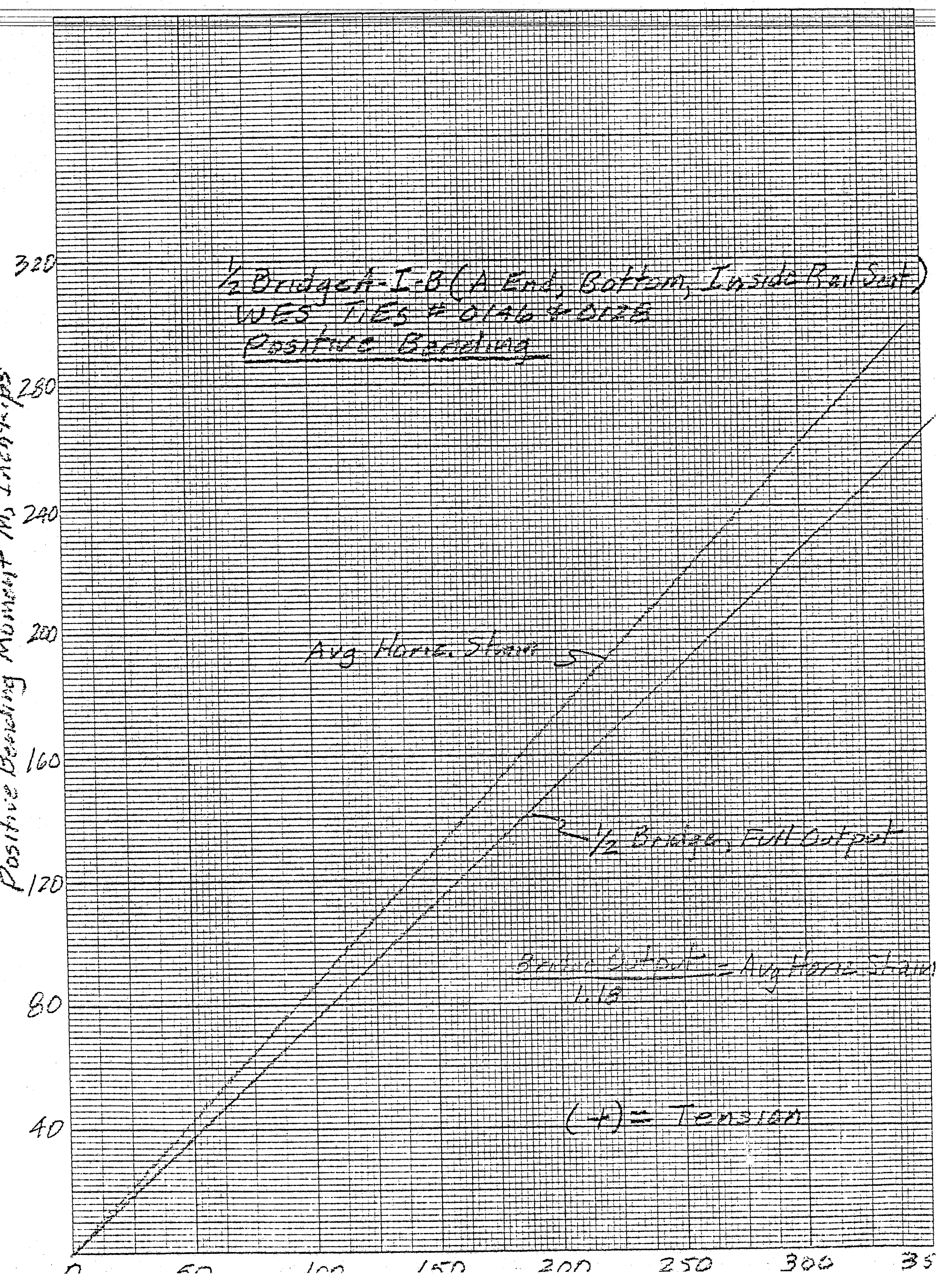
WES FORM NO. 1253
REV OCT 1968

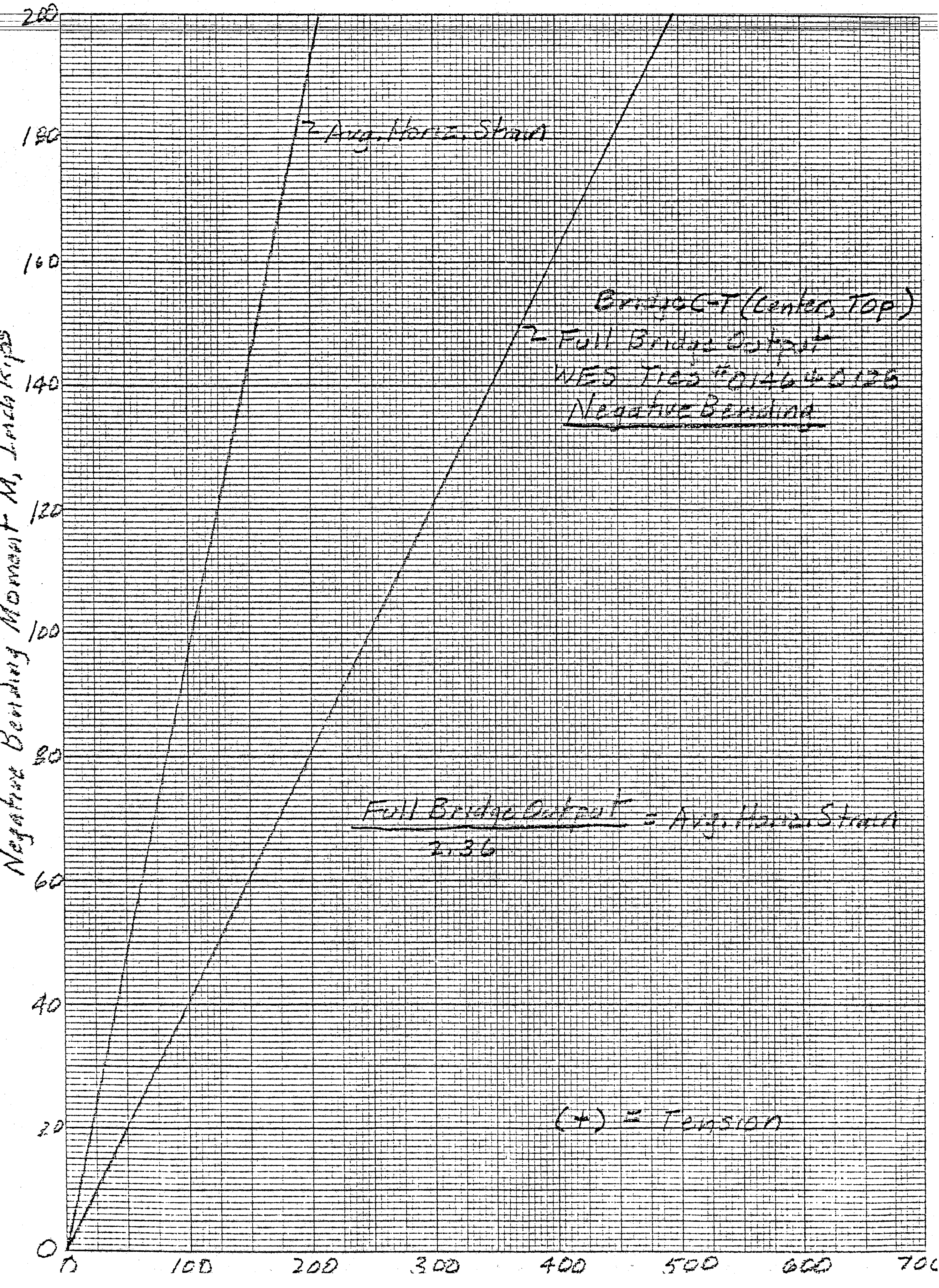

½ Bridge A1-O-T (A End, Outside Rail Seat, Top)
Avg. Hand Strain
½ Bridge Full Output Was This Large, Due to Positive Bending
(—) = Compression
320
280
240
200
160
120
80
40
0
0
-50
-100
-150
-200
-250
-300


½ Bridge A1-O-B (A End, Outside Rail Seat, Bottom)
Avg. Horiz. Strain
½ Bridge, Full output
WES Ties #0140, 0123
Positive Bending
(+) = Tension
Positive Bending Moment, M, Inch Kips
0
40
80
120
160
200
240
280
320
0
50
100
150
200
250
300
350
Indicated Strain ε μin/in
DIETZGEN CORPORATION
MADE IN U.S.A.
NO. 340-20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH


Positive Bending Moment M, Inch-kips
320
280
240
200
160
120
80
40
0
A1-BH8TH (Rail Seat)
½ Bridge, Full Output
WES Ties 0146 & 0128
Positive Bending
(+) = Positive Bending


Positive Bending Moment At, Inch-kips
320
280
240
200
160
120
80
40
0
0
- 50
- 100
- 150
- 200
- 250
- 300
- 35
Avg. Horiz Strain
A1-I-T (A End, Inside Rail Seat, Top)
1/2 Bridge, Full Output
WES Ties #0146 + 0128
Positive Bending
Bridge Output / 1.15 = Avg. Horiz. Strain
(—) = Compression


½ Bridge A-I-B (A End, Bottom, Inside Rail Seat)
WES TIES # 0146 & 0128
Positive Bending
Positive Bending Moment M, Inch-kips
320
280
240
200
160
120
80
40
0
50
100
150
200
250
300
35
Avg. Horiz. Strain
½ Bridge, Full Output
Bridge Output / 1.18 = Avg Horiz Strain
(+) = Tension


Negative Bending Moment M, Inch kips
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
70
Avg. Horiz. Strain
Bridge C-T (Center Top)
Full Bridge Output
WES Test #01460126
Negative Bending
Full Bridge Output / 2.36 = Avg. Horiz. Strain
(+) = Tension

INCLOSURE 1

Calibration Test Results
On Replicate Ties

SUBJECT:

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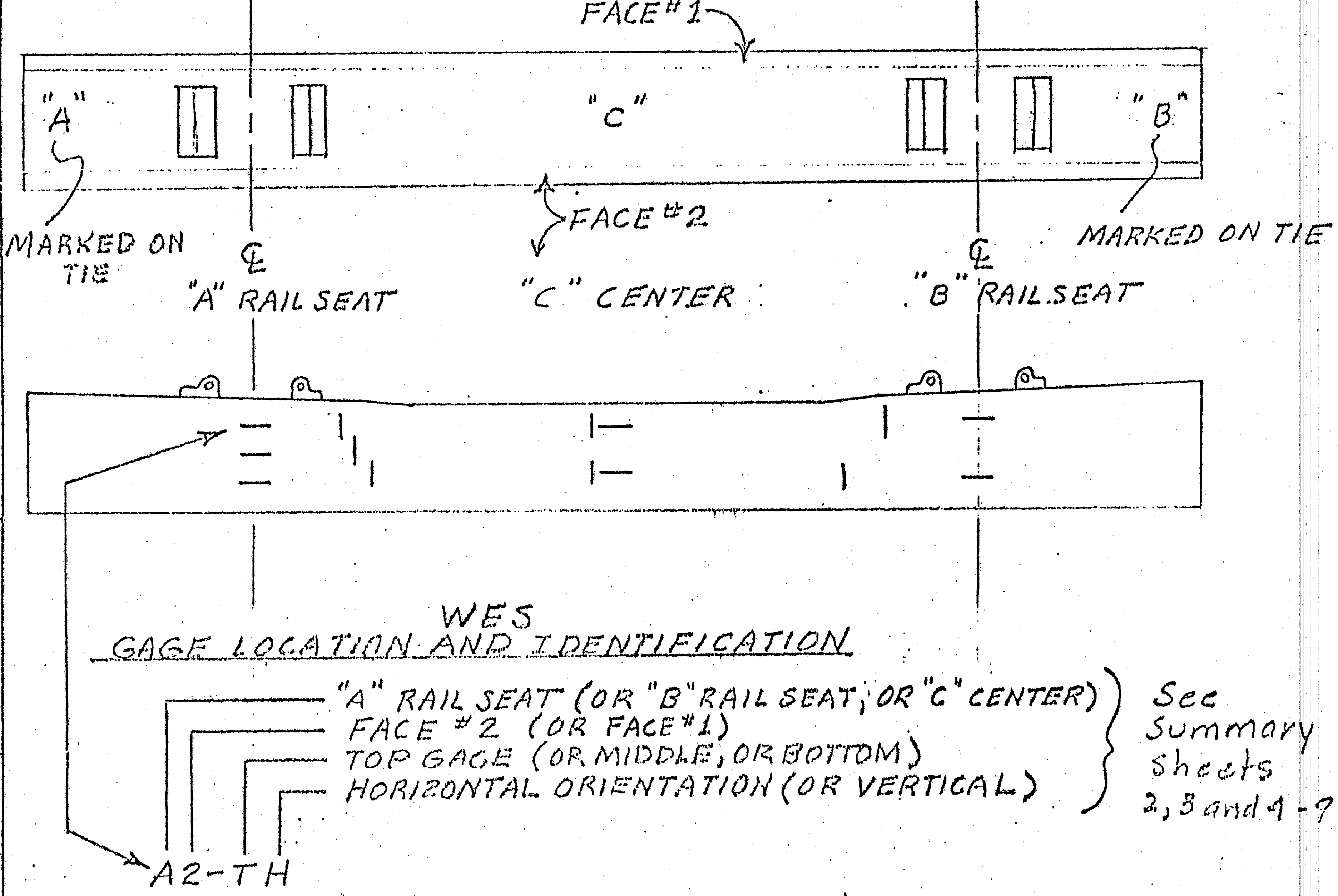
FILE NO.

SHEET NO.

TOP VIEW OF 244-C CROSSTIE (WES-Instrumented)



Note: FACE 1 AND FACE 2 GAGE PATTERNS ARE IDENTICAL (MIRROR IMAGES)

Fig 1 9-13-76 SSL

SHEET NO.

DATE:

CHECKED BY:

Summary Of Gage Locations (As Built) "A" Rail Seat

Gage Designation	Gage Location	Full Bridge Designation
A1-TH	Horizontal gage, 2.5" above centroid, Face 1	A-T (Top Bridge)
A2-TH	Horizontal gage, 2.5" above centroid, Face 2	
A1-TV	Vertical gage, companion to A1-TH, Face 1	
A2-TV	Vertical gage, companion to A2-TH, Face 2	
A1-MH	Horizontal gage, on centroid, Face 1	A-M (Middle Bridge)
A2-MH	Horizontal gage, on centroid, Face 2	
A1-MV	Vertical gage, companion to A1-MH, Face 1	
A2-MV	Vertical gage, companion to A2-MH, Face 2	
A1-BH	Horizontal gage, 2.5" below centroid, Face 1	A-B (Bottom Bridge)
A2-BH	Horizontal gage, 2.5" below centroid, Face 2	
A1-BV	Vertical gage, companion to A1-BH, Face 1	
A2-BV	Vertical gage, companion to A2-BH, Face 2	

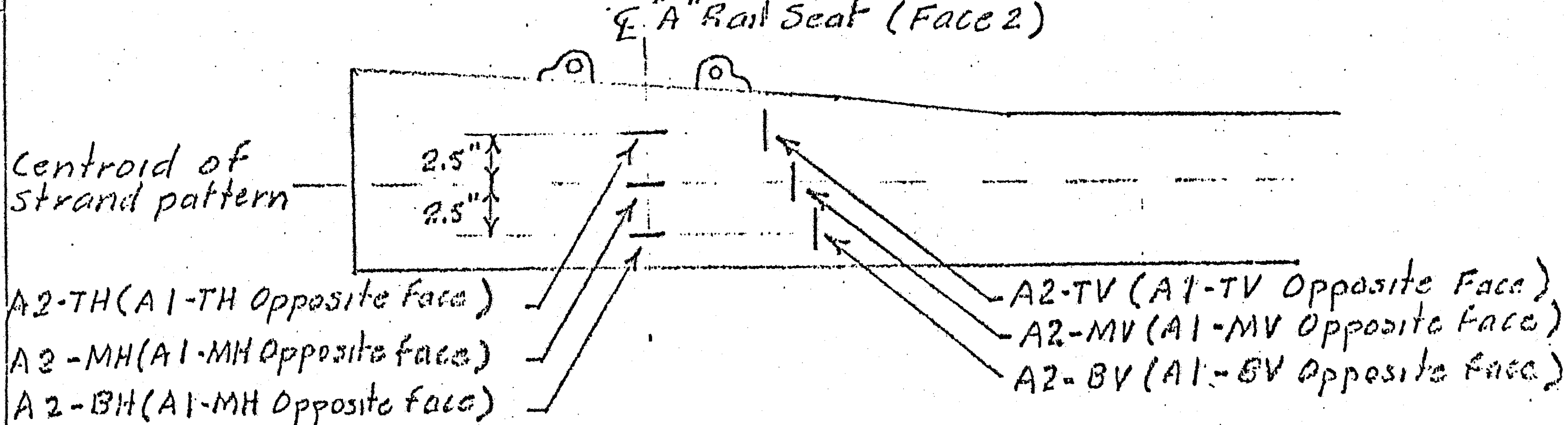


Fig 2

9-13-76 SSG

SUBJECT:

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Summary Of Gage Locations (As Built)

"C", Center Of Tie

Gage Designation	Gage Location	Full Bridge Designation
C1-TH	Horizontal gage, 1.75" above centroid, Face 1	C-T (Top Bridge)
C2-TH	Horizontal gage, 1.75" above centroid, Face 2	
C1-TV	Vertical gage, companion to C1-TH, Face 1	
C2-TV	Vertical gage, companion to C2-TH, Face 2	
C1-BH	Horizontal gage, 1.75" below centroid, Face 1	C-B (Bottom Bridge)
C2-BH	Horizontal gage, 1.75" below centroid, Face 2	
C1-BV	Vertical gage, companion to C1-BH, Face 1	
C2-BV	Vertical gage, companion to C2-BH, Face 2	

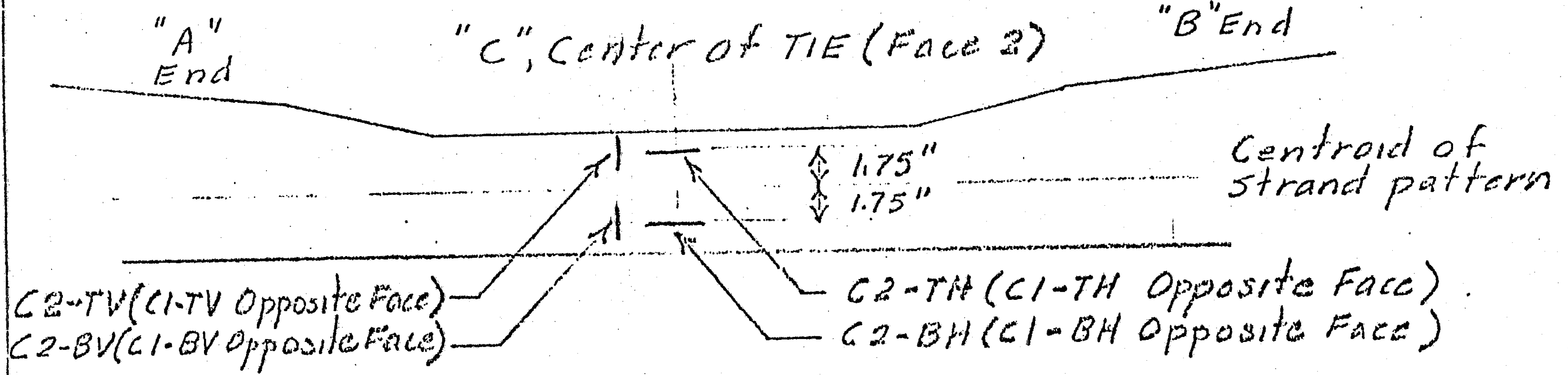

Fig 3

9-13-76 SSC

FILE NO.
SHEET NO.
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DATE:
COMPUTED BY:
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SUBJECT:

Summary Of Gage Locations (As Built)
"B" Rail Seat

Gage Designation	Gage Location	Full Bridge Designation
B1-TH	Horizontal gage, 2.5" above centroid, Face 1	B-T (Top Bridge)
B2-TH	Horizontal gage, 2.5" above centroid, Face 2	
B1-TV	Vertical gage, companion to B1-TH, Face 1	
B2-TV	Vertical gage, companion to B2-TH, Face 2	
B1-BH	Horizontal gage, 2.5" below centroid, Face 1	B-B (Bottom Bridge)
B2-BH	Horizontal gage, 2.5" below centroid, Face 2	
B1-BV	Vertical gage, companion to B1-BH, Face 1	
B2-BV	Vertical gage, companion to B2-BH, Face 2	

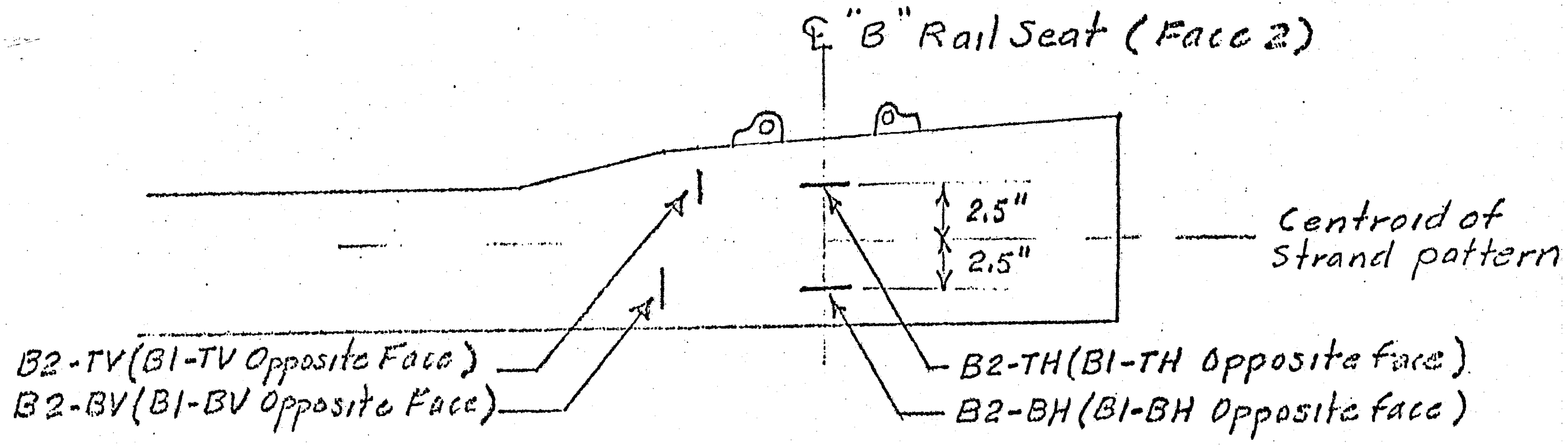

Fig 4

9-13-76 SSC

FILE NO.

SHEET NO.

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SUBJECT:

Summary Of Gage Locations (As Built)
"B" Rail Seat

Gage Designation	Gage Location	Full Bridge Designation
B1-TH	Horizontal gage, 2.5" above centroid, Face 1	B-T (Top Bridge)
B2-TH	Horizontal gage, 2.5" above centroid, Face 2	
B1-TV	Vertical gage, companion to B1-TH, Face 1	
B2-TV	Vertical gage, companion to B2-TH, Face 2	
B1-BH	Horizontal gage, 2.5" below centroid, Face 1	B-B (Bottom Bridge)
B2-BH	Horizontal gage, 2.5" below centroid, Face 2	
B1-BV	Vertical gage, companion to B1-BH, Face 1	
B2-BV	Vertical gage, companion to B2-BH, Face 2	

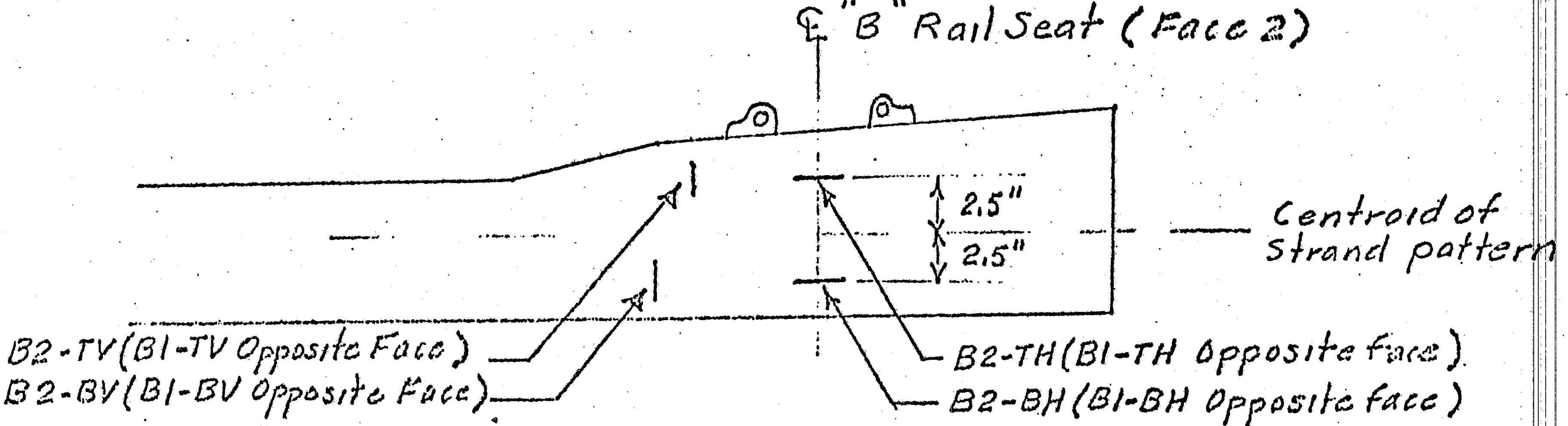

Fig 4

9-13-76 SSG

FORM NO. 1253

FILE NO.

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DATE:

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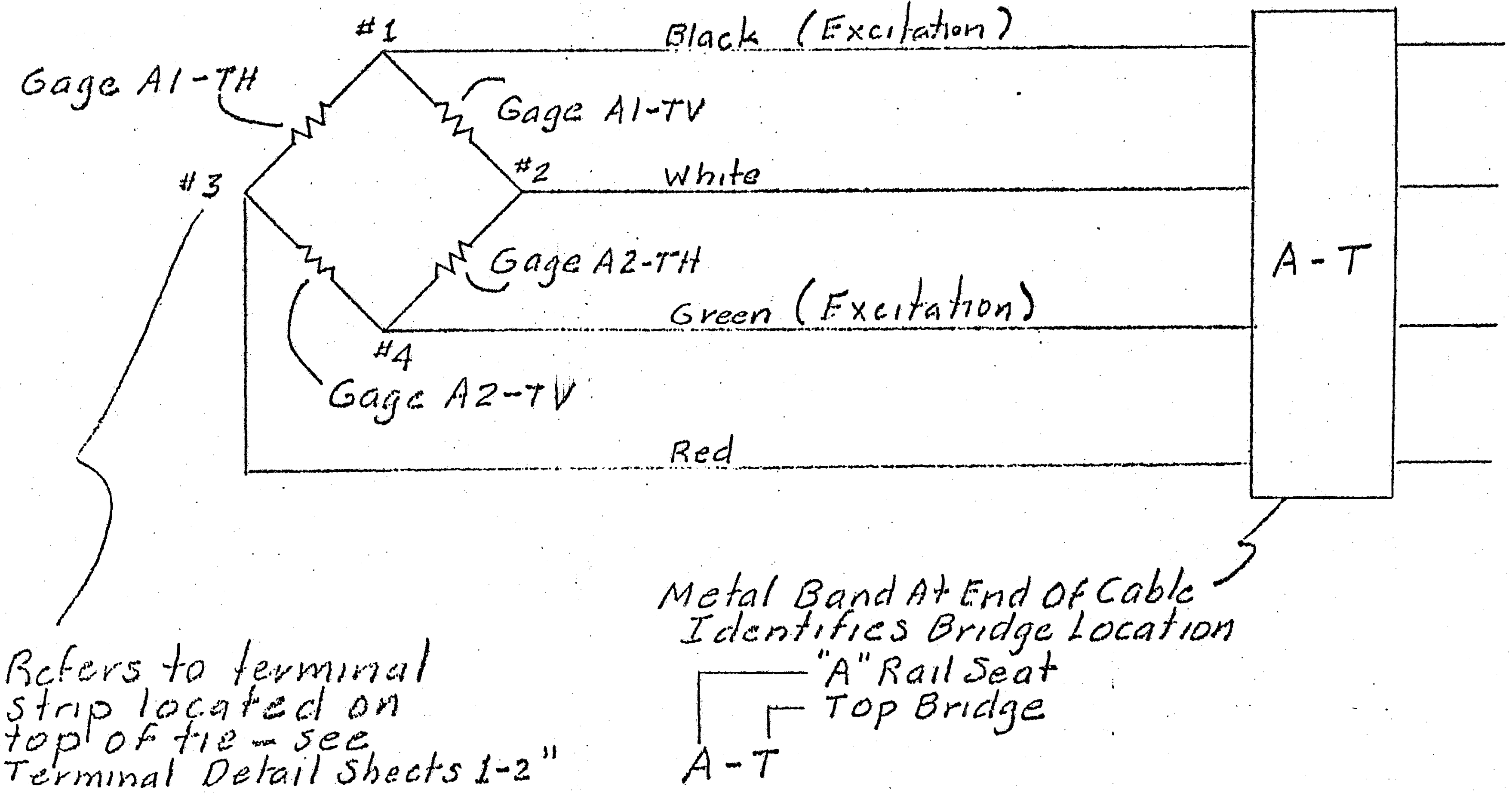
SUBJECT:

Typical Wiring Diagram

(Example shown is for top bridge, "A" Rail Seat)



Refers to terminal strip located on top of tie – see "Terminal Detail Sheets 1-2"

Metal Band At End Of Cable Identifies Bridge Location

Fig 5

9-13-76 SSG

1253

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DATE:

DATE:

FILE NO.

SHEET NO.

Terminal Detail Sheet 1

Location Of Bridge Terminals

Top View Of Tie

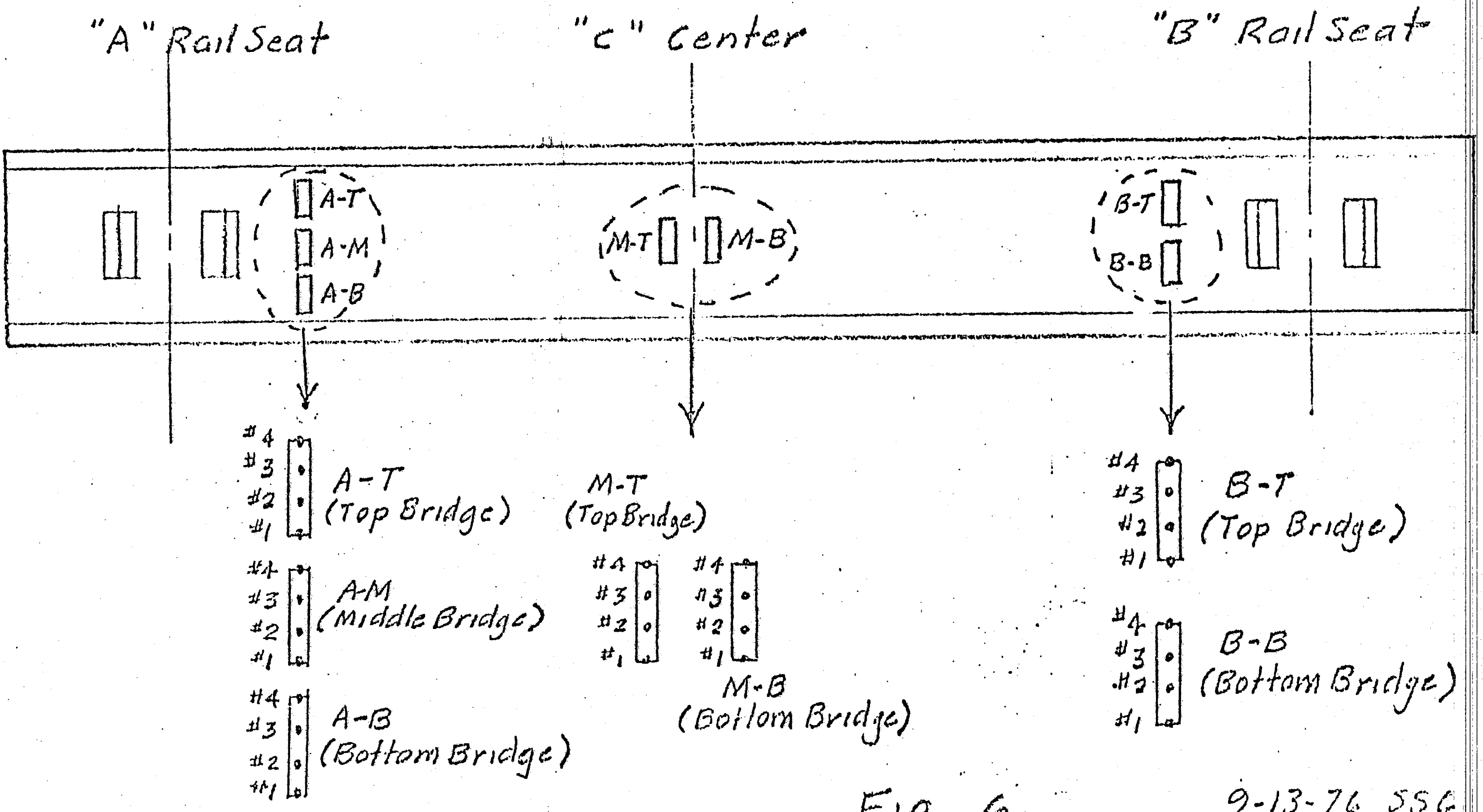

Fig 6

9-13-76 SSG

WES FORM NO. 1253
REV OCT 1966

SHEET NO.

DATE:

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Terminal Detail Sheet 2

Cross-Section of Typical Terminal Covering

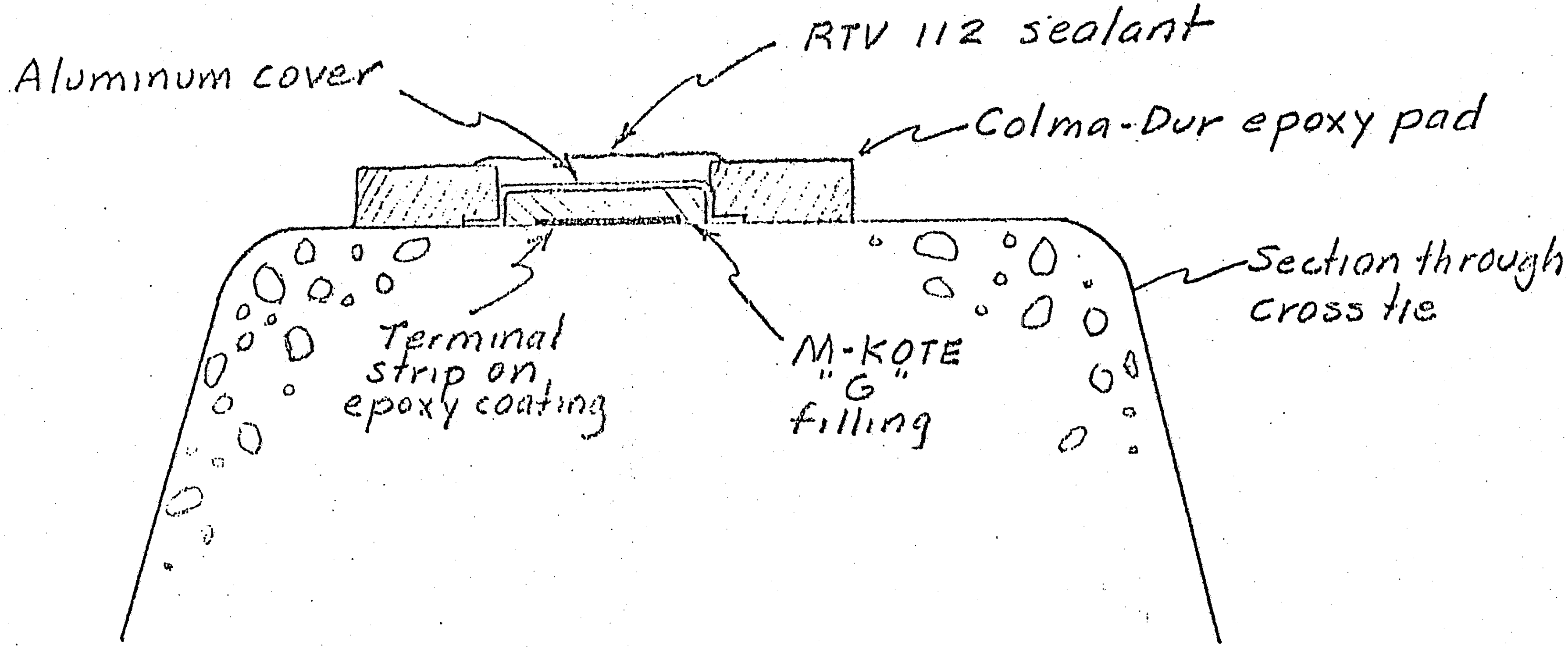
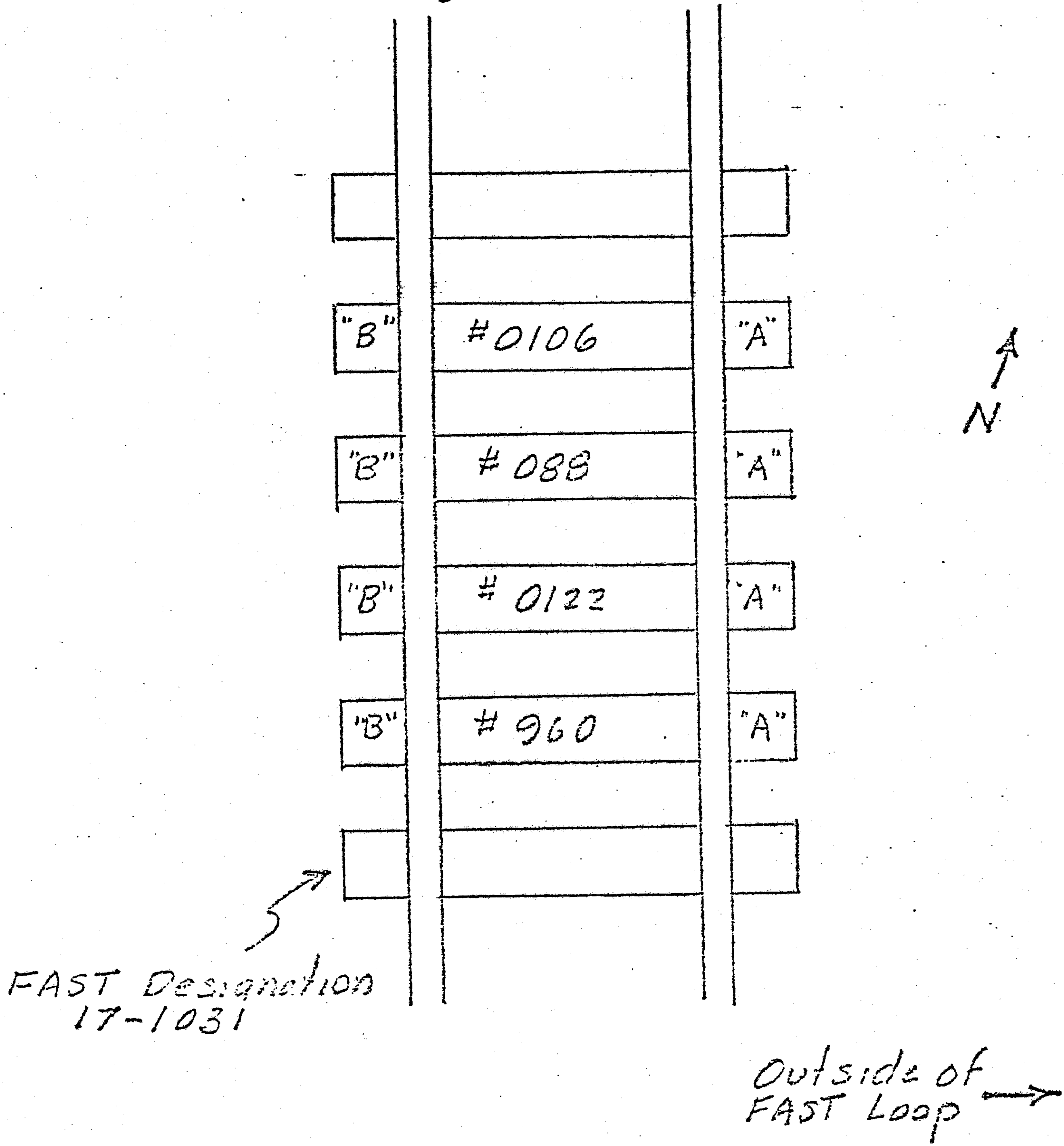


Fig 7

9-13-76 SSG

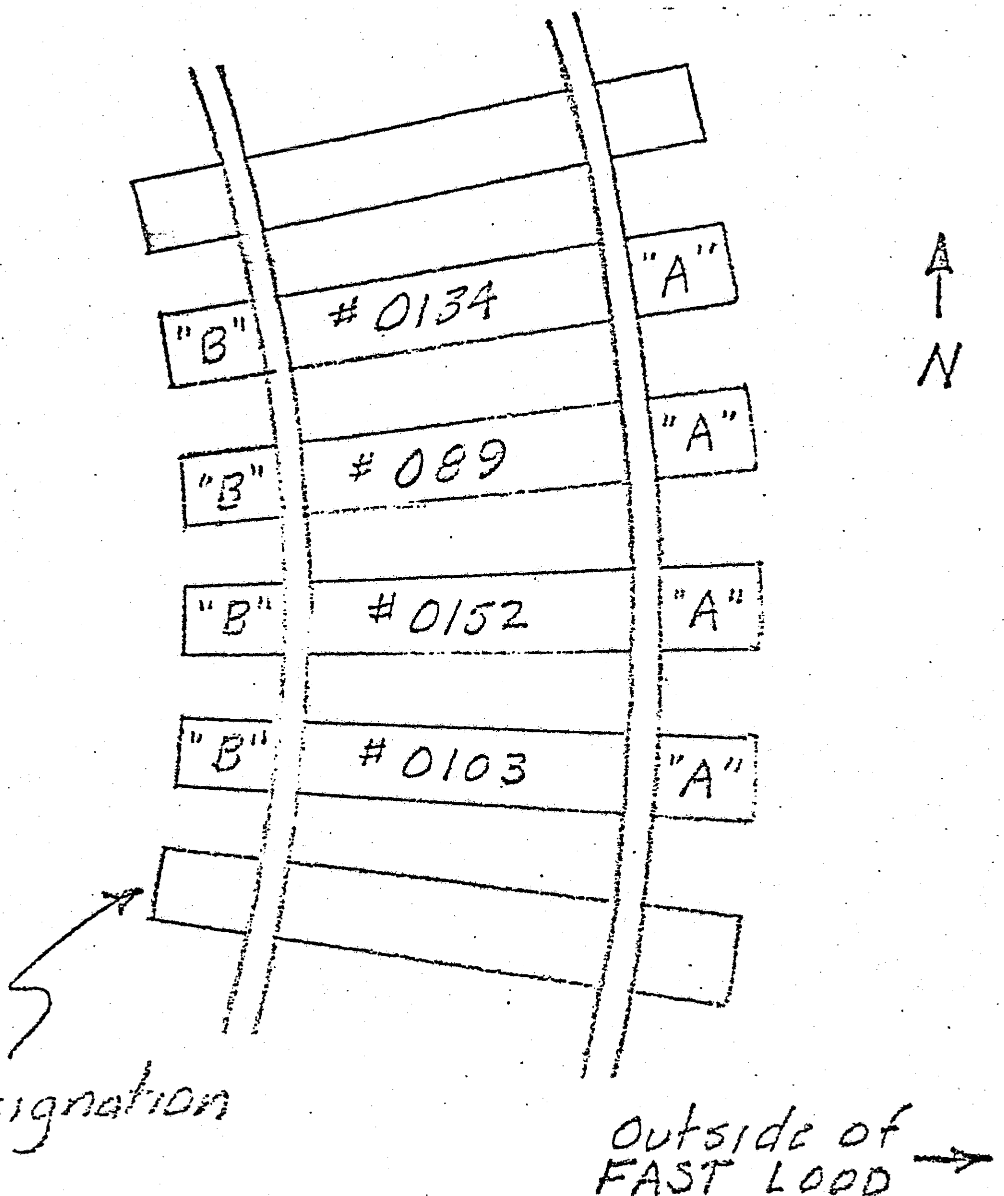
SUBJECT:	COMPUTED BY:	DATE:	FILE NO.
	CHECKED BY:	DATE:	SHEET NO.

Location of WES-Instrumented Ties
FAST Section 17E
Tangent Track

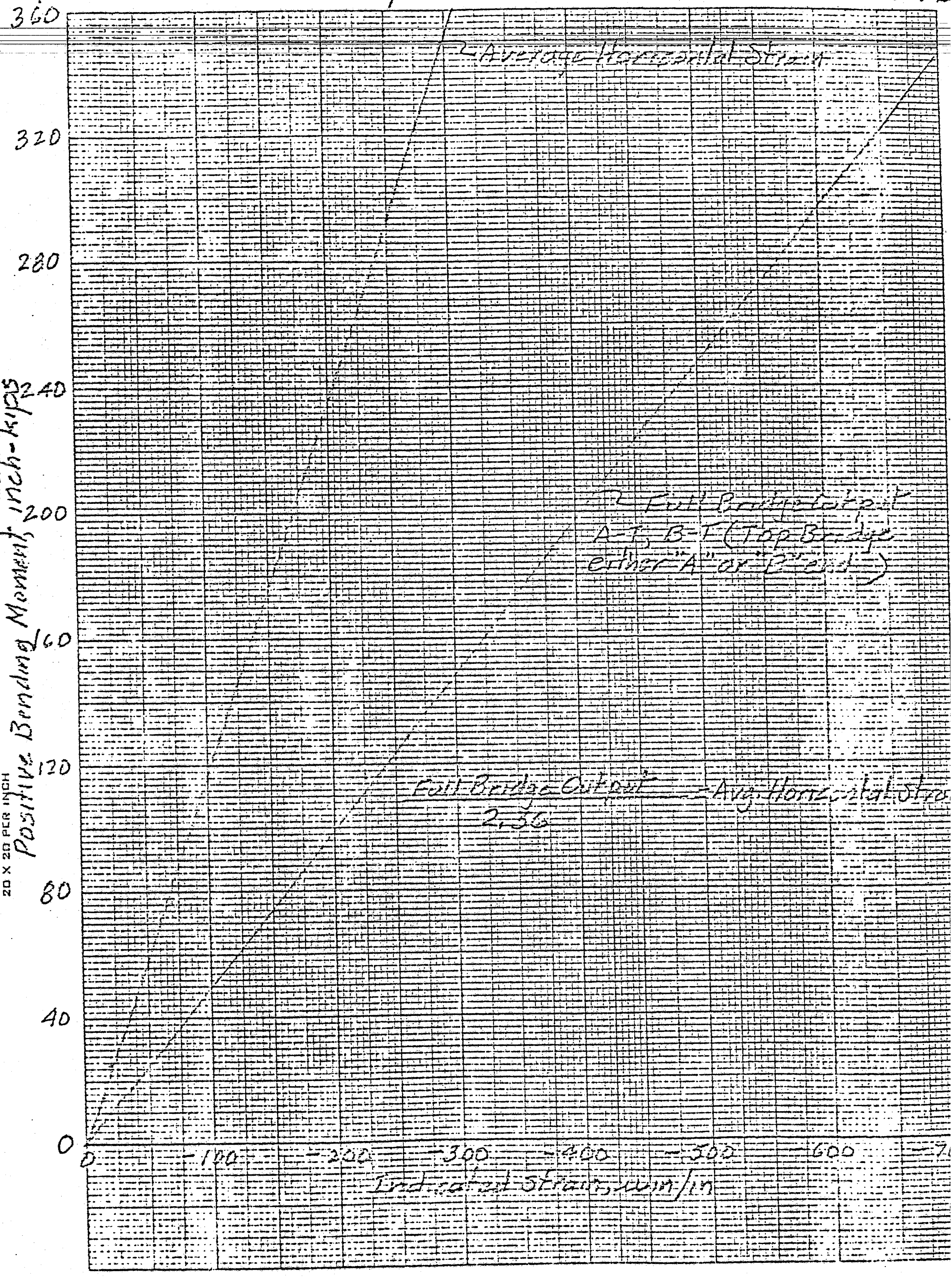


SUBJECT:	COMPUTED BY:	DATE:	FILE NO.
	CHECKED BY:	DATE:	SHEET NO.

Location Of WES-Instrumented Ties
FAST Section 17E
Curved Track



WES- Preliminary Calibration Curves - FAST 9-14-76



SUBJECT WES SIMULATED (STATIC) SERVICE LOADING TEST

DATE 28 Mar 77

PAGE OF PAGES

OURCE OF DATA CONFORCE COSTAIN TYPE 244-C CROSSTIE #0143

COMPUTED BY

CHECKED BY

SECTION

APPLIED LOAD P/2, LBS		DEFLECTION, INCHES							
		DIAL GAGE #1	DIAL GAGE #2	DIAL GAGE #3	DIAL GAGE #4	DIAL GAGE #5	DIAL GAGE #6	DIAL GAGE #7	DIAL GAGE #8
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5000		0.0446	0.0000	-0.0022	-0.0022	-0.0018	-0.0009	0.0001	0.0467
10000		0.0698	0.0000	-0.0023	-0.0022	-0.0015	0.0000	0.0002	0.0733
15000		0.0898	0.0001	-0.0024	-0.0021	-0.0012	0.0003	0.0004	0.0908
20000		0.1191	0.0002	-0.0024	-0.0018	-0.0006	0.0016	0.0007	0.1170
25000		0.1443	0.0004	-0.0019	-0.0011	0.0003	0.0028	0.0011	0.1409
				TEST #2					
0		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5000		0.0389	0.0000	-0.0005	-0.0005	-0.0005	0.0001	0.0001	0.0410
10000		0.0637	0.0001	-0.0005	-0.0005	0.0001	0.0009	0.0004	0.0677
15000		0.0895	0.0002	-0.0006	-0.0003	0.0004	0.0019	0.0008	0.0895
20000		0.1129	0.0003	-0.0006	0.0000	0.0009	0.0027	0.0010	0.1129
25000		0.1371	0.0005	0.0000	0.0008	0.0019	0.0040	0.0014	0.1348
0 000		0.1600	0.0009	0.0017	0.0025	0.0037	0.0057	0.0019	0.1515

SUBJECT:

COMPUTED BY:

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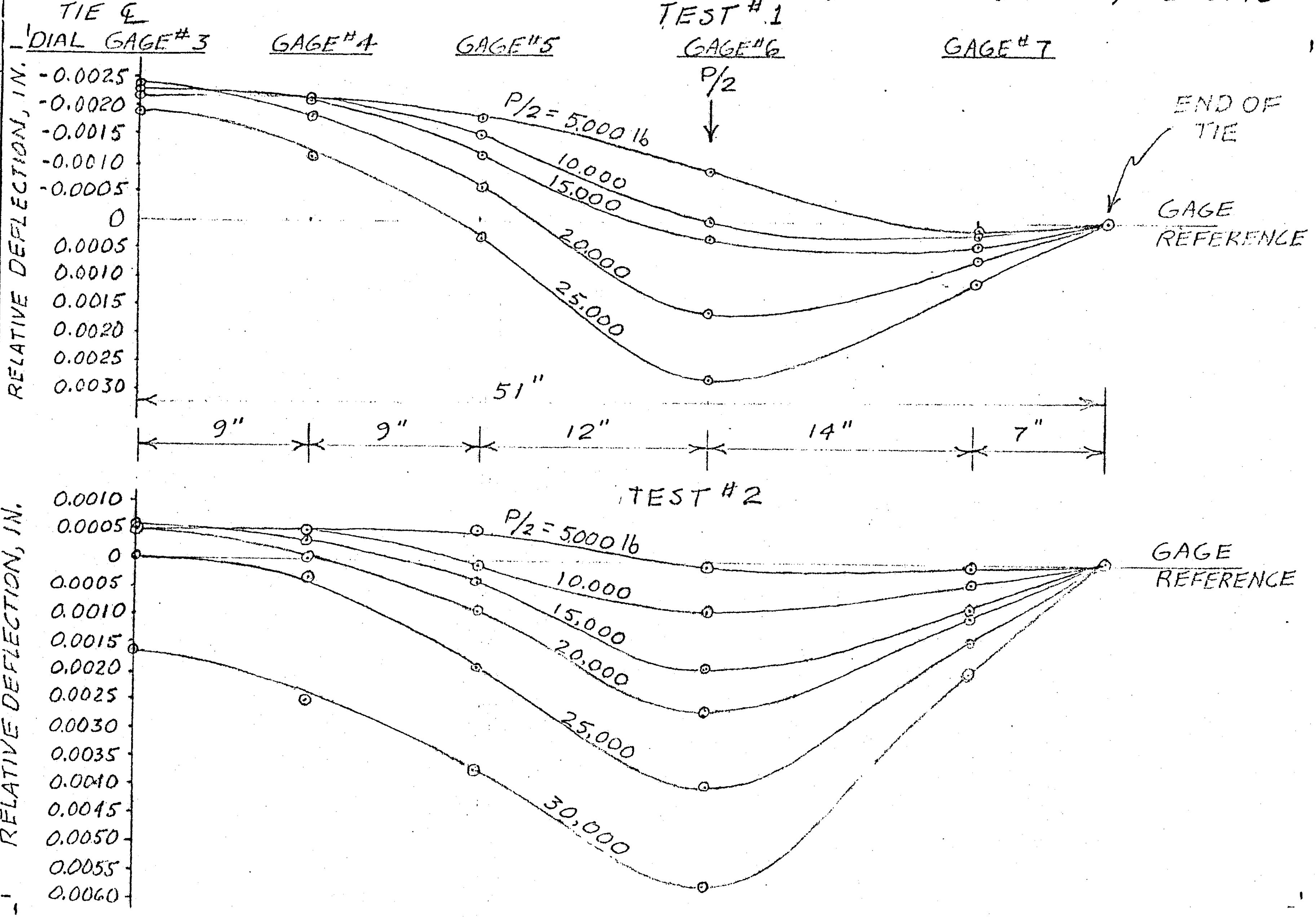
DATE:

DATE:

FILE NO.

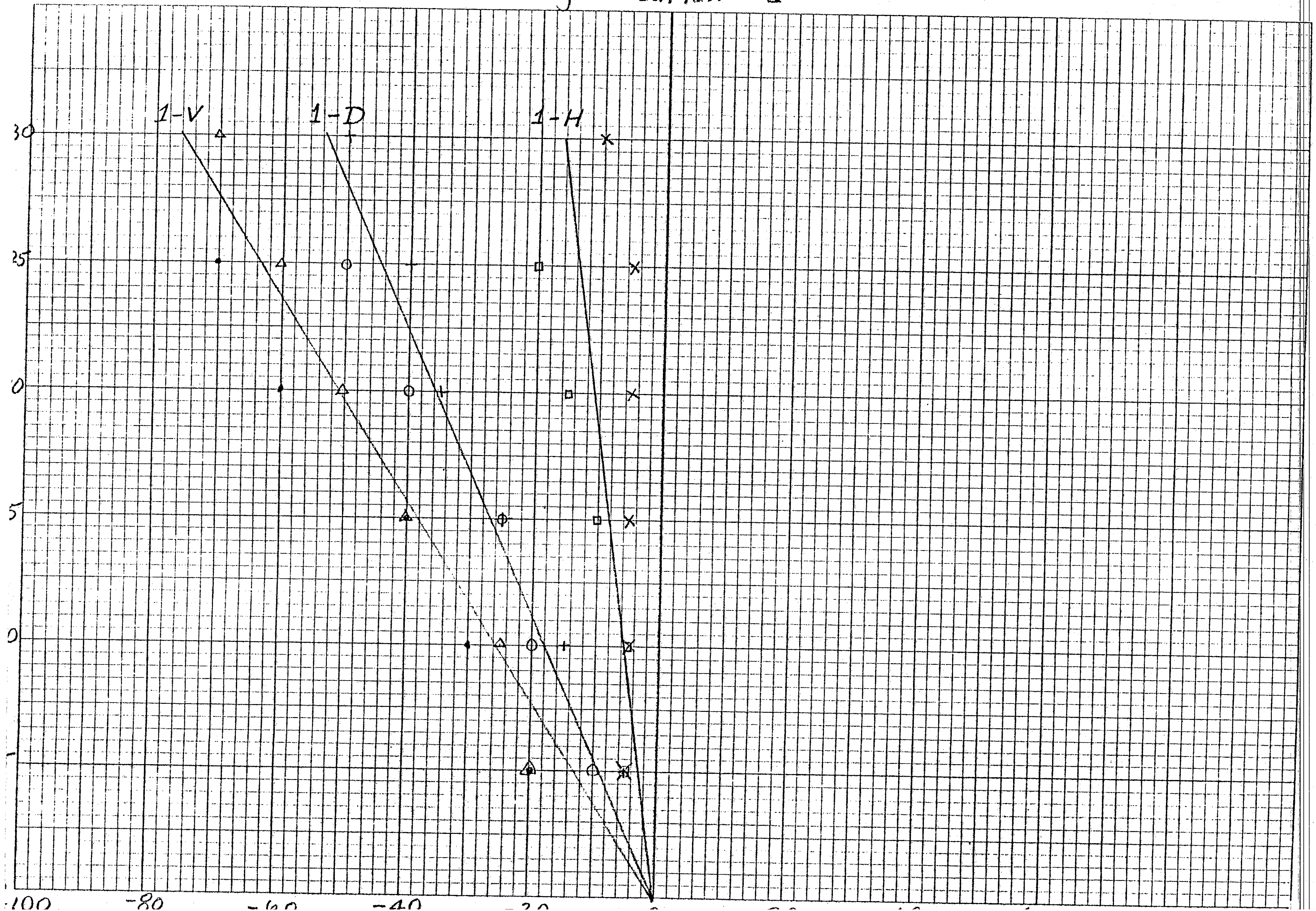
SHEET NO.

TIE DEFLECTION UNDER SIMULATED (STATIC) SERVICE LOADING, TIE #0143

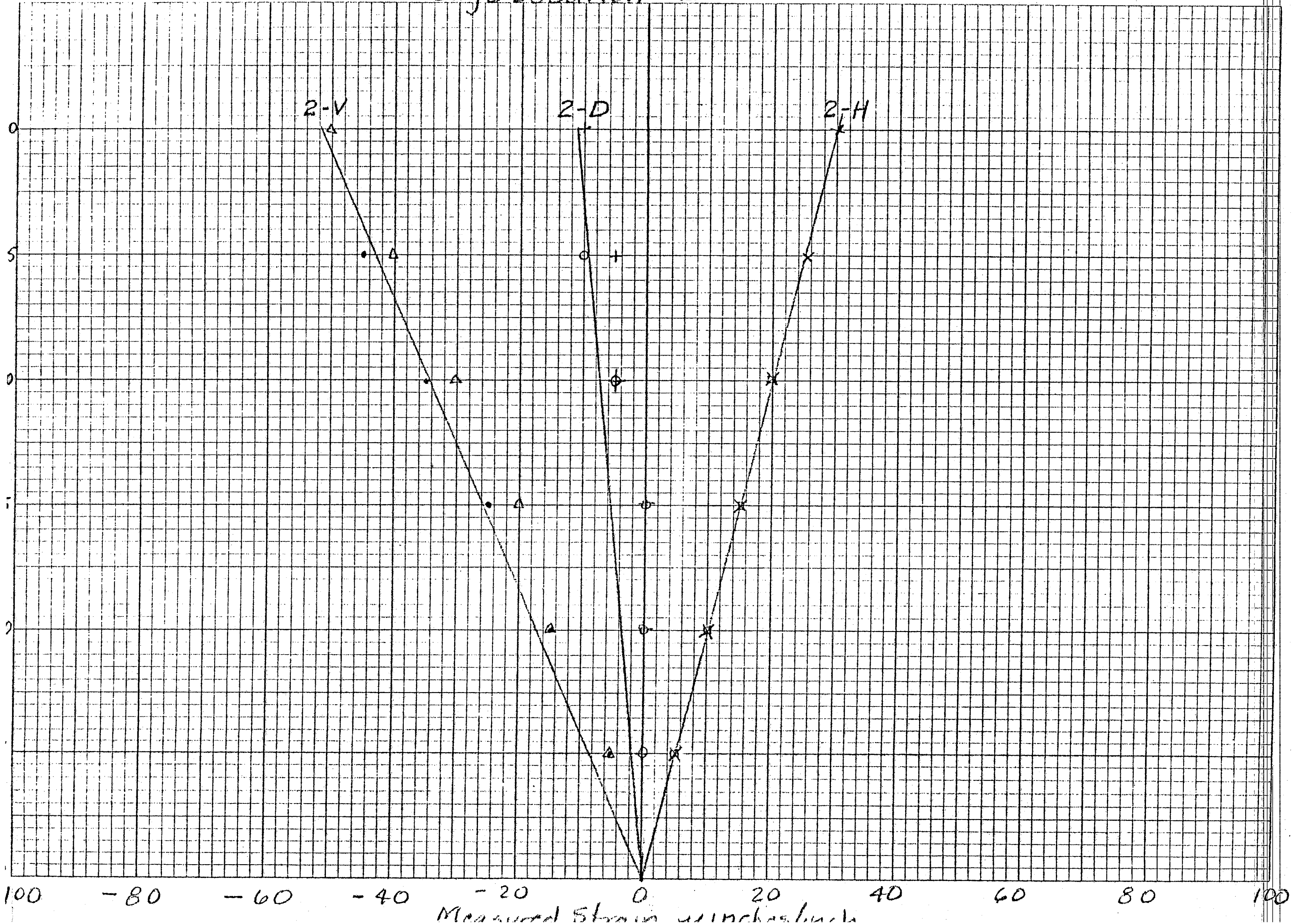


WES FORM NO. 1253

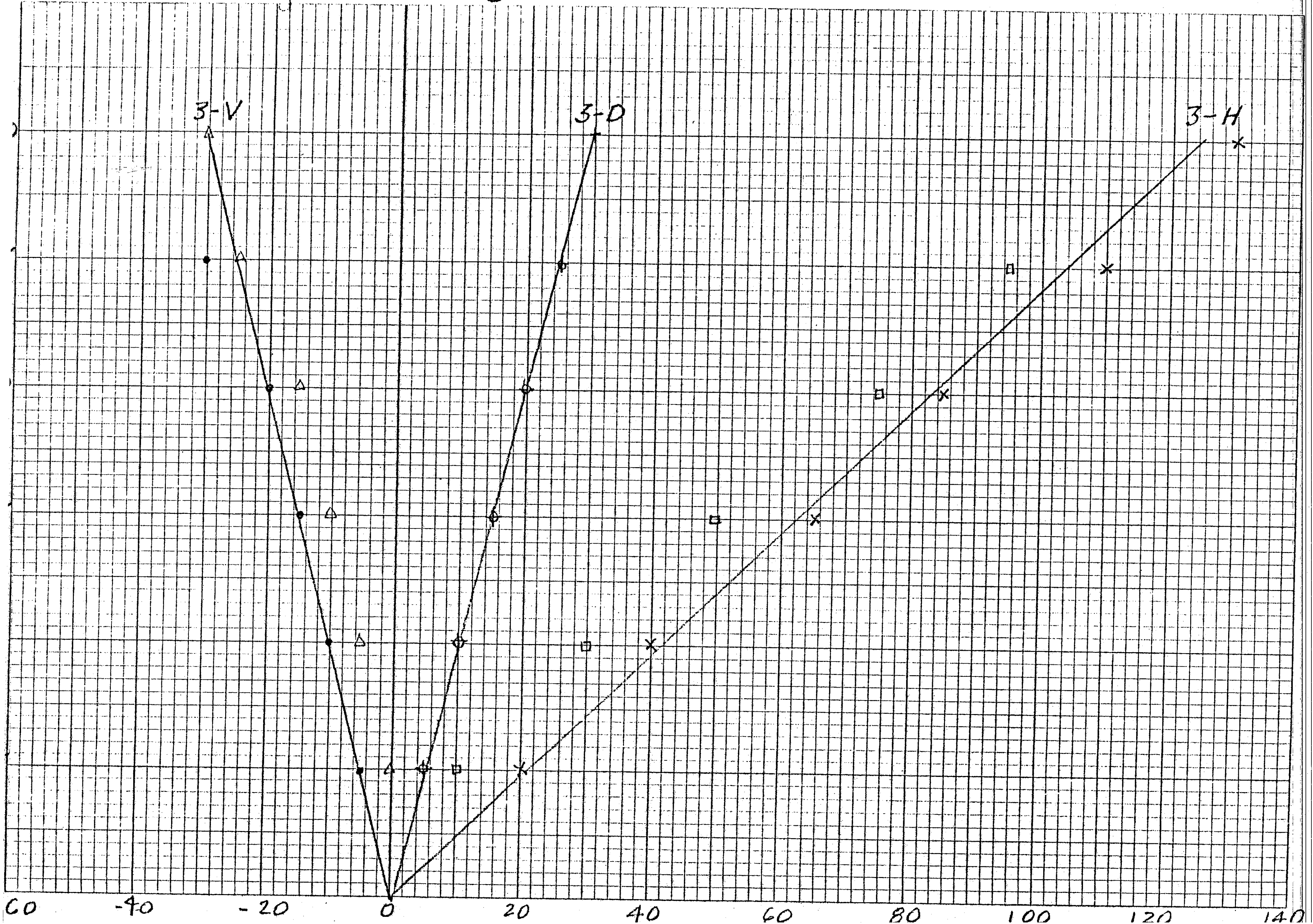
Gage Location #1

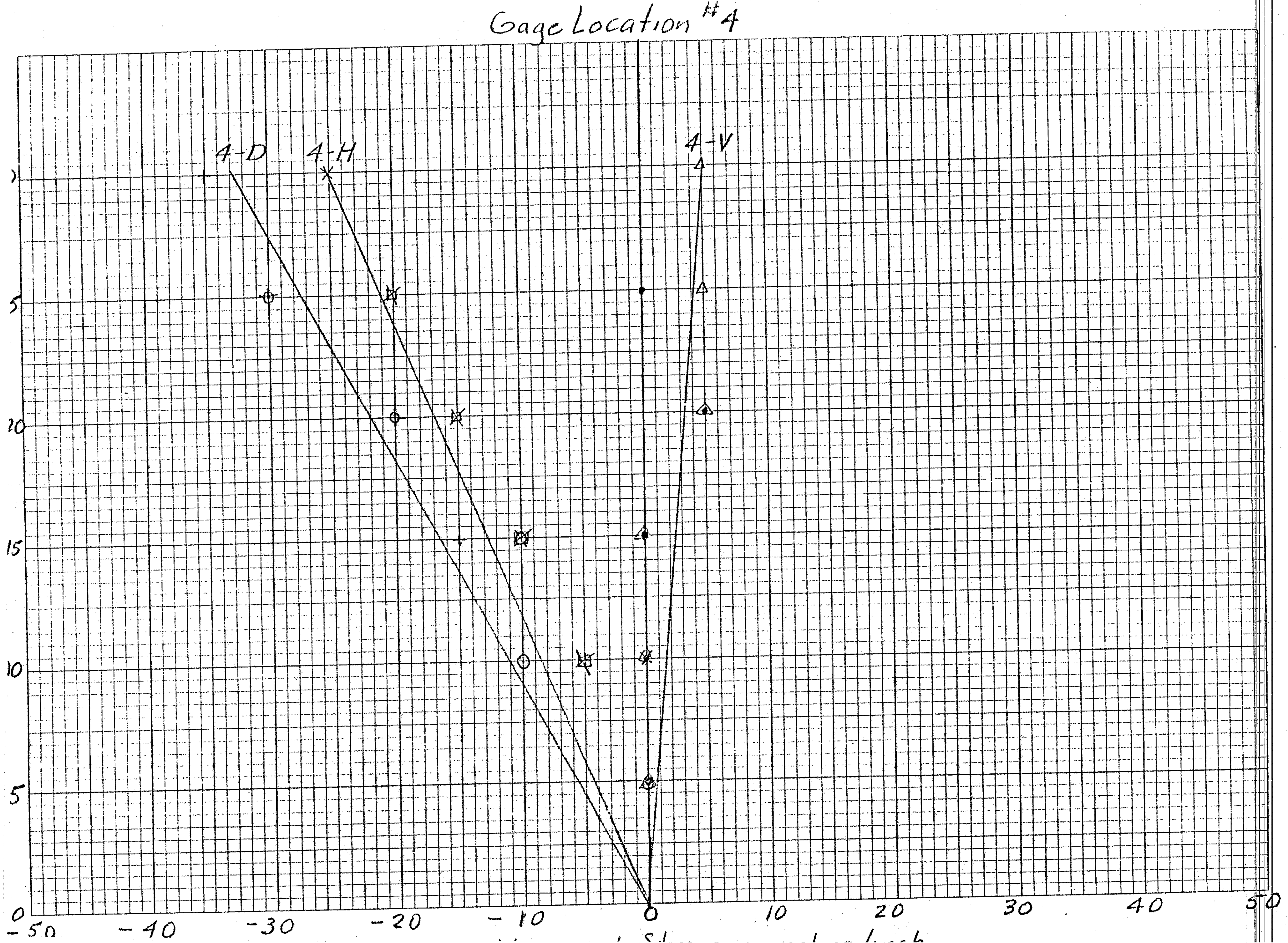


Gage Location #2



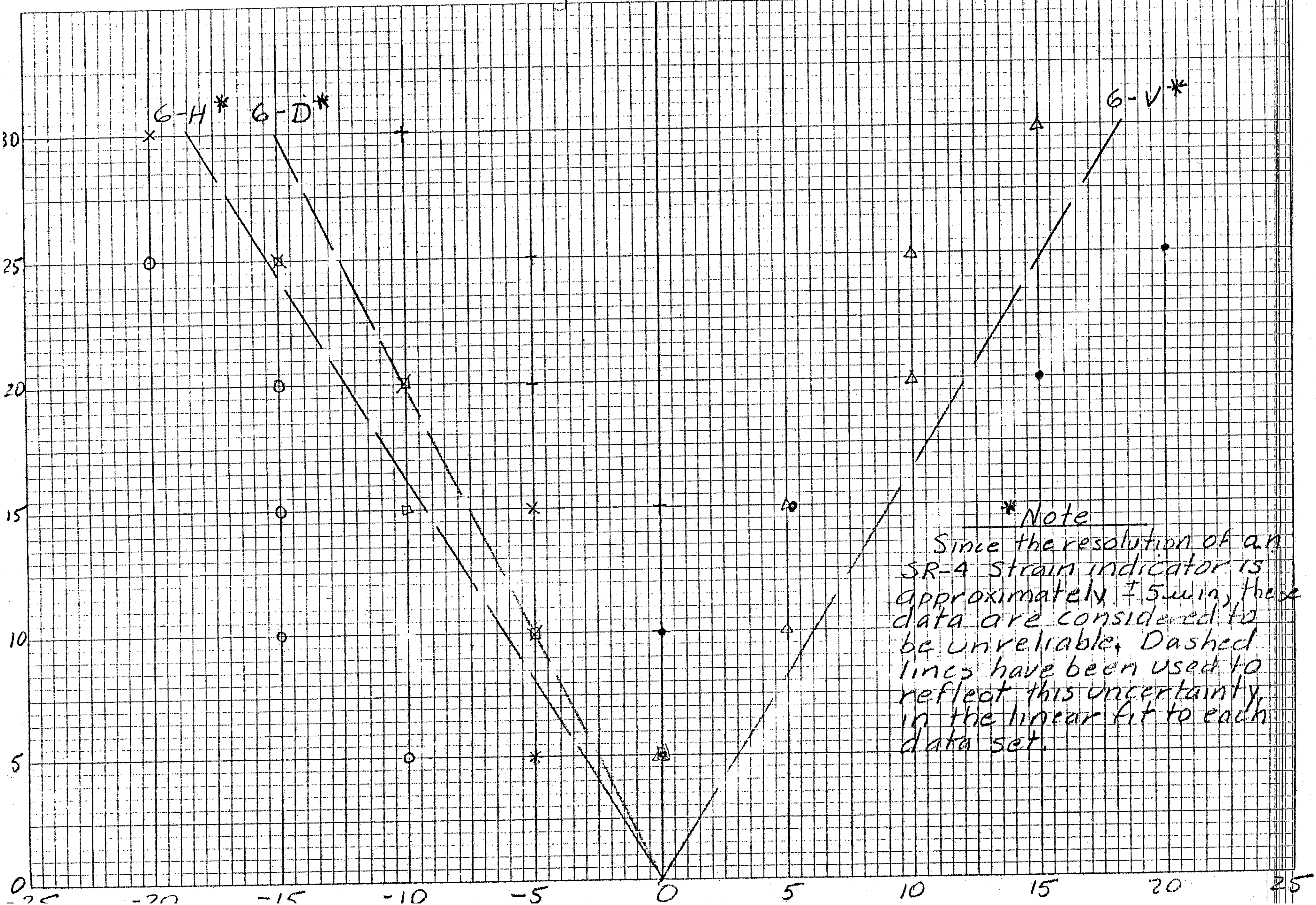
Gage Location #3




Gage Location #4
4-D
4-H
4-V
5
10
15
20
25
0
-50
-40
-30
-20
-10
0
10
20
30
40
50

Gage Location #5

Gage Location #6

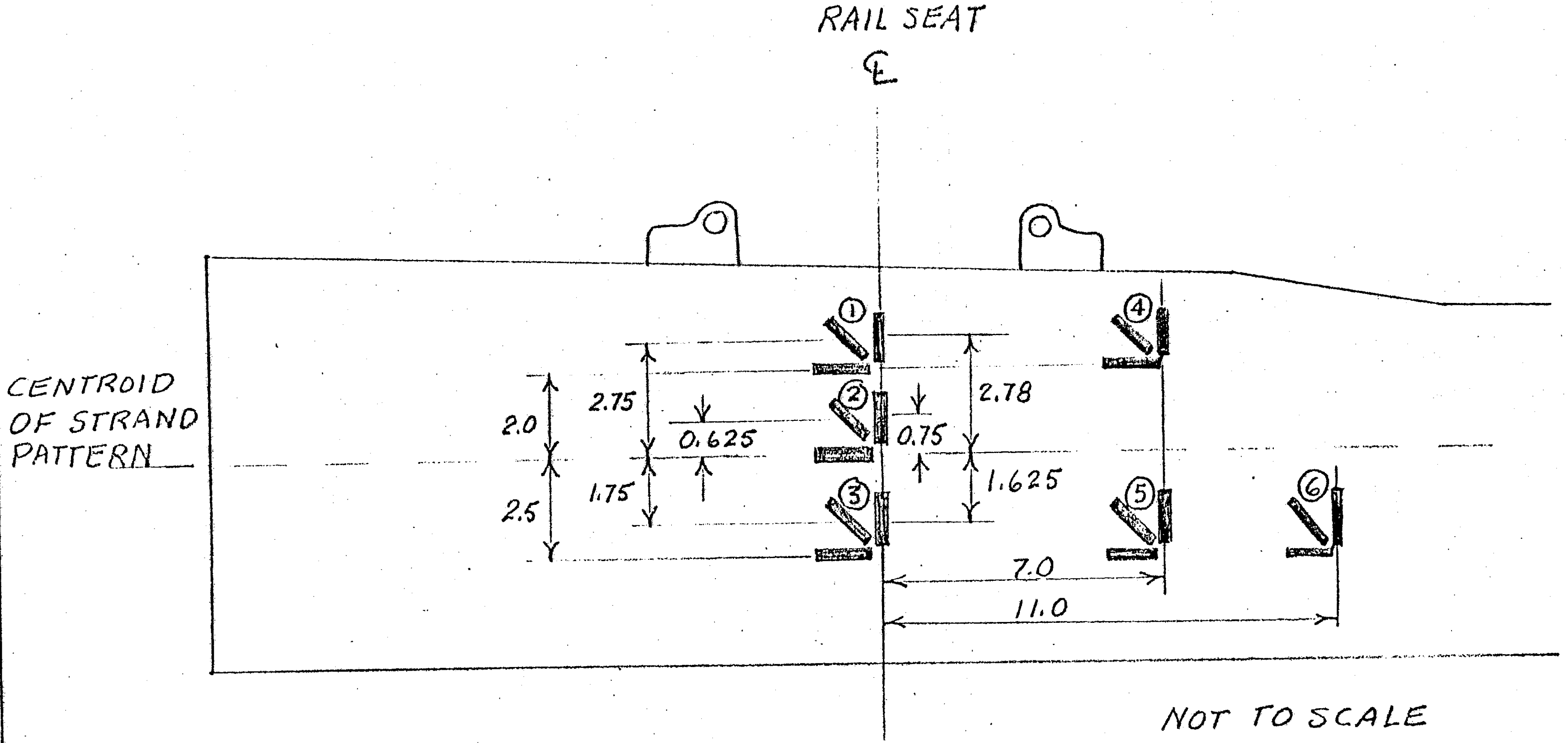


*Note

Since the resolution of an SR-4 Strain indicator is approximately ± 5 μin, these data are considered to be unreliable. Dashed lines have been used to reflect this uncertainty in the linear fit to each data set.

SUBJECT:	COMPUTED BY:	DATE:	FILE NO.
	CHECKED BY:	DATE:	SHEET NO.

AS INSTALLED
STRAIN GAGE LOCATIONS ON COSTAIN 244-C CROSSTIE #0143



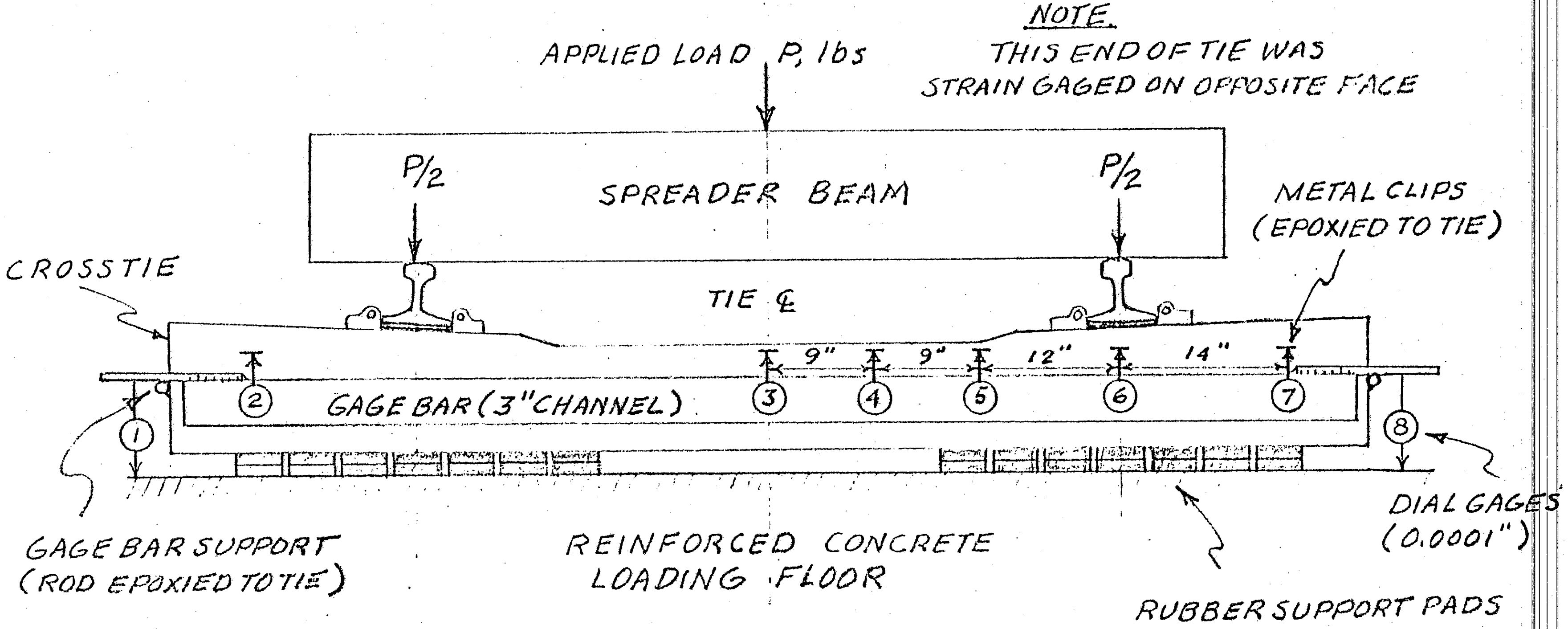
NOTES

GAGES AT LOCATIONS ① AND ③ ARE IDENTICALLY SPACED FROM CENTROID LINE
GAGES AT LOCATIONS ③ ⑤ AND ⑥ ARE IDENTICALLY SPACED FROM CENTROID LINE
ALL GAGES HAVE A ONE INCH GAGE LENGH
DISTANCES SHOWN ARE IN INCHES TO MIDPOINT OF GAGE ELEMENT

WES FORM NO. 1253
REV OCT 1968

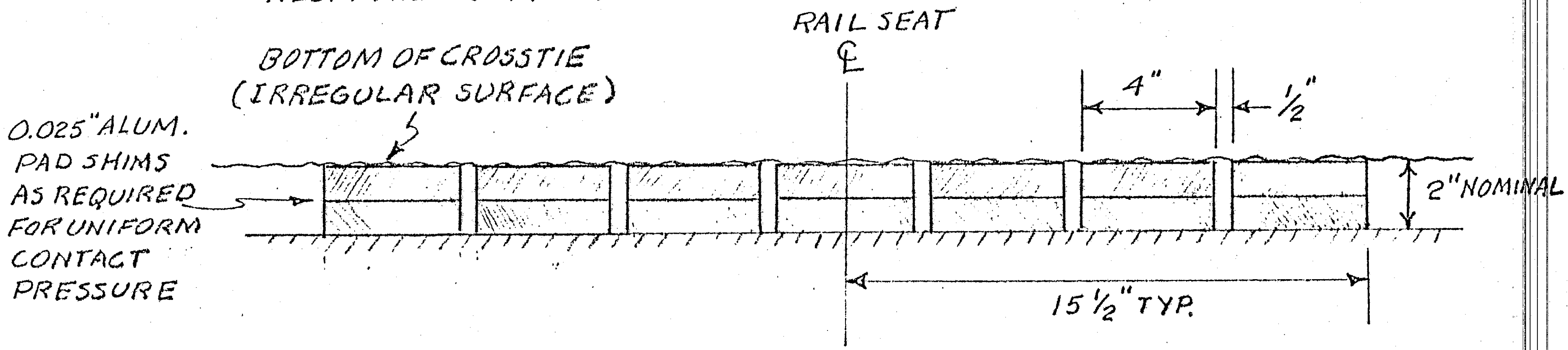
FILE NO.
SHEET NO.
DATE:
DATE:
COMPUTED BY:
CHECKED BY:
SUBJECT:

WES SIMULATED (STATIC) SERVICE LOADING
COSTAIN 244-C CROSSTIE # 0143

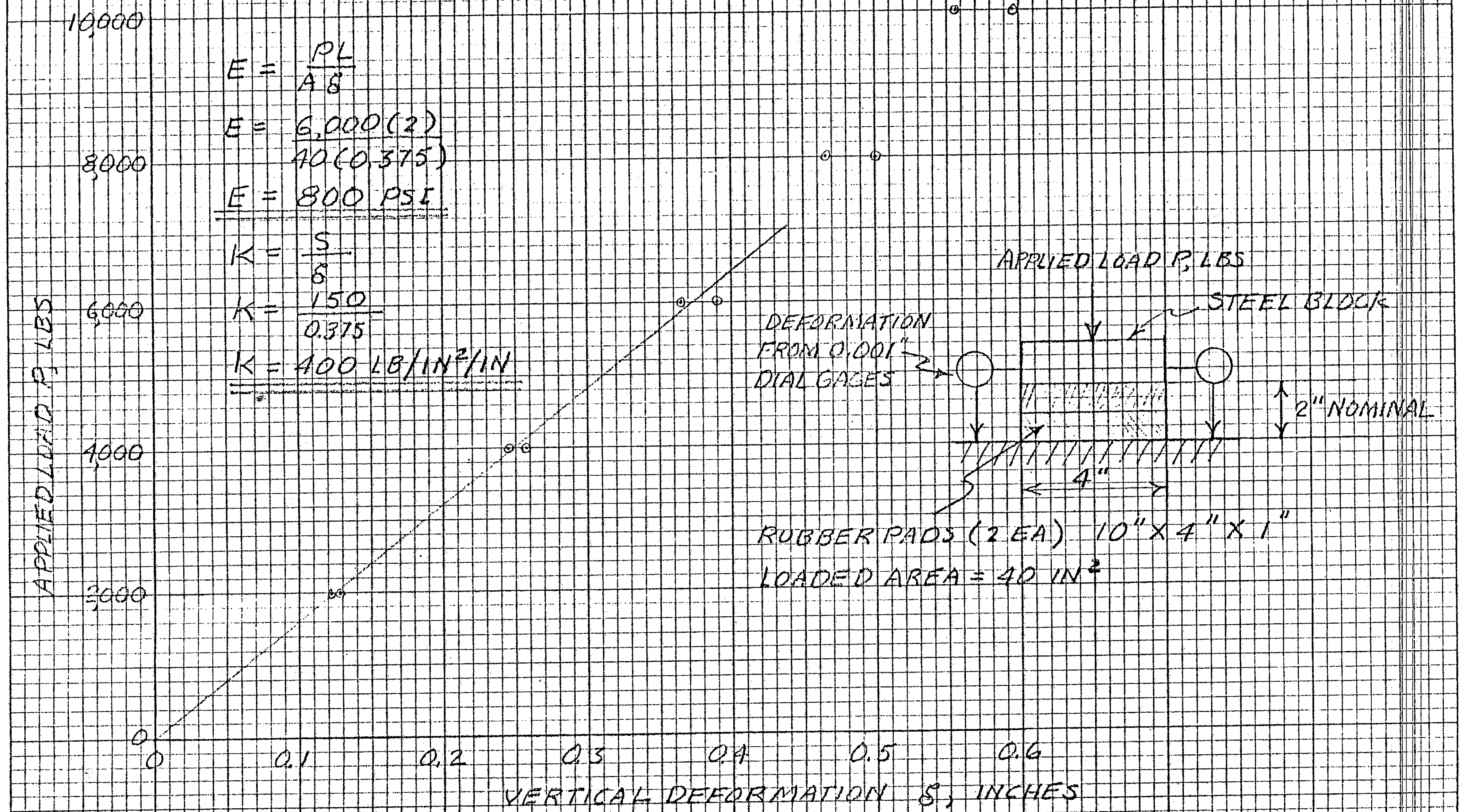


SUPPORT PAD DETAIL

NEOPRENE RUBBER 11" × 4" × 1" THICK, STACKED TWO DEEP



LOAD-DEFLECTION TEST ON NEOPRENE RUBBER SUPPORT PADS FOR WES SIMULATED (STATIC) SERVICE LOADING COSTAIN 24 A-C CROSSTIE # 0143



$E = \frac{PL}{A\delta}$

$E = \frac{6{,}000(2)}{40(0.375)}$

$\underline{E = 800 \text{ PSI}}$

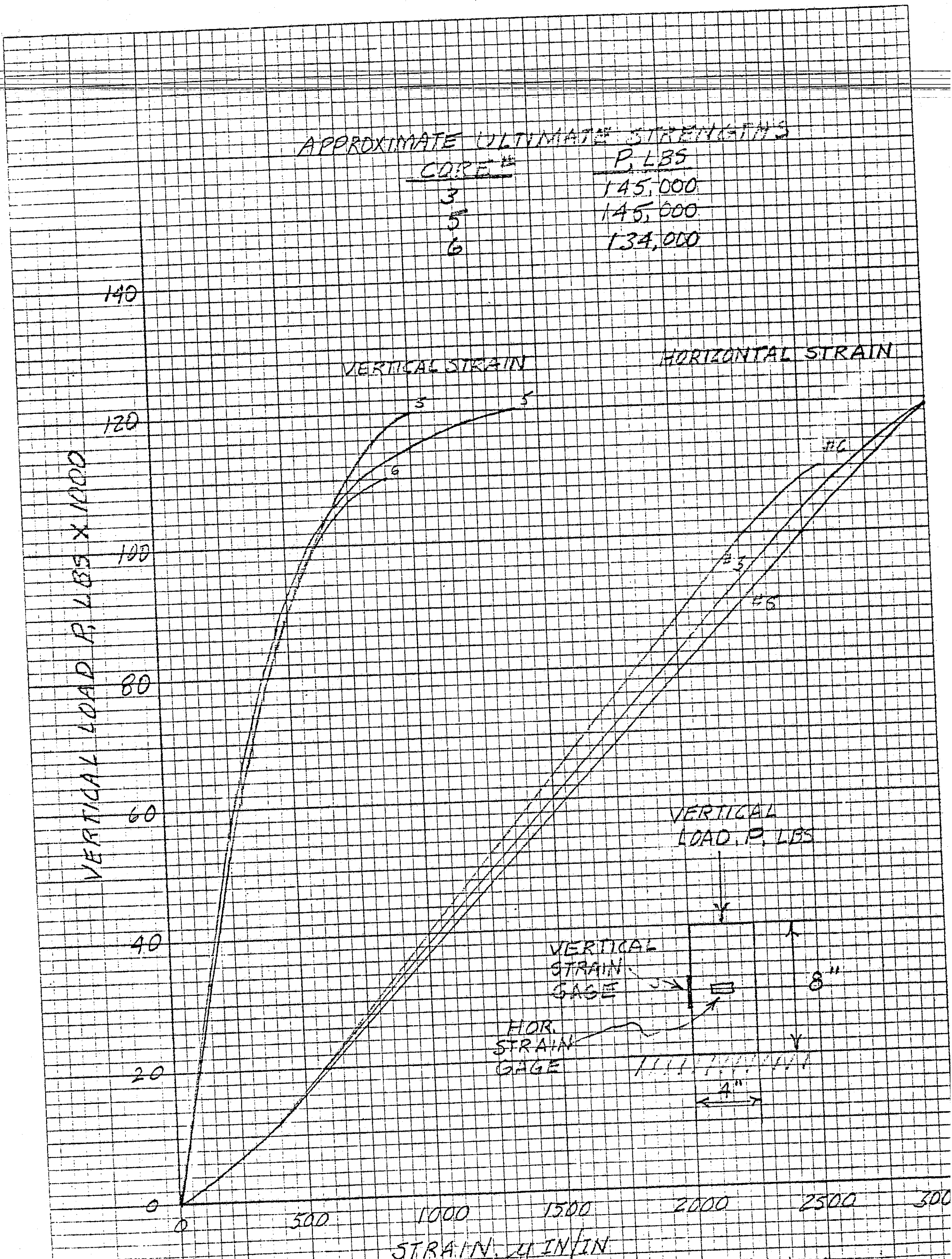
$K = \frac{S}{\delta}$

$K = \frac{150}{0.375}$

$\underline{K = 400 \text{ LB/IN}^2\text{/IN}}$

APPROXIMATE ULTIMATE STRENGTHS

CORE #	P, LBS
3	145,000
5	145,000
6	134,000



STRESS-STRAIN CURVES FOR SAMPLES 3, 5 AND 6
(4-IN. DIAM. CORES FROM COSTAIN 244-C TIE #079)

SUBJECT: TYPICAL VALUES OF E AND μ FOR CONCRETE (COSTAIN 244-C CROSSTIE)	COMPUTED BY:	DATE:	FILE NO.
	CHECKED BY:	DATE:	SHEET NO.

COMPUTATION OF YOUNGS E MODULUS AND POISSONS RATIO FROM TESTS ON CORES 3, 5 AND 6 (CORES TAKEN FROM COSTAIN 244-C TIE #079)

CORES WERE STRAIN GAGED IN MIDDLE THIRD TO MINIMIZE END EFFECTS. ALL THREE CORES HAD A 3.95-IN-DIAM, AND WERE APPROXIMATELY 8-IN IN HEIGHT. THERE WERE SOME PIECES OF 5 MM DIAMETER REINFORCING STEEL IN THE SPECIMENS. THE STRAIN GAGES WERE ORIENTED TO AVOID THESE.

CALCULATION OF AVERAGE STRAIN (FROM ORIGINAL DATA PLOTS)

SAMPLE NO.	VERT. STRAIN @ P=60000 LB μ IN/IN	VERT. STRAIN @ P=20,000 LB μ IN/IN	HOR. STRAIN @ P=60000 LB μ IN/IN	HOR. STRAIN @ P=20000 LB μ IN/IN
3	1500	580	300	100
5	1550	600	250	80
6	1420	560	280	90
AVG.	1490	580	277	90

1490
580

$\epsilon_{VERT} = 910\mu$ IN/IN

277
90

$\epsilon_{HOR} = 187\mu$ IN/IN

POISSONS RATIO $\mu = \frac{187}{910} = 0.21$

NOMINAL STRESS AREA $= \frac{\pi(3.95)^2}{4} = 12.25$ IN^2

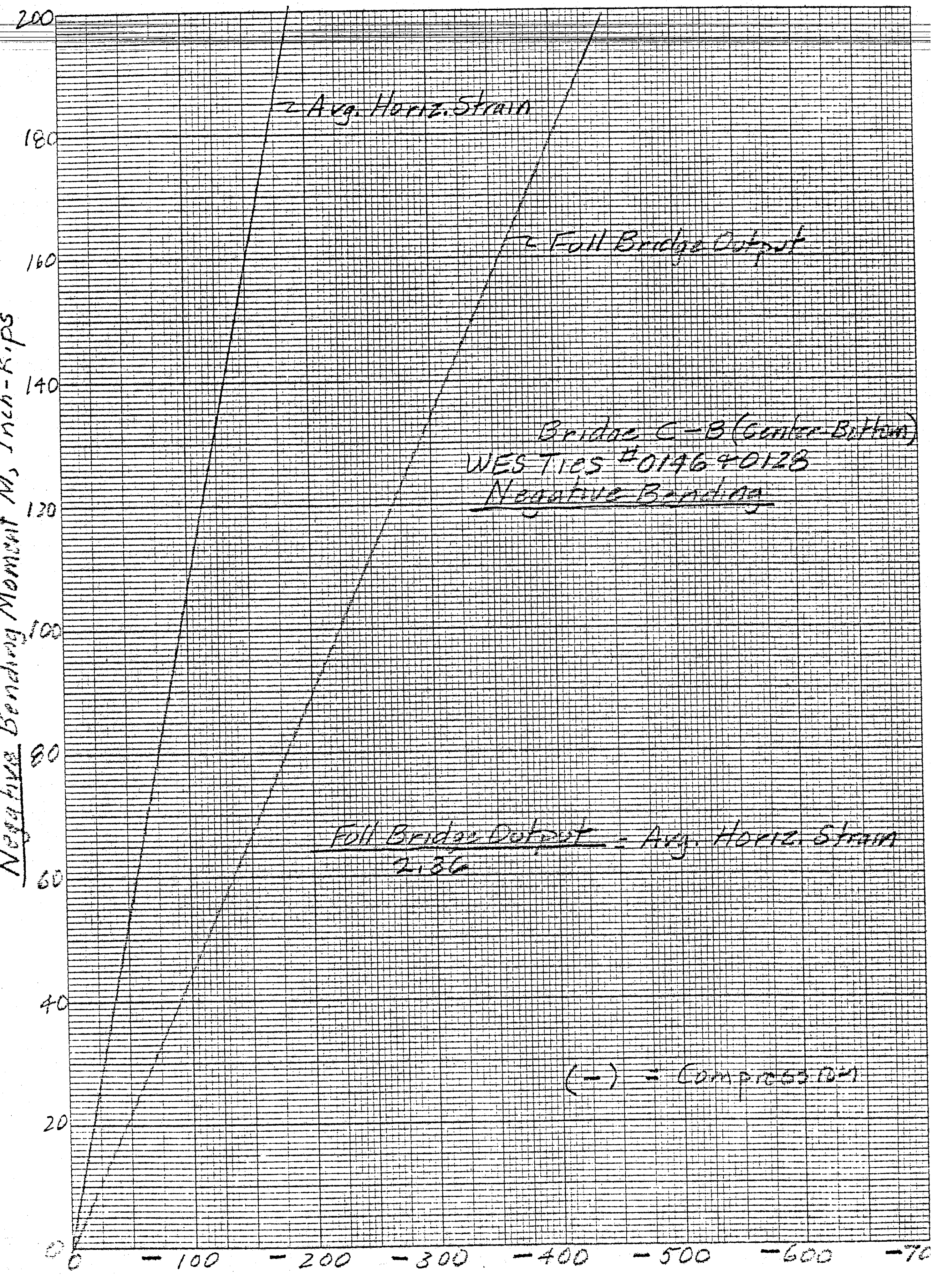
$$\delta = \frac{PL}{AE}, \quad E = \frac{SL}{\delta} = \frac{S}{\epsilon}$$

WHERE

P = 60000 − 20000 = 40,000 LB

$$E = \frac{\frac{40,000}{12.25}}{0.000910} = \frac{3265}{0.000910} = 3.59 \times 10^6 \text{ PSI}$$

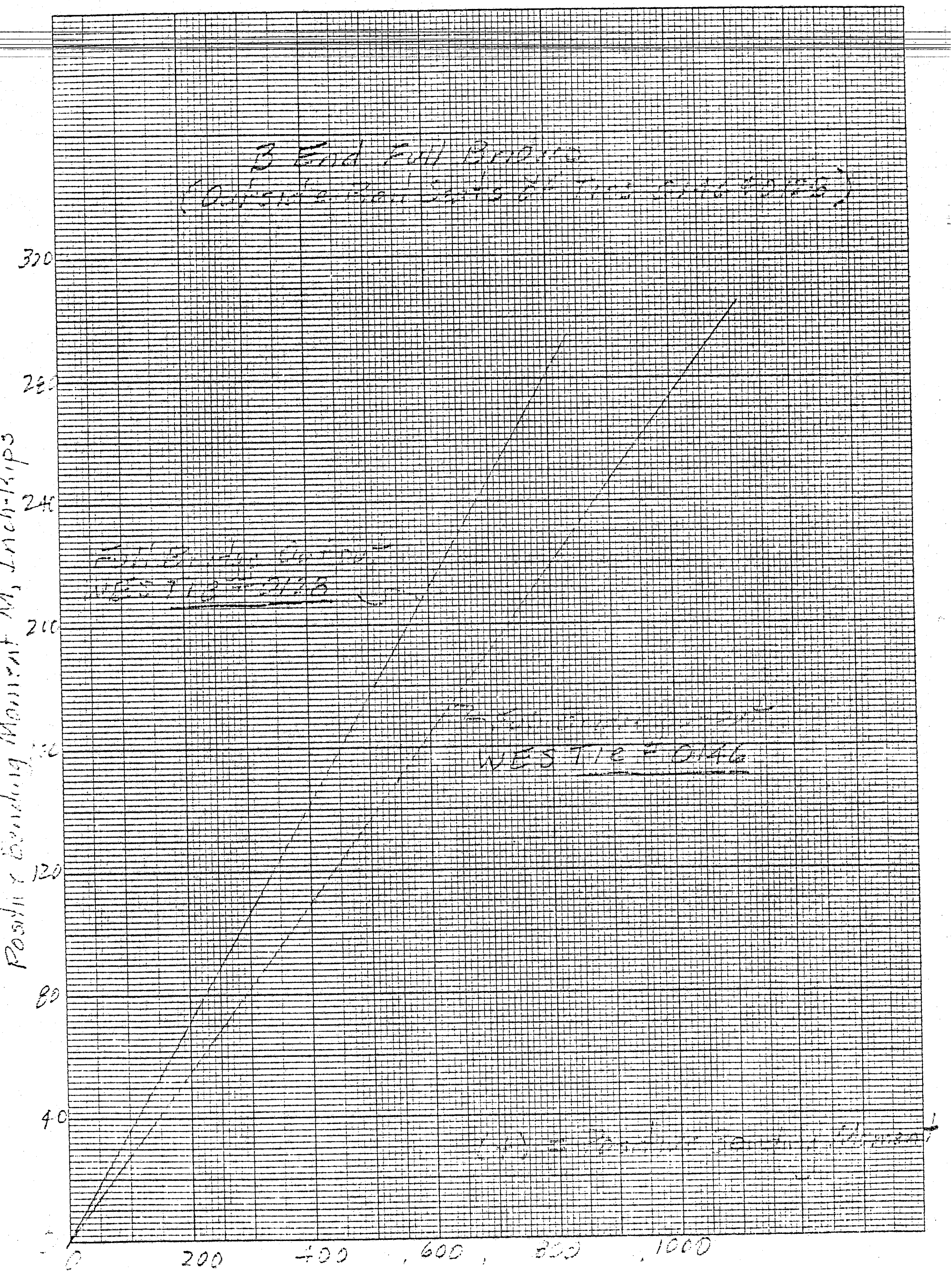
WES FORM NO. 1253
REV OCT 1958



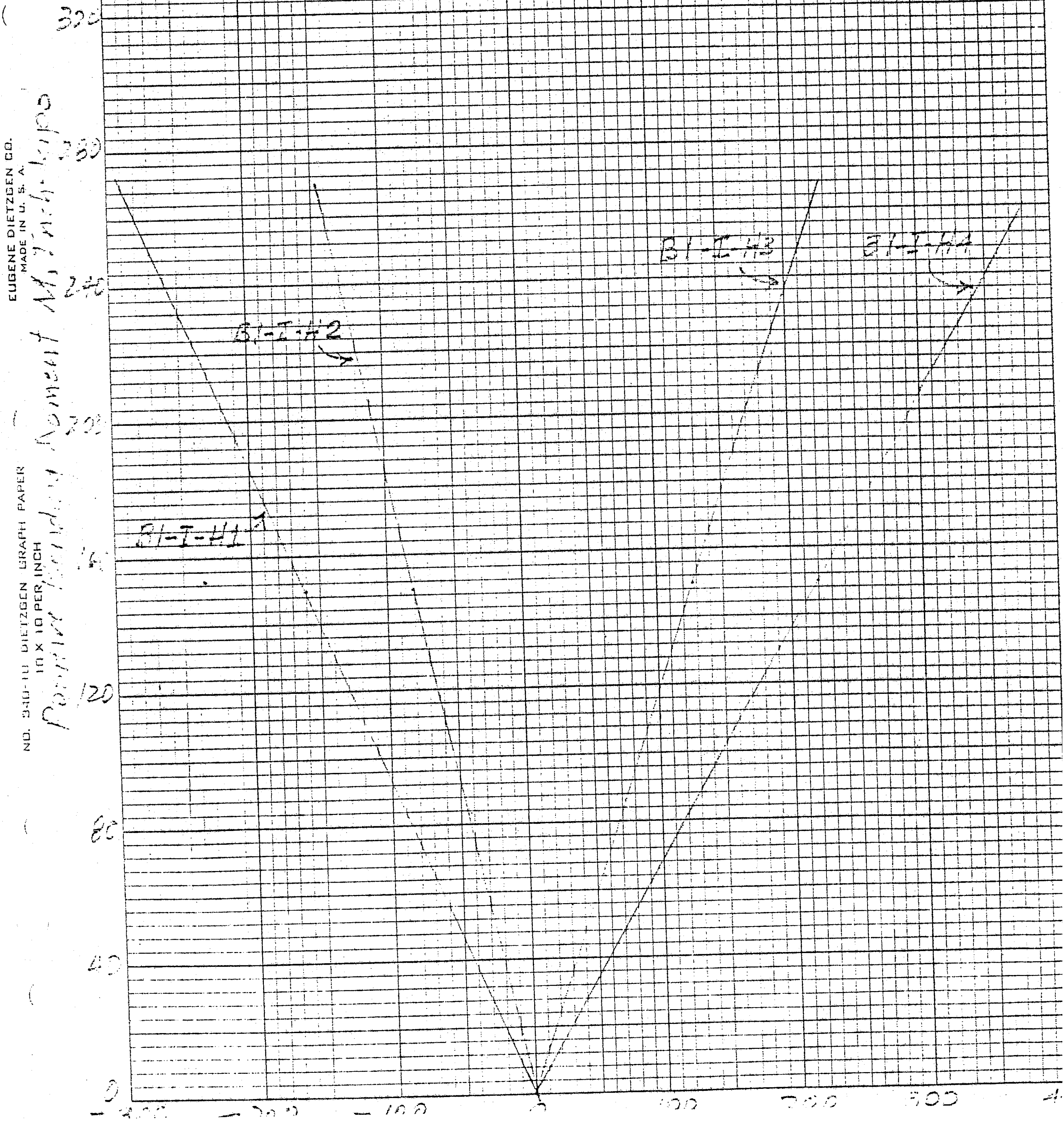
Bridge C-B (Center Bottom)
WES Ties #0146 40128
Negative Bending

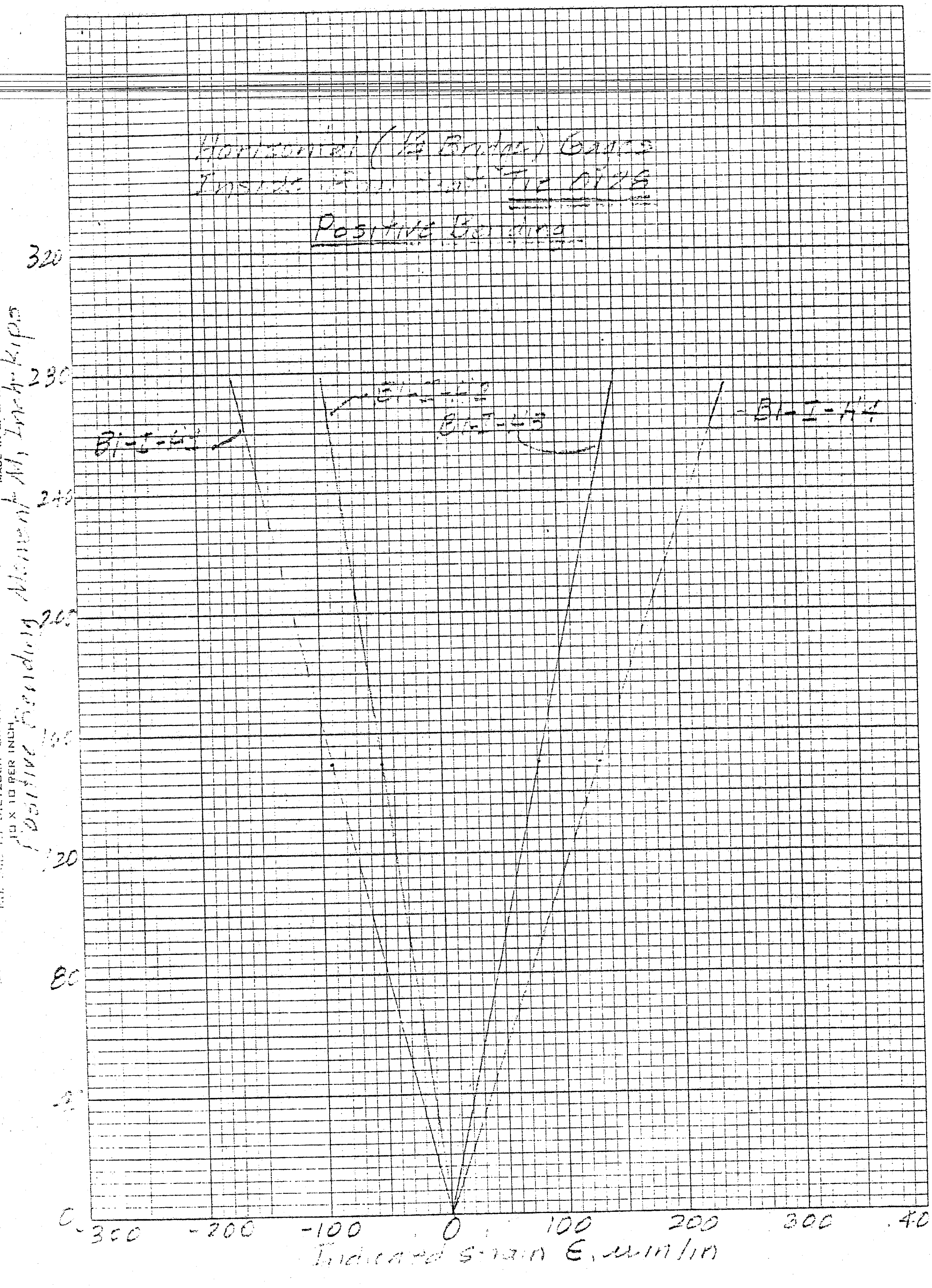
$$\frac{\text{Full Bridge Output}}{2.36} = \text{Avg. Horiz. Strain}$$

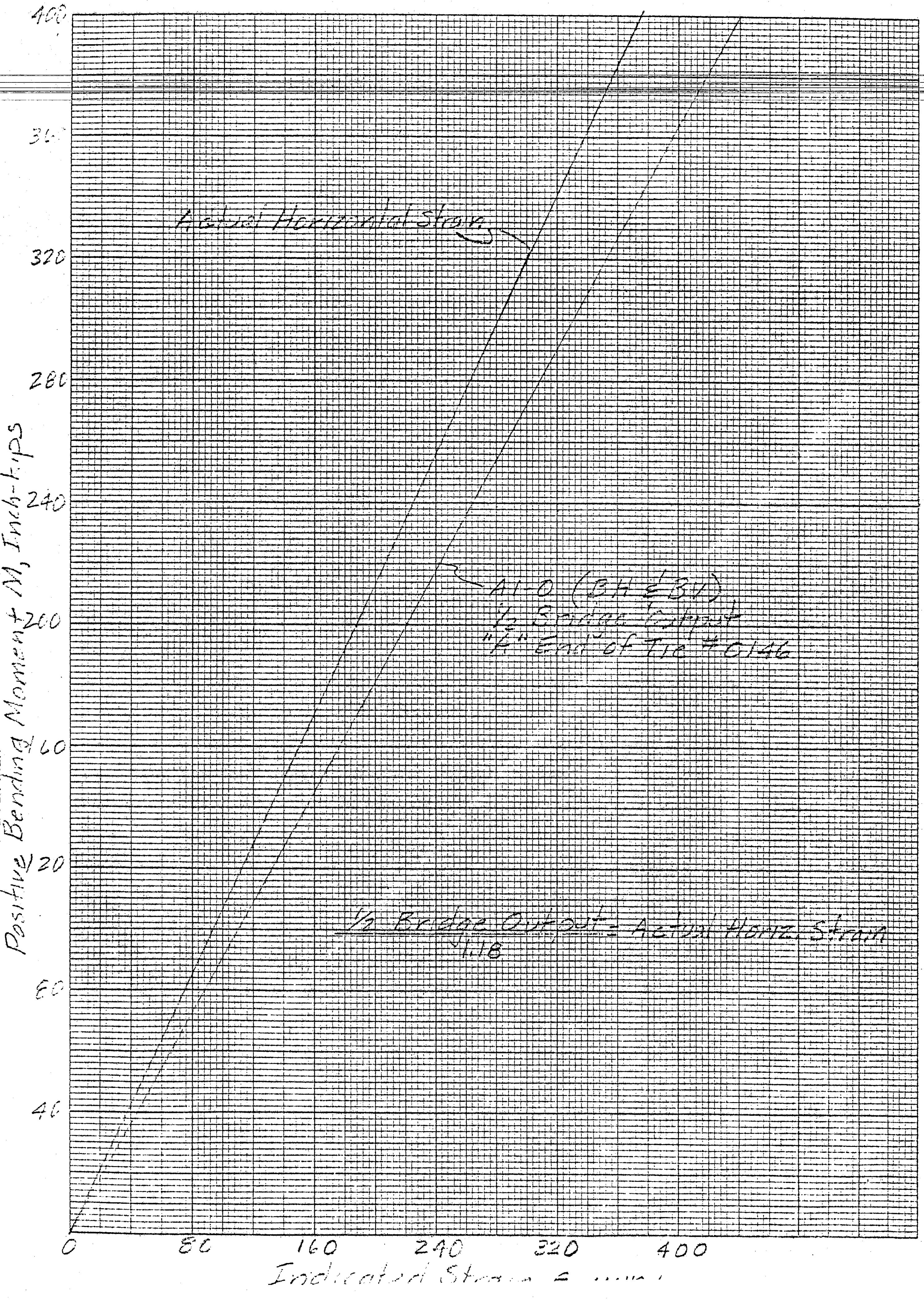
(−) = Compression


3 End Full Braced
(Outside Rail Seats of [illegible])
[illegible] 3128
WESTIE F0146
(+) = [illegible]
Positive Bending Moment M, Inch-kips
320
280
240
200
160
120
80
40
0
0
200
400
600
800
1000

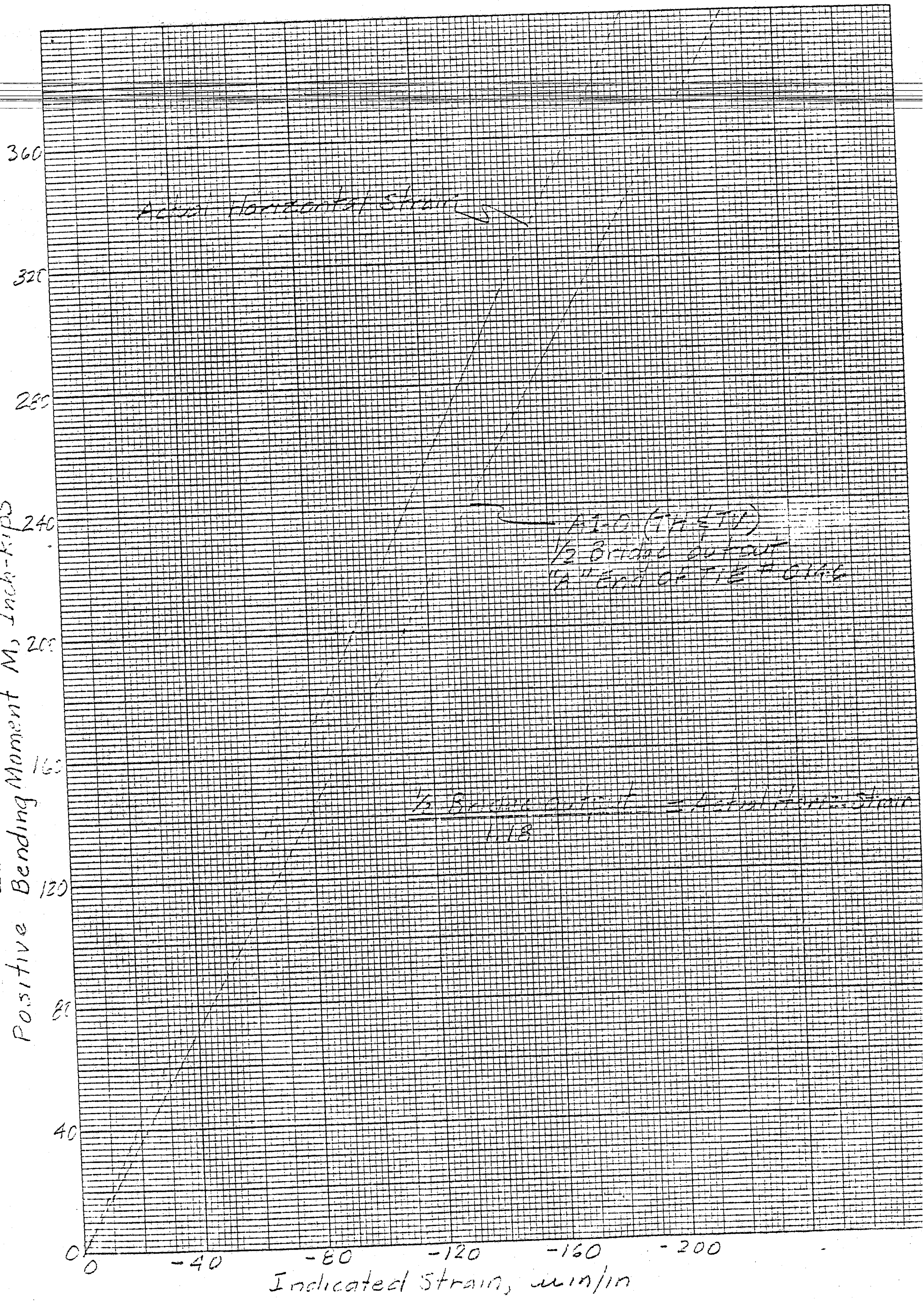
Horizontal (½ Bridge) Gages
Inside Rail Seat, Tie 0144
Positive Bending




Horizontal (¼ Bridge) Gages
Inside Hole at Tie 0128
Positive Bending
B1-I-H1
B1-I-H2
B1-I-H3
B1-I-H4
320
280
240
200
160
120
80
40
0
-300
-200
-100
0
100
200
300
400
Positive Bending Moment M, Inch-kips
Indicated strain E, μin/in



$$\frac{\tfrac{1}{2}\text{ Bridge Output}}{1.18} = \text{Actual Horiz. Strain}$$


Actual Horizontal Strain
A1-0 (TH & TV)
1/2 Bridge output
"A" End of TIE # 0146
1/2 Bridge output / 1.18 = Actual Horiz. Strain
Positive Bending Moment M, Inch-kips
360
320
280
240
200
160
120
80
40
0
0
-40
-80
-120
-160
-200
Indicated Strain, µin/in