Technical Report Documentation Page

1. REPORT No.
636407

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Seam Strength Of Asphalt Coated Structural Plate Pipe

5. REPORT DATE
February 1968

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
Nordlin, E.F. and W.H. Ames

8. PERFORMING ORGANIZATION REPORT No.
636407

9. PERFORMING ORGANIZATION NAME AND ADDRESS
State of California
Department of Public Works
Division of Highways
Materials and Research Department

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

12. SPONSORING AGENCY NAME AND ADDRESS

13. TYPE OF REPORT & PERIOD COVERED

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A factorial statistical experiment was performed in order to determine the effect of asphalt coating and/or bolt torque level on the seam strength of structural steel plate pipe specimens. Laboratory tests were performed on specimens, one foot in width, of three and eight gage asphalt coated and plain hot-dip galvanized structural steel plate pipe. The specimens were connected with four bolts which for half of the specimens were torqued to 50 ft-lbs. The connecting bolts on the remaining specimens were torqued to 200 ft-lbs. Findings indicate that there is no significant difference in ultimate seam strength between specimens coated with asphalt and those with a hot-dip galvanized coating. Findings also indicate that there is no significant difference between ultimate seam strengths of specimens connected with bolts torqued to the two levels stated above. Individual test results indicate that proper alignment of the bolt holes, in order to assure uniform distribution of bearing forces along the seam, is critical to ultimate seam strength.

17. KEYWORDS
Pipes, steel pipes, corrugated pipe culverts, culverts, joints, pipe joints, bolted joints, torque, asphalts, coatings, protective coatings, strength, statistical analysis

18. No. OF PAGES:
36

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1968/68-54.pdf

20. FILE NAME
68-54.pdf

68-54

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HIGHWAY RESEARCH REPORT

SEAM STRENGTH OF ASPHALT COATED STRUCTURAL PLATE PIPE

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636407

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads February, 1968

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

February 1968
Report M & R No. 636407

Mr. J. A. Legarra
State Highway Engineer
Sacramento, California

Dear Sir:

Submitted herewith is a research report titled:

SEAM STRENGTH OF ASPHALT COATED STRUCTURAL PLATE PIPE

Eric F. Nordlin
Principle Investigator

W. H. Ames
Co-Investigator

Assisted By
M. H. Johnson
R. R. Trimble

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ABSTRACT

REFERENCE: Nordlin, E. F., and W. H. Ames, "Seam Strength of Asphalt Coated Structural Plate Pipe", State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 636407, February 1968.

ABSTRACT: A factorial statistical experiment was performed in order to determine the effect of asphalt coating and/or bolt torque level on the seam strength of structural steel plate pipe specimens. Laboratory tests were performed on specimens, one foot in width, of three and eight gage asphalt coated and plain hot-dip galvanized structural steel plate pipe. The specimens were connected with four bolts which for half of the specimens were torqued to 50 ft-lbs. The connecting bolts on the remaining specimens were torqued to 200 ft-lbs. Findings indicate that there is no significant difference in ultimate seam strength between specimens coated with asphalt and those with a hot-dip galvanized coating. Findings also indicate that there is no significant difference between ultimate seam strengths of specimens connected with bolts torqued to the two levels stated above. Individual test results indicate that proper alignment of the bolt holes, in order to assure uniform distribution of bearing forces along the seam, is critical to ultimate seam strength.

KEY WORDS: Pipes, steel pipes, corrugated pipe culverts, culverts, joints, pipe joints, bolted joints, torque, asphalts, coatings, protective coatings, strength, statistical analysis.

I. INTRODUCTION

The California Division of Highways often uses large structural plate steel pipe for culverts under high fills. Experience has shown that ultimate seam strength of structural plate pipe cannot be accurately calculated by theoretical means and, therefore, it must be determined experimentally. Fairly good approximations of the seam strength of galvanized structural pipe are available, but to our knowledge nothing has been published on seam strength applicable to areas where environmental conditions dictate the use of shop applied asphalt coating to prevent corrosion. This study was, therefore, undertaken to determine the effect of asphalt coating on the seam strength of bolted sections of structural steel plate pipe.

This study was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, Bureau of Public Roads, as Item D-4-70 of Work Program HPR-1(4). The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

II. CONCLUSIONS

An analysis of variance of ultimate seam strength indicates that there is no significant difference between the seam strength of bolted sections of shop applied asphalt coated and non-asphalt coated galvanized structural steel plate pipe.

The analysis of variance also indicates that the ultimate seam strength of bolted sections of shop applied asphalt coated structural steel plate pipe connected with bolts torqued to 50 ft.-lbs. is not significantly different from those connected with bolts torqued to 200 ft.-lbs.

An analysis of the individual test results indicates that proper alignment of the bolt holes, in order to assure the uniform distribution of bearing forces along the seam, is critical to ultimate seam strength.

III. DISCUSSION

It was decided that a 2 x 2 x 2 factorial experiment, with 3 replicates, would be performed on specimens of galvanized structural steel plate pipe in order to determine the effect of asphalt coating and/or torque level on ultimate seam strength.

Twenty-four one-foot test specimens, including twelve eight-gage and twelve three-gage, were fabricated as shown in Figure 1. These gages represent the upper and lower range of gage sizes used by the California Division of Highways for galvanized structural steel plate pipe culvert. It was felt that data obtained from tests on these gage sizes would yield information that would be useful for all gage sizes within the presently used range.

Six test specimens, from each gage, were coated with paving grade asphalt prior to assembly (Figure 2). The remaining six, from each gage, had a standard hot-dip galvanized surface, only.

Three of each gage's asphalt coated test specimens were connected with four 3/4" galvanized A-325 bolts torqued to 50 ft.-lbs. The remaining three coated test specimens, for each gage, were connected with bolts torqued to 200 ft.-lbs. The same torquing procedure was used for the galvanized test specimens.

The test specimens were loaded in compression, between rigid steel plates to failure (Figure 3). Two dial micrometers were used in order to measure deformation. These measurements were recorded at load intervals of 5 kips.

The mode of failure in most cases was a combination of plate bearing (at the bolt holes) and buckling (Figures 4, 5, and 6). The rotation of the bolt axis, as seen in Figure 5, indicates plate bearing failure. In two cases, some bolt shearing failure was also observed.

The results of the ultimate seam strength tests are shown in Table I. An analysis of variance was performed on the test data (see Appendix). Variance ratio tests (F - tests) were performed in order to determine significance. It can be noted that the F-ratios for the effects of asphalt coating, torquing and the interaction of coating and torque are not significant. It is, therefore, concluded that the current seam strength design criteria for galvanized structural plate pipe is also valid for seam strengths of asphalt coated structural plate pipe. However, due to cold flow or creep characteristics of the asphalt, it is essential that the connecting bolts be tightened to a minimum torque level prior to backfilling.

The test results indicate that under short-term loading there is no significant difference in compressive seam strength when connecting bolts are torqued to 50 ft.-lbs. as compared to 200 ft.-lbs. This indicates that torquing of the bolts above 50 ft.-lbs. would only serve more intimately to seat the plates. Since virtually all culvert installations are under sustained load, it may be desirable to use higher torque, particularly with asphalt coated plate to minimize any slippage in the seam before the development of ultimate seam strength in bearing. It is, however, concluded that due to the mode of failure (plate bearing) and the special A-325 bolt and nut configuration, that torque values over 50 ft.-lbs. will not result in increased ultimate seam strength.

A comparison of individual ultimate seam strengths within some test cells indicated that some values were considerably lower than others. Subsequent visual observations of the test specimens, exhibiting low seam strengths, revealed that the angle of bolt tip varied among the four connecting bolts (Figure 7). This indicates that proper alignment of the bolt holes, in order to assure a uniform distribution of bearing forces along the seam, is critical to ultimate seam strength. The effect of minor misalignment of bolt holes in field installations would probably be less significant due to the much wider plate widths used. The phenomenon of improper hole alignment is a random variable and is included in the error term of the model equation.

Shown in Table II are the tensile strengths of test coupons taken from the tangent of the corrugation in the corrugated test plates. The tensile strength, in all cases, is above that specified by the California Division of Highways for structural steel plate pipe. Until recently, the minimum was specified at 45,000 psi tension in the flat plate before corrugation but is now established at 42,000 psi in the flat. Tensile strength is generally greater in the corrugated plate due to cold working. This varies with the location on the corrugation where the sample is taken.

An attempt was made to separate two of the failed specimens to determine the thickness of the bituminous coating after torquing. Two were successfully separated and both showed an average of 0.03" of coating between the bolted surfaces. Within an area of approximately one inch around the bolt hole, the coating thickness was nil (Figure 8).

Load deformation curves are shown in Figures 9 through 16. These curves indicate the joint's capacity for considerable movement before ultimate load is reached. This movement is shown by the bolt tipping seen in Figures 3, 4, 5, and 6. This indicates that the specimens retained their structural integrity while the deformations took place. It appears, therefore, that under field conditions the pipe would have the capacity to relieve itself of load by bolt tipping and subsequent sliding of the plates.

TABLE I

Structural Plate Thickness	8 Gage		3 Gage	
Bolt Torque	50 ft-lbs	200 ft-lbs	50 ft-lbs	200 ft-lbs
Asphalt Coated (Test Values)	86.0k	83.0k	141.0k	140.0k
	97.0k	93.5k	140.0k	125.0k
	91.5k	104.0k	138.5k	140.5k
Non-Asphalt Coated (Test Values)	90.0k	91.5k	140.0k	151.5k
	89.0k	91.5k	150.5k	153.5k
	81.5k	88.0k	148.5k	115.0k
Design Values (currently used by California Div. of Hwys.)	81.0k	81.0k	132.0k	132.0k

<u>Ultimate Seam Strength</u>

24 Specimens Total

TABLE II

MULTI-PLATE

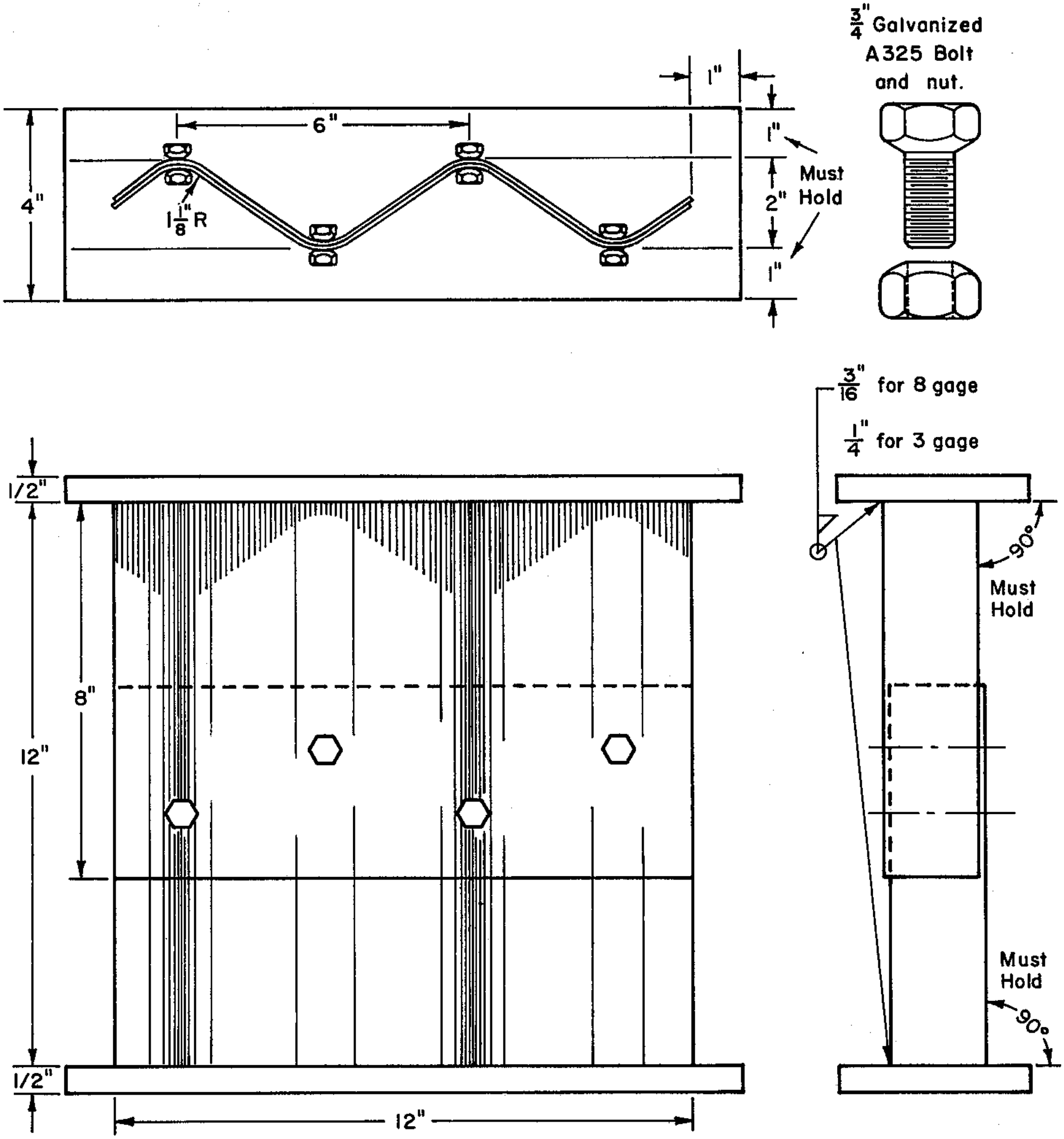
Results of Tensile Specimens
(Taken from the tangent section of corrugated plates)

Specimen No.	Yield Strength (psi)	Ultimate Strength (psi)	Elong. (%)
1 a	36,000	49,200	36.0
b	35,800	49,400	37.0
2 a	37,000	50,000	35.0
b	36,200	49,500	37.0
3 a	37,300	50,300	33.0
b	36,700	50,400	34.0
4 a	38,300	50,700	37.0
b	36,400	50,100	35.0
5 a	37,600	50,500	33.0
b	38,000	50,400	34.0
6 a	36,300	50,600	34.0
b	35,800	50,400	37.0
7 a	44,000	53,800	31.0
b	45,900	54,500	28.0
8 a	48,400	56,800	28.0
b	49,400	56,900	27.0
9 a	49,000	56,900	30.0
b	48,600	56,500	27.0
10 a	48,300	57,200	30.0
b	48,700	56,600	30.0
11 a	48,800	56,700	28.0
b	48,500	56,900	30.0
12 a	44,500	54,150	30.0
b	48,900	56,850	28.0
13 a	39,150	50,300	33.0
b	40,200	51,000	33.0
14 a	39,150	50,300	33.0
b	40,200	51,000	33.0
15 a	39,150	50,300	33.0
b	40,200	51,000	33.0

TABLE II (Cont'd.)

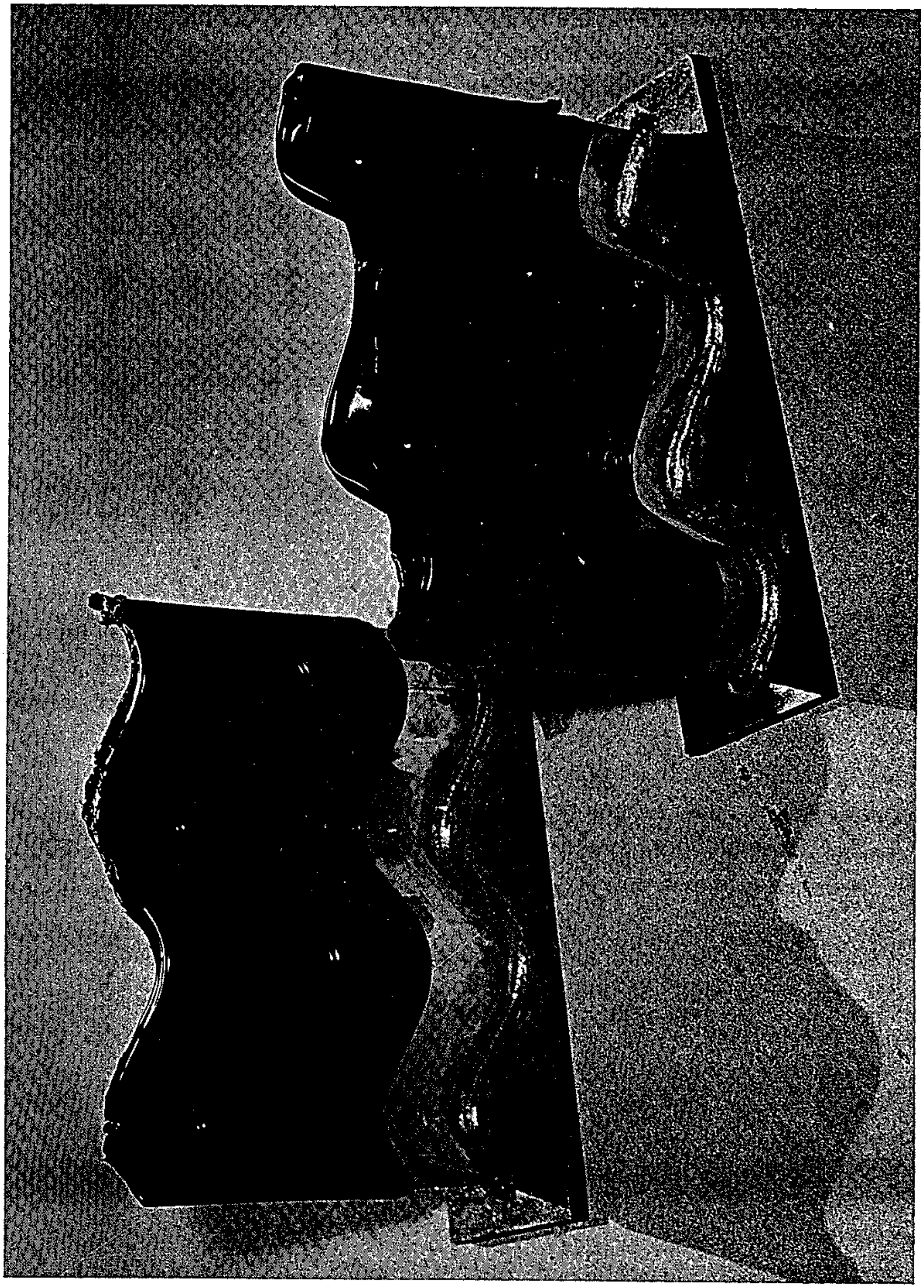
Specimen No.		Yield Strength (psi)	Ultimate Strength (psi)	Elong. (%)
16	a	39,150	50,300	33.0
	b	40,200	51,000	33.0
17	a	39,150	50,300	33.0
	b	40,200	51,000	33.0
18	a	39,150	50,300	33.0
	b	40,200	51,000	33.0
19	a	46,100	53,700	32.0
	b	44,900	53,000	30.0
20	a	46,100	53,700	32.0
	b	44,900	53,000	30.0
21	a	39,200	48,600	28.0
	b	42,700	54,500	30.0
22	a	46,100	53,700	32.0
	b	44,900	53,000	30.0
23	a	46,100	53,700	32.0
	b	44,900	53,000	30.0
24	a	39,200	48,300	35.0
	b	40,500	52,700	27.0

Figure 1



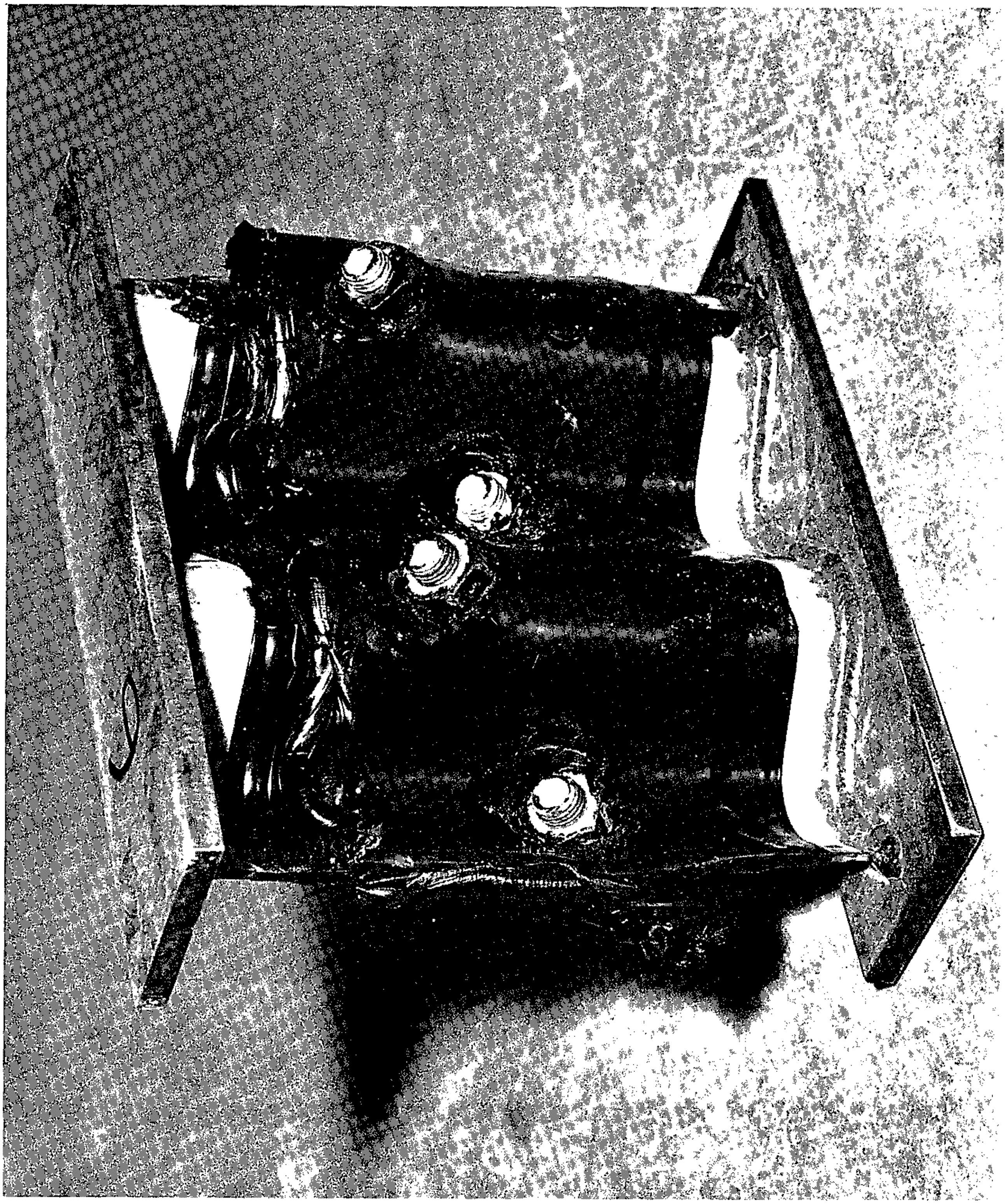
3/4" Galvanized A325 Bolt and nut.
1"
6"
1"
4"
2"
1"
Must Hold
1 1/8" R
3/16" for 8 gage
1/4" for 3 gage
1/2"
8"
12"
90°
Must Hold
Must Hold
90°
1/2"
12"

Figure 2



A typical coated specimen is shown here before assembly

Figure 4



Coated specimen after being tested to ultimate load. Note bolt tipping.

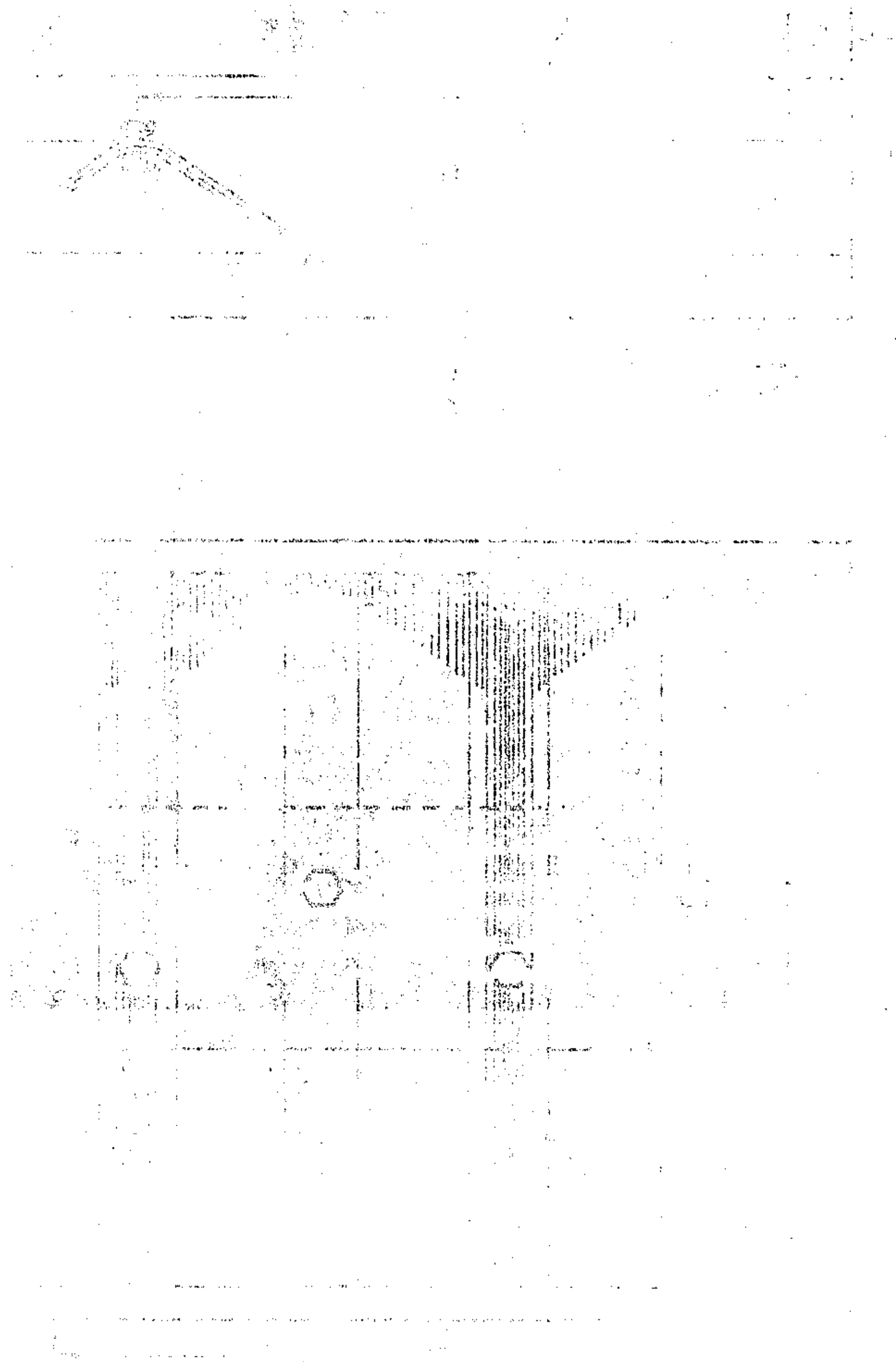
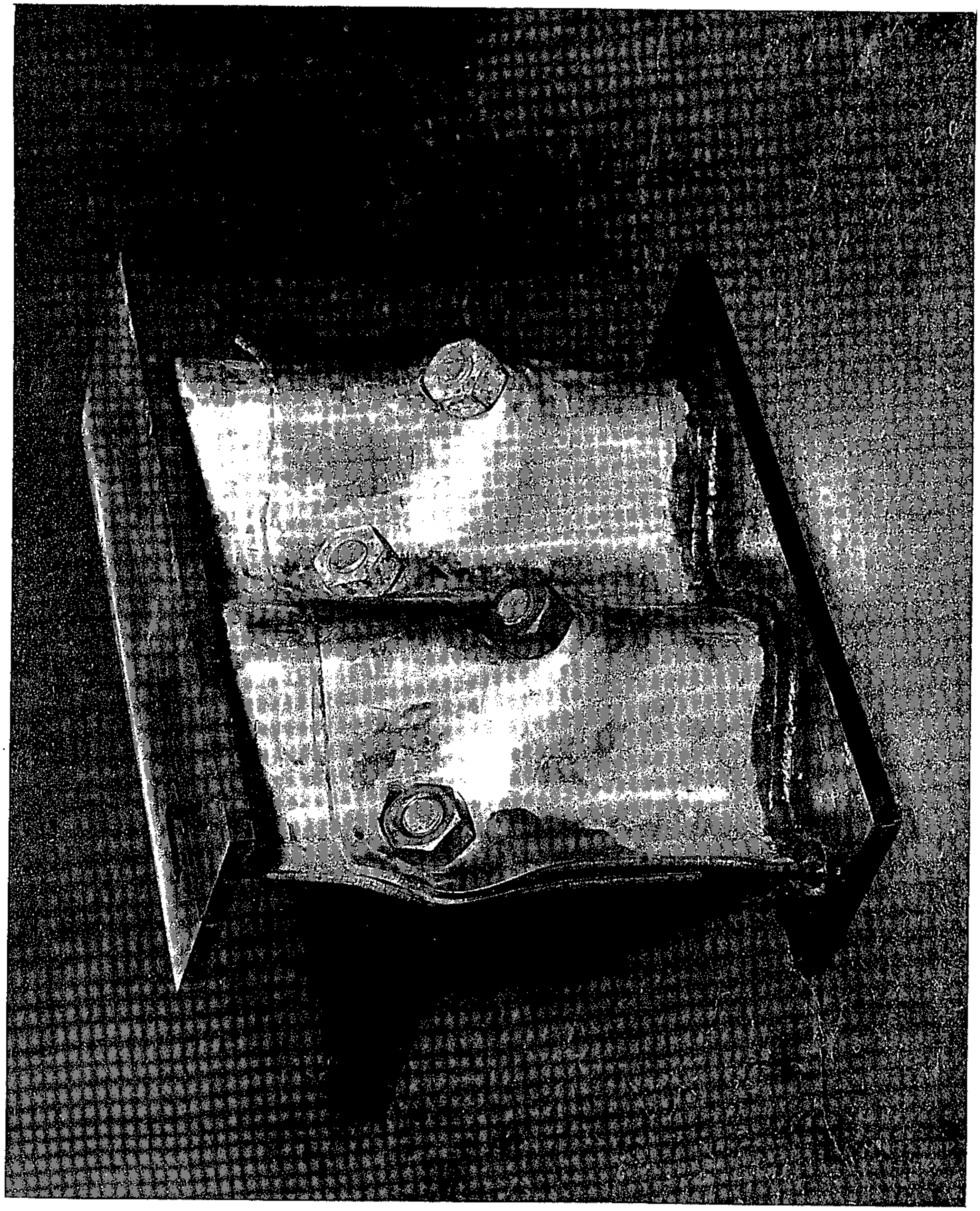


Figure 5

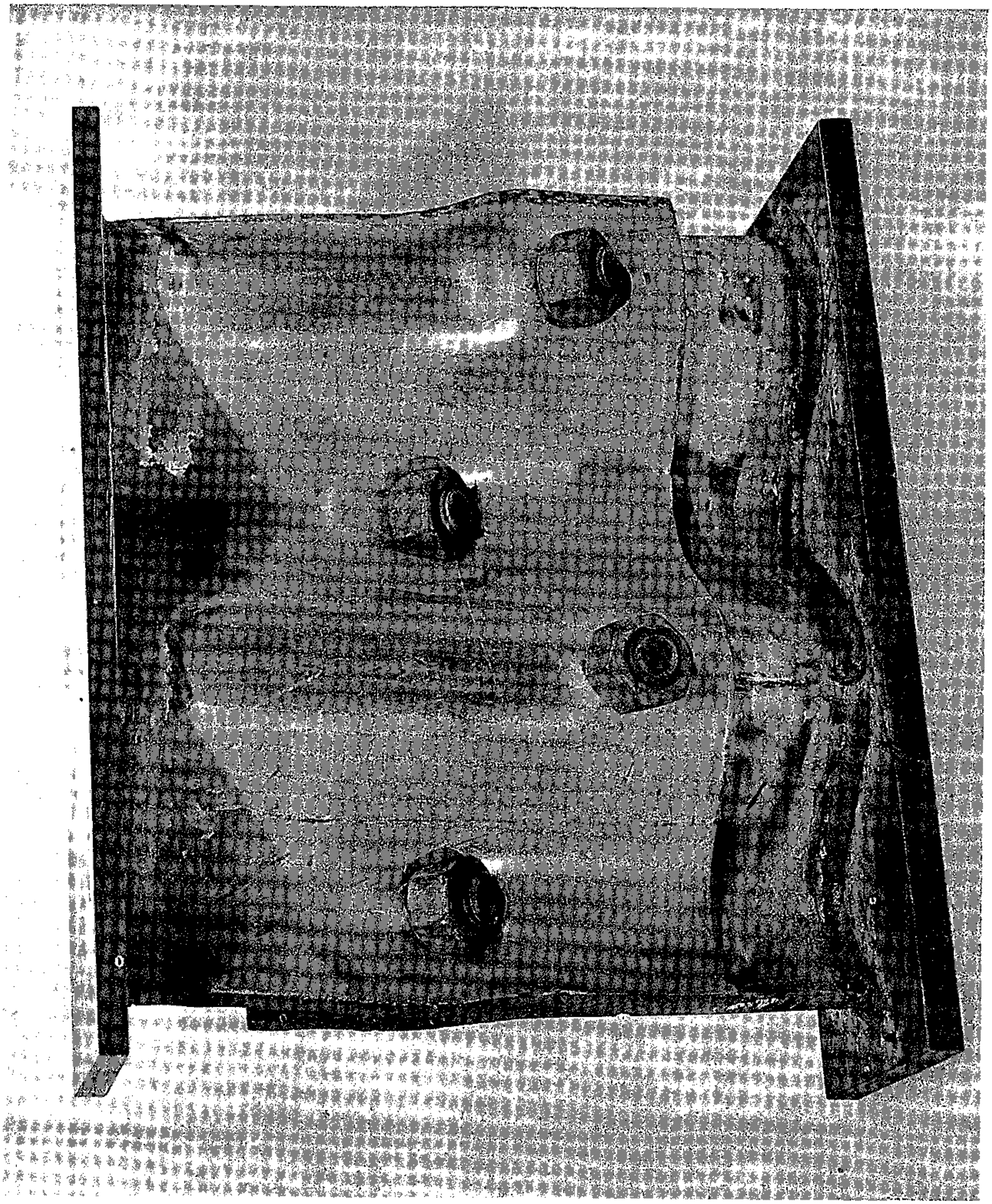


Uncoated specimen after being tested to ultimate load. Buckling of plates can be seen.

Figure 6

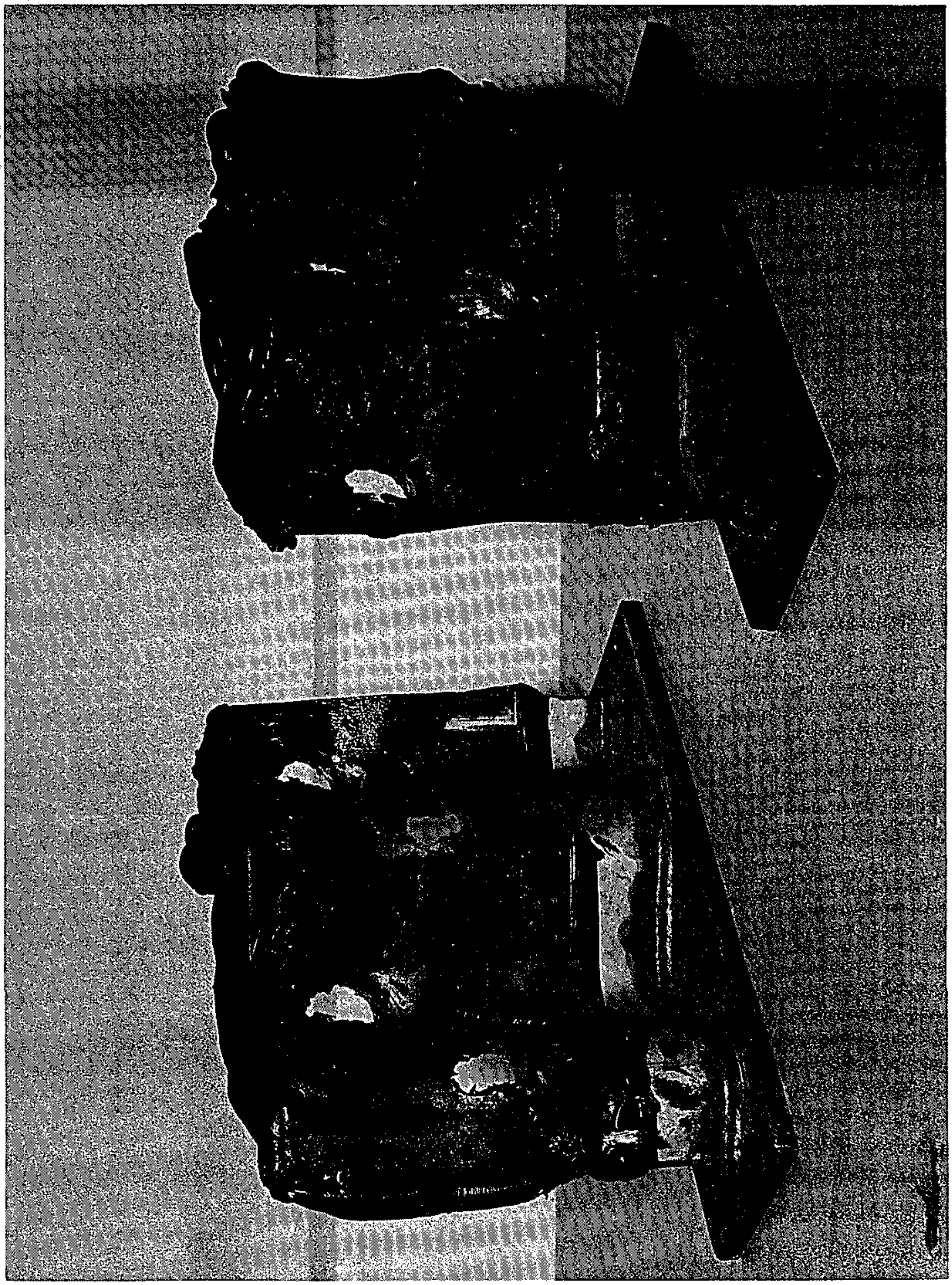
Disassembled specimen after being tested to ultimate load.
Note bearing failures as well as slight buckling.

Figure 7



Specimen showing differential bolt tipping. This is caused by poor hole alignment and results in unequal bearing forces along the seam, which results in low ultimate seam strength.

Figure 8



Disassembled coated specimen after testing. Sparsity of coating in the vicinity of the bolt holes can be noted.

Figure 9

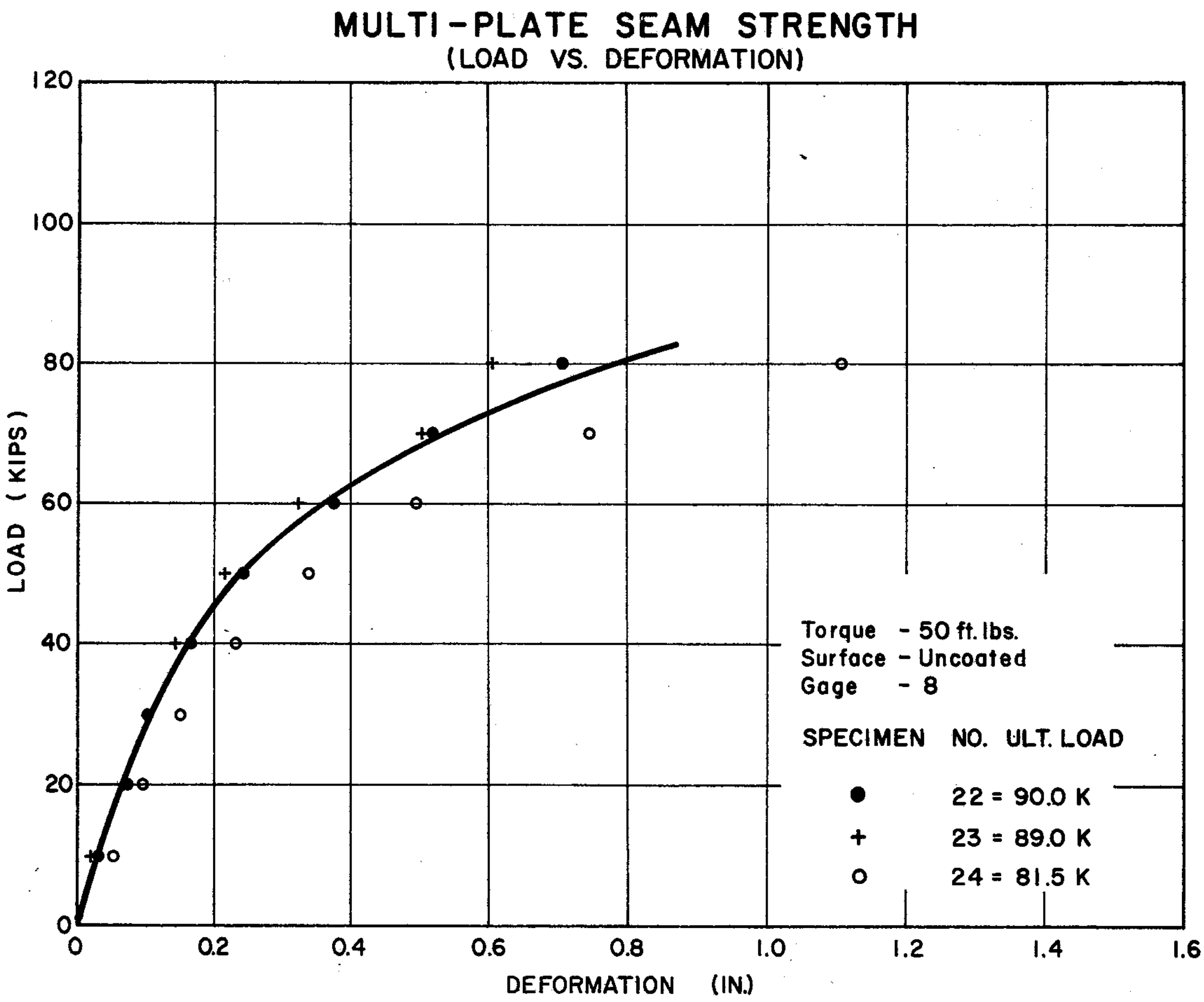

MULTI-PLATE SEAM STRENGTH
(LOAD VS. DEFORMATION)
LOAD (KIPS)
DEFORMATION (IN.)
0
20
40
60
80
100
120
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Torque - 50 ft. lbs.
Surface - Uncoated
Gage - 8
SPECIMEN NO. ULT. LOAD
22 = 90.0 K
23 = 89.0 K
24 = 81.5 K

Figure 10

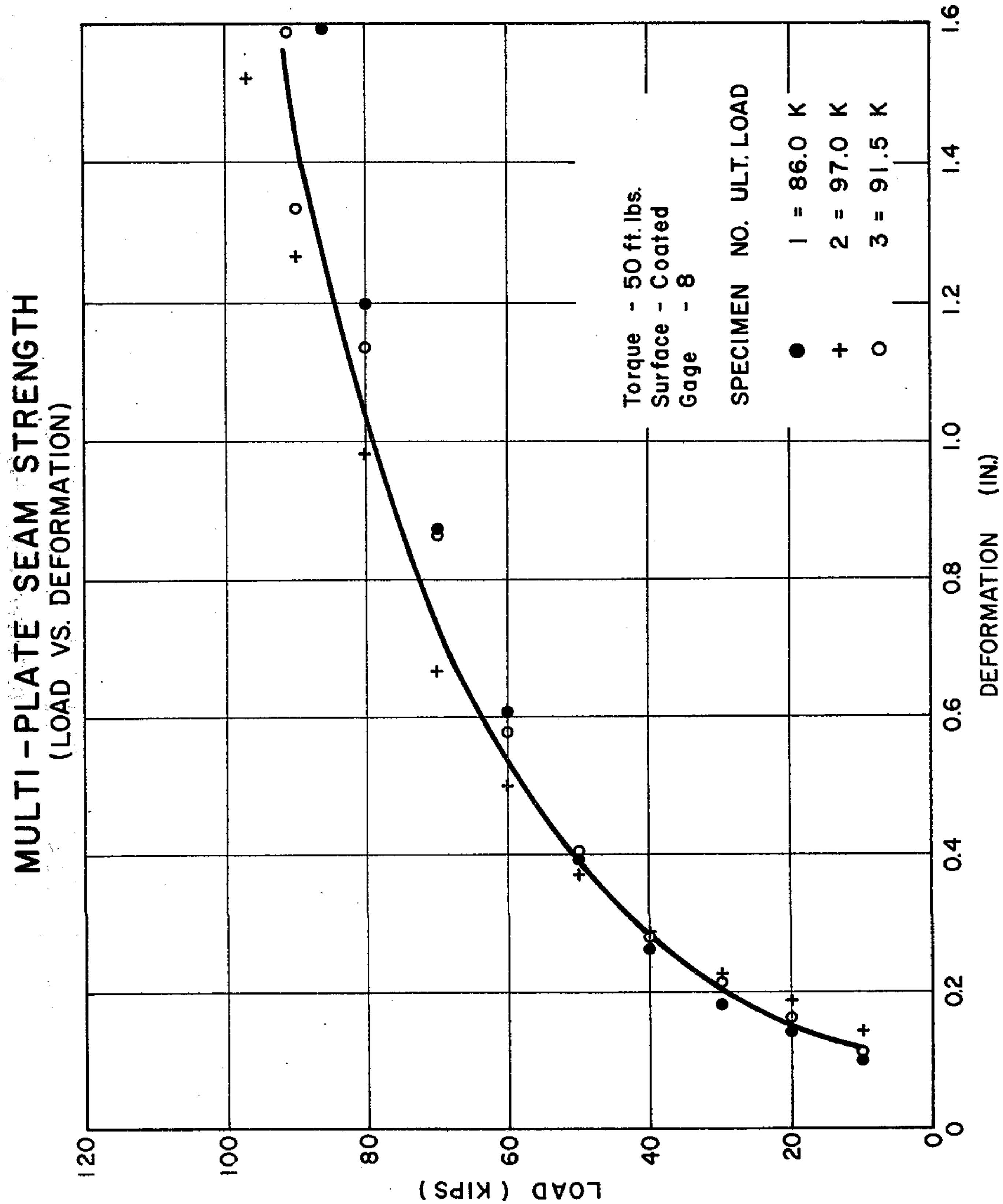

MULTI-PLATE SEAM STRENGTH
(LOAD VS. DEFORMATION)
Torque - 50 ft. lbs.
Surface - Coated
Gage - 8
SPECIMEN NO. ULT. LOAD
1 = 86.0 K
2 = 97.0 K
3 = 91.5 K
LOAD (KIPS)
DEFORMATION (IN.)
0
20
40
60
80
100
120
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

Figure 11

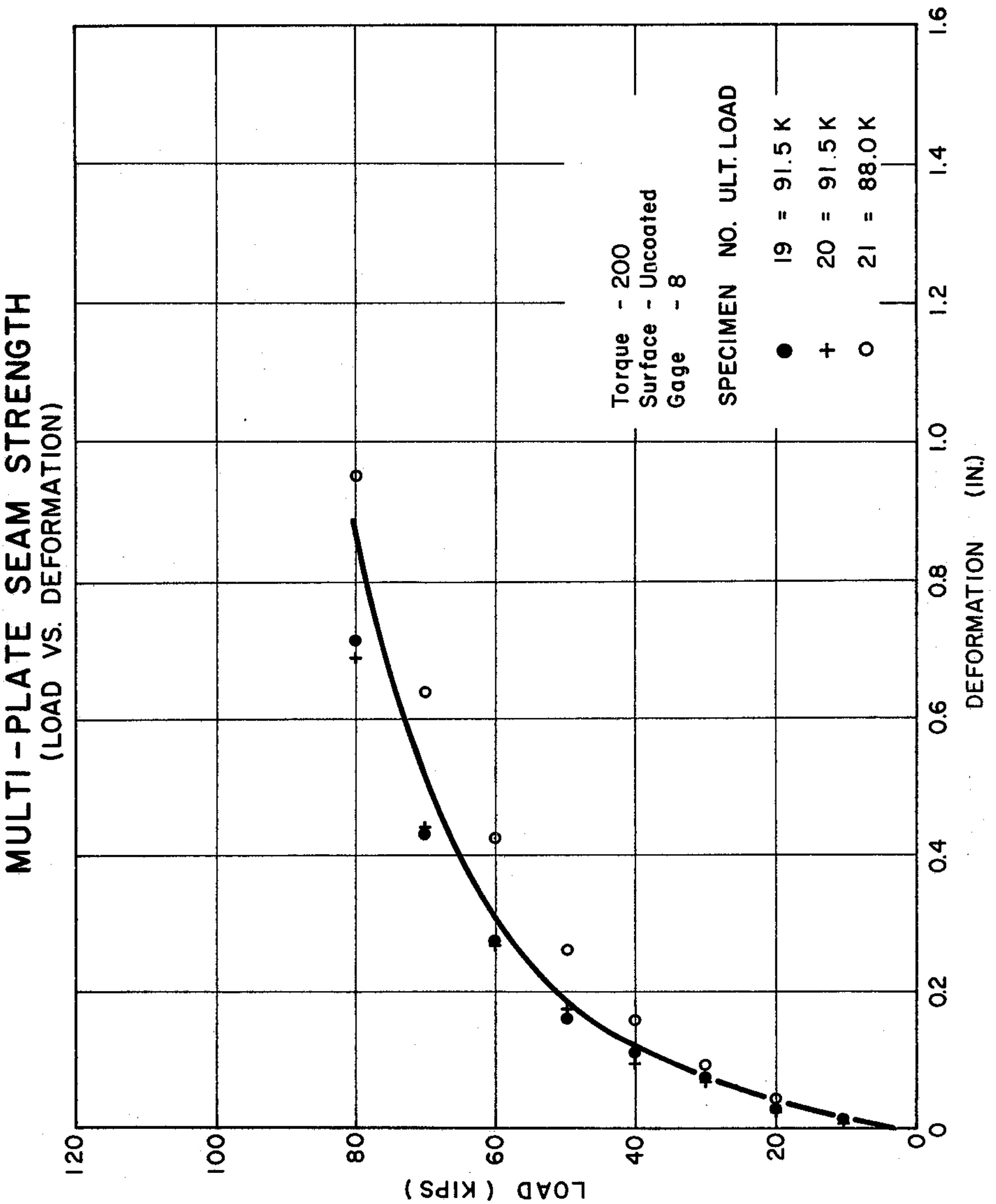

MULTI-PLATE SEAM STRENGTH
(LOAD VS. DEFORMATION)
Torque - 200
Surface - Uncoated
Gage - 8
SPECIMEN NO. ULT. LOAD
19 = 91.5 K
20 = 91.5 K
21 = 88.0 K
DEFORMATION (IN.)
LOAD (KIPS)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
20
40
60
80
100
120

Figure 12

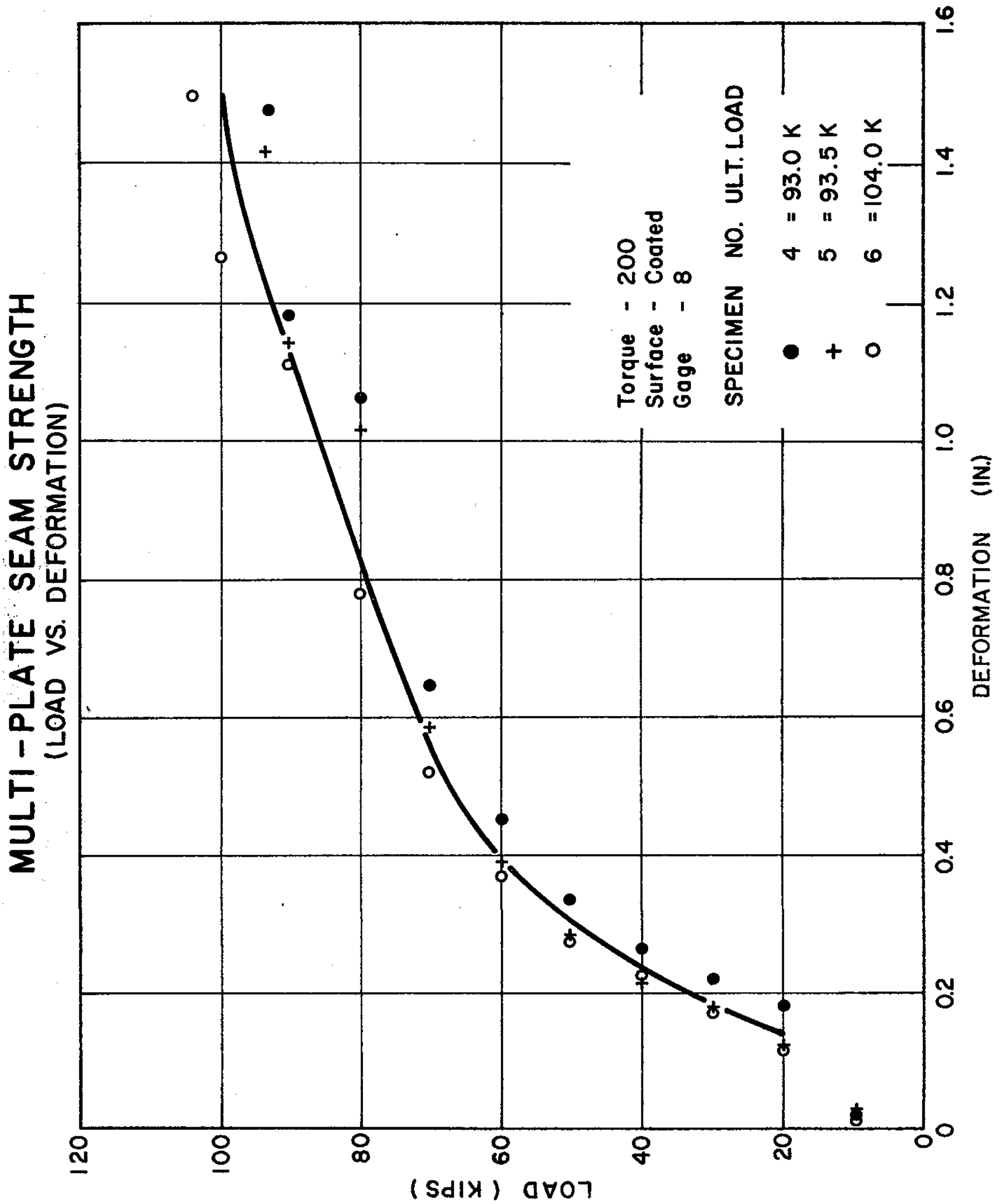

MULTI-PLATE SEAM STRENGTH
(LOAD VS. DEFORMATION)
Torque - 200
Surface - Coated
Gage - 8
SPECIMEN NO. ULT. LOAD
4 = 93.0 K
5 = 93.5 K
6 =104.0 K
LOAD (KIPS)
0
20
40
60
80
100
120
DEFORMATION (IN.)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

Figure 13

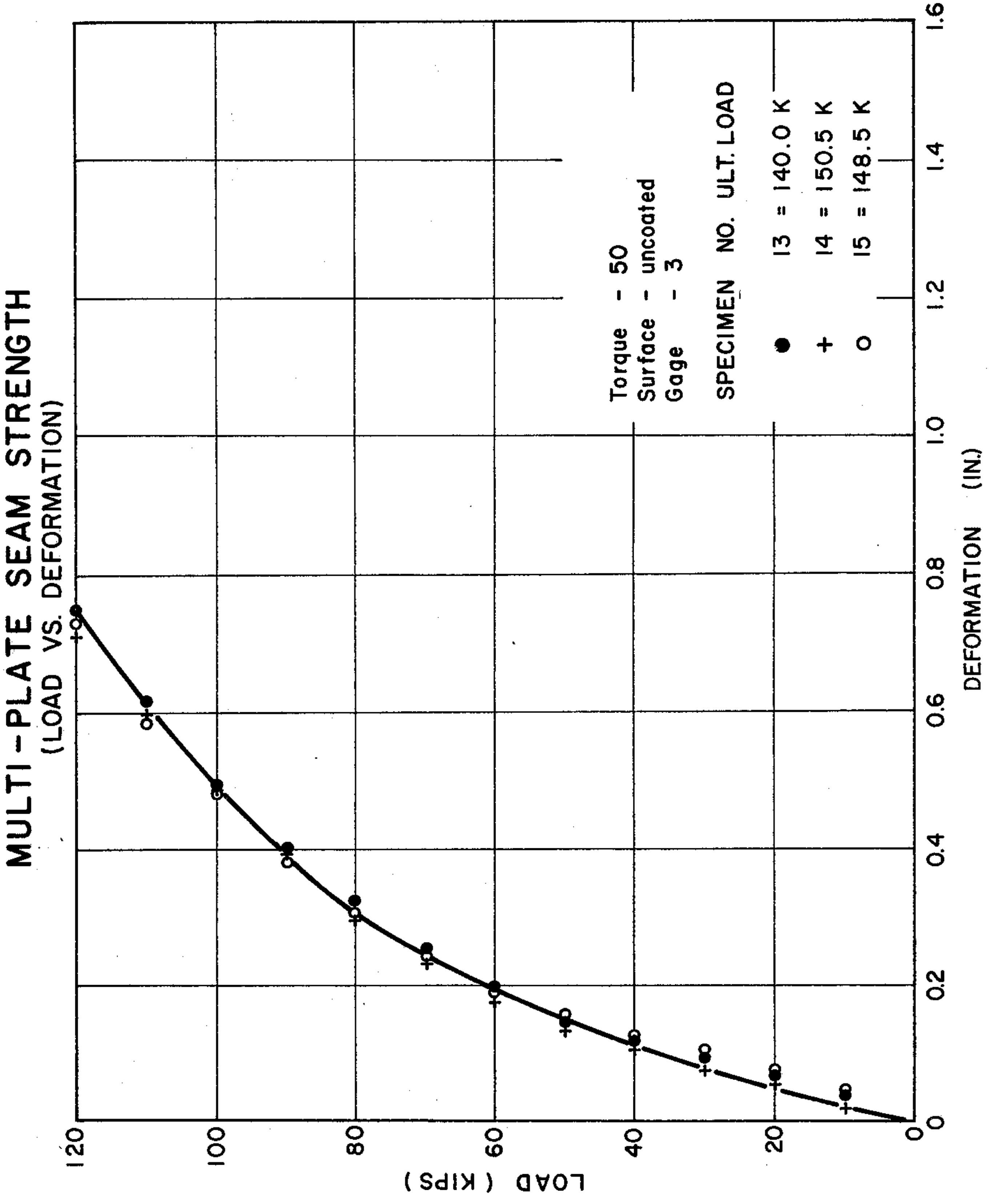
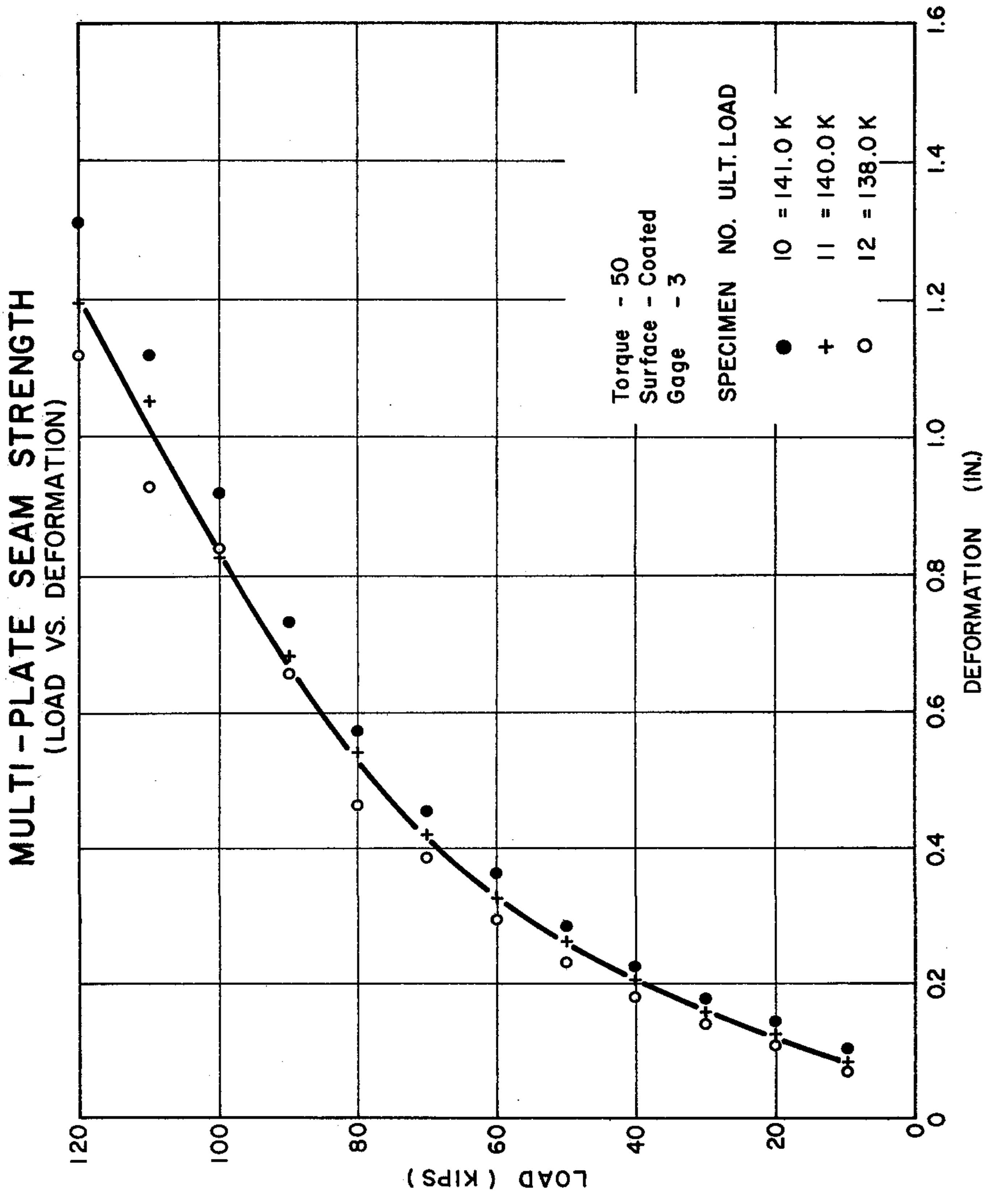

MULTI-PLATE SEAM STRENGTH
(LOAD VS. DEFORMATION)
Torque - 50
Surface - uncoated
Gage - 3
SPECIMEN NO. ULT. LOAD
● 13 = 140.0 K
+ 14 = 150.5 K
o 15 = 148.5 K
DEFORMATION (IN.)
LOAD (KIPS)
0
20
40
60
80
100
120
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

Figure 14



MULTI - PLATE SEAM STRENGTH
(LOAD VS. DEFORMATION)
Torque - 50
Surface - Coated
Gage - 3
SPECIMEN NO. ULT. LOAD
10 = 141.0 K
11 = 140.0 K
12 = 138.0 K
DEFORMATION (IN.)
LOAD (KIPS)
0
20
40
60
80
100
120
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

Figure 15

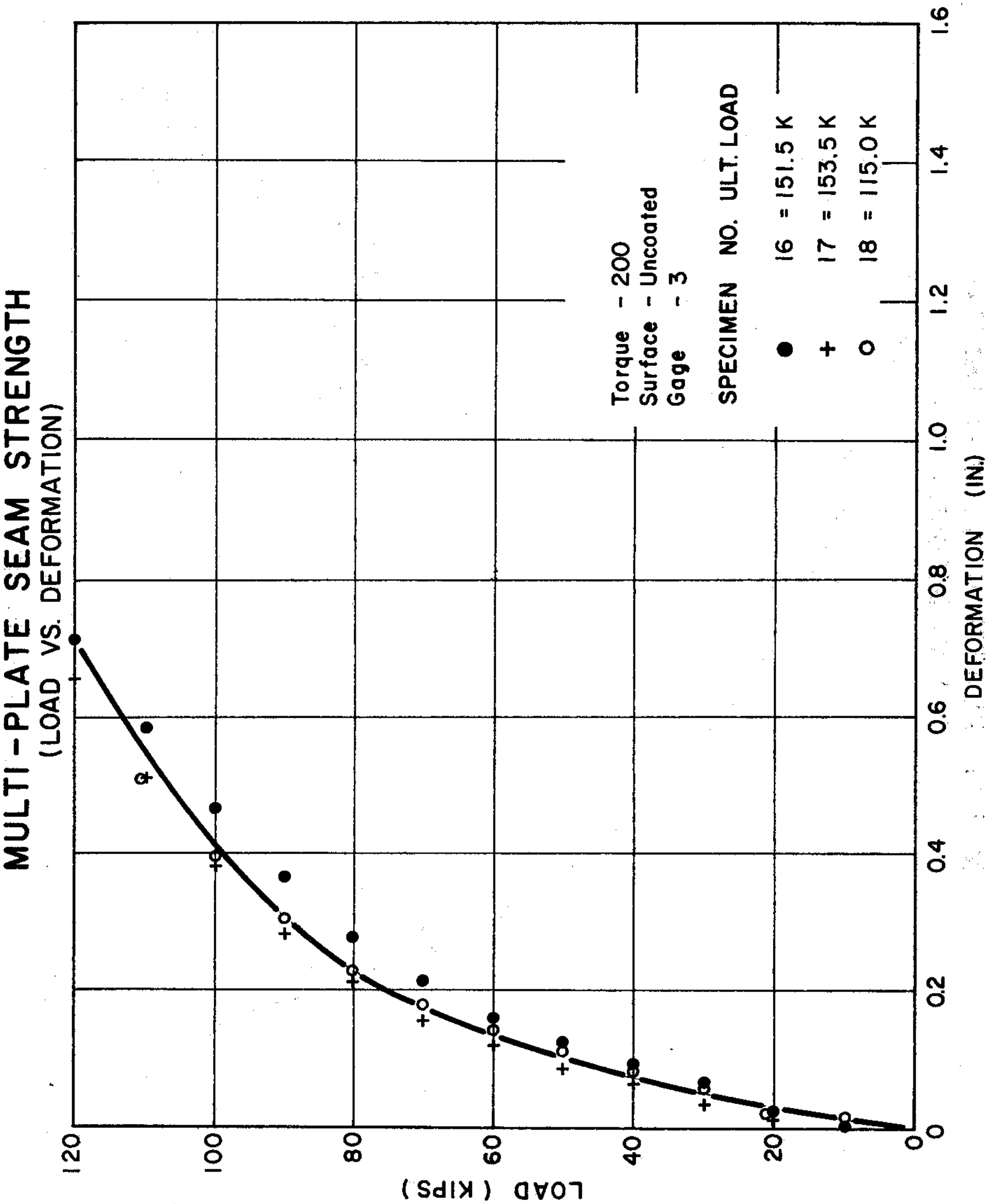
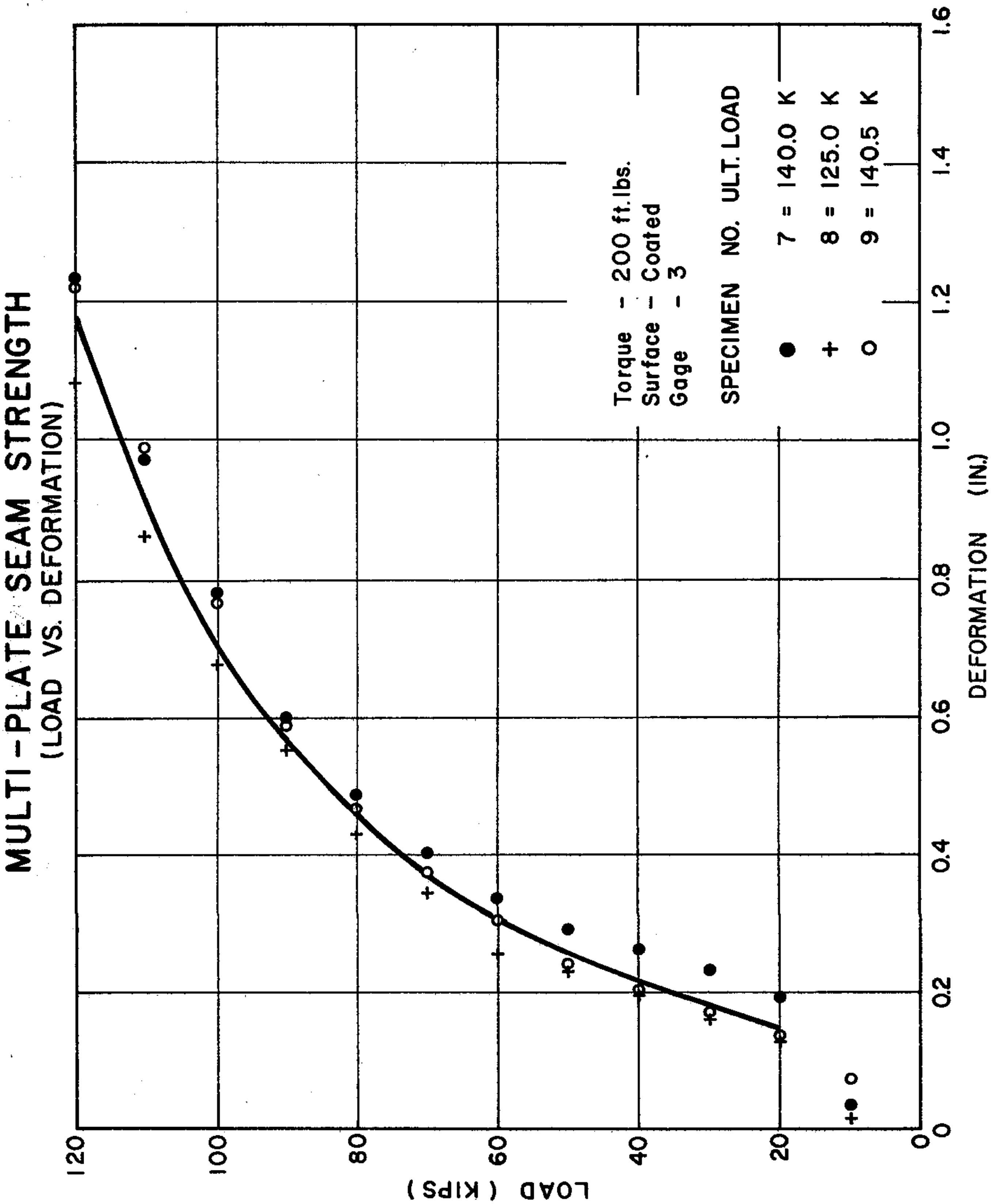

MULTI-PLATE SEAM STRENGTH
(LOAD VS. DEFORMATION)
Torque - 200
Surface - Uncoated
Gage - 3
SPECIMEN NO. ULT. LOAD
16 = 151.5 K
17 = 153.5 K
18 = 115.0 K
LOAD (KIPS)
DEFORMATION (IN.)
0
20
40
60
80
100
120
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

Figure 16



MULTI-PLATE SEAM STRENGTH
(LOAD VS. DEFORMATION)
Torque - 200 ft.lbs.
Surface - Coated
Gage - 3
SPECIMEN NO. ULT. LOAD
● 7 = 140.0 K
+ 8 = 125.0 K
o 9 = 140.5 K
LOAD (KIPS)
120
100
80
60
40
20
0
DEFORMATION (IN.)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

APPENDIX

This experiment is a 2 x 2 x 2 factorial experiment with 3 observations per cell.

An analysis of variance table is developed from the experimental data in order to perform F-tests, the results of which are used to determine the validity of the following null hypotheses:

1. There is a significant difference between the ultimate seam strengths of asphalt coated structural steel plate pipe specimens and conventional galvanized structural steel plate pipe specimens.

2. There is a significant difference between the ultimate seam strength of specimens of structural steel plate pipe connected with bolts torqued to 50-ft. lbs. and those connected with bolts torqued to 200-ft. lbs.

These hypotheses take into consideration the two factors of asphalt coating and torque level. Obviously, the gage is a significant factor in ultimate seam strength and it is not necessary to investigate its significance. However, for purposes of analysis it was included in the following model equation:

$$Xijkl = \mu + Gi + Tj + Ck + GTij + GCik + CTjk + GTCijk + \epsilon l(ijk)$$

G = Multi-plate gage (3 & 8)

T = Torque (50 & 200 ft.-lbs.)

C = Coating (asphalt & non-asphalt)

GT = Gage - Torque interaction

GC = Gage - Coating interaction

CT = Coating - Torque interaction

GTC = Gage - Torque-Coating interaction

ϵ = Random Error Term

TEST RESULTS - ULTIMATE STRENGTHS

Plate Thickness	8 Gage		3 Gage	
Bolt Torque	50 ft-lbs.	200 ft-lbs.	50 ft-lbs.	200 ft-lbs.
Asphalt Coated	86.0k	83.0k	141.0k	140.0k
	97.0k	93.5k	140.0k	125.0k
	91.5k	104.0k	138.5k	140.5k
Non-Asphalt Coated	90.0k	91.5k	140.0k	151.5k
	89.0k	91.5k	150.5k	153.5k
	81.5k	88.0k	148.5k	115.0k

To simplify the statistical treatment of the data, 100 is subtracted from each value.

Plate Thickness	8 Gage		3 Gage	
Bolt Torque	T = 50	T = 200	T = 50	T = 200
Asphalt Coated	-14.0	-17.0	+41.0	+40.0
	- 3.0	- 6.5	+40.0	+25.0
	- 8.5	+ 4.0	+38.5	+40.5
	-25.5	-19.5	+119.5	+105.5
Non-Asphalt Coated	-10.0	- 8.5	+40.0	+51.5
	-11.0	- 8.5	+50.5	+53.5
	-18.5	-12.0	+48.5	+15.0
	-39.5	-29.0	+139.0	+120.0

$$\Sigma\Sigma\Sigma\Sigma Xijkl^2 = 22,346.75$$

$$\Sigma\Sigma\Sigma Xijk.^2 = 62,563.25/3 = 20,854.42$$

$$\Sigma\Sigma X.jk.^2 = 34,413.25/6 = 5,735,54$$

$$\Sigma\Sigma Xi.k.^2 = 124,423.25/6 = 20,737.21$$

$$\Sigma\Sigma Xij..^2 = 124,249.75/6 = 20,708.29$$

$$\Sigma Xi...^2 = 247,138.25/12 = 20,594.85$$

$$\Sigma X.j..^2 = 68,771.25/12 = 5,730.94$$

$$\Sigma X..k.^2 = 68,690.25/12 = 5,724.19$$

$$\Sigma X....^2 = 137,270.25/24 = 5,719.59$$

ANOVA TABLE

Effect		df	SS	MS(ss/df)	F-Ratio
Gage	(Gi)	1	14,875.26	14,875.26	159.49
Torque	(Tj)	1	11.35	11.35	0.12
Interaction Gage-Torque	(GTij)	1	102.09	102.09	1.09
Coating	(Ck)	1	4.60	4.60	0.05
Interaction Gage & Coating	(GCik)	1	137.76	137.76	1.47
Interaction Coating & Torque	(CTjk)	1	0	0	0
Interaction Gage & Coating & Torque	(GTCijk)	1	3.77	3.77	0.04
Error Term	(ϵ1(ijk))	16	1,492.33	93.27	1.00

The F-ratios for the effects of torque and asphalt coating are less than 1.00 and therefore are not significant. The two previously stated null hypotheses are therefore rejected.