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FINAL REPORT

on

CLEAVAGE FRACTURE OF SHIP PLATES AS INFLUENCED BY SIZE EFFECT

by

W. M. WILSON, R. A. HECHTMAN AND W. H. BRUCKNER
UNIVERSITY OF ILLINOIS
Under Navy Contract NObs-31224

COMMITTEE ON SHIP CONSTRUCTION
DIVISION OF ENGINEERING & INDUSTRIAL RESEARCH
NATIONAL RESEARCH COUNCIL

Advisory to
BUREAU OF SHIPS, NAVY DEPARTMENT
Under Contract NObs-34231

Serial No. SSC-10

Copy No. 20

June 12, 1947

NATIONAL RESEARCH COUNCIL
2101 Constitution Avenue
Washington, D. C.

June 12, 1947

Chief, Bureau of Ships
Navy Department
Washington, D. C.

Dear Sir:

Attached is Report Serial No. SSC-10, entitled "Cleavage Fracture of Ship Plates as Influenced by Size Effect". This report has been submitted by the contractor as the final report of the work done on Research Project SR-93 under Contract NObs-31224 between the Bureau of Ships, Navy Department and the University of Illinois.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Construction, Division of Engineering and Industrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Navy Department and the National Academy of Sciences.

Very truly yours,

Frederick M. Feiker

Frederick M. Feiker, Chairman
Division of Engineering and
Industrial Research

Enclosure

PREFACE

The Navy Department through the Bureau of Ships is distributing this report to those agencies and individuals that were actively associated with this research program. This report represents a part of the research work contracted for under the section of the Navy's directive "to investigate the design and construction of welded steel merchant vessels."

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FINAL REPORT

NAVY BUREAU OF SHIPS CONTRACT NObs-31224
PROJECT SR-93

CLEAVAGE FRACTURE OF SHIP PLATES AS INFLUENCED BY SIZE EFFECT

September 30, 1946

From:

University of Illinois
College of Engineering

Report Prepared by:

Wilbur M. Wilson
Robert A. Hechtman
Walter H. Bruckner

ABSTRACT

This final report contains a description of tests made to determine why ship plates crack in service, which were not included in the previous reports*(1)(2) on the same subject, "Cleavage Fracture of Ship Plates as Influenced by Size Effect." The tests were based upon the hypothesis that the cracks begin at points where there are severe geometrical stress-raisers and that the tendency for the plates to crack increases, for specified geometrical characteristics, with an increase in the notch-sensitivity of the steel.

Plates with nominal widths of 72, 48, 24 and 12 inches were tested. The 72-in. and 48-in. plates were made of three kinds of steel,** rimmed-steel E as-rolled, killed-steel D as-rolled, and killed-steel D normalized. The 24-in. plates were made of the same kinds of steel as the 72-in. and 48-in. plates with the addition of killed-steel F as-rolled. The 12-in. plates were made of the same kinds of steel as the 24-in. plates with the addition of killed-steel G as-rolled and rimmed-steel E normalized. The 12-in. wide plates were, therefore, made from six kinds of steel. All plates were loaded parallel to the direction of rolling except four of the 12-in. rimmed-steel E plates, which were loaded transverse to the direction of rolling. All plates of each kind of steel were from the same heat.

The mechanical properties of all steels were obtained from tests of both flat and round coupon specimens. Charpy impact values, determined by tests of standard V-notch specimens, were obtained for all steels, except rimmed-steel E normalized, throughout the temperature range covered by the

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* The numbers in parentheses refer to references in the bibliography, page 45 of this report.

**The letter designations and properties of all steels are given in Appendix B.

tests of the wide plates.

The standard stress-raiser, which was centrally located in the plate, was a transverse slot 1/2-in. wide with a hacksaw cut at each end which terminated in a jeweler's-saw cut 1/8-in. long. For all tests, L/W was equal to 0.25. The plates were tested at temperatures ranging from -73 to 140 degrees F.

Tests of plates with other types of stress-raiser and with various L/W ratios were reported in the Progress Report.

The elongation of the wide plates was measured at all[2] loads with mechanical gages, the gage length being 3/4 of the gross width of the plate. The elastic and early plastic strains in the plate at mid-length were measured with electric strain gages having a 13/16-in. gage length; the plastic strain in the same region was measured with mechanical gages of 1/4-in. and 1-in. gage lengths at loads up to the initial fracture. All strains were measured on both sides of the plate. After failure, the thickness of the plate adjacent to the fracture was measured with micrometer calipers; and the character of the fracture, percentage of shear and cleavage, was noted.

The tests were planned to determine:

(1) The relative energy-absorbing capacity and strength of plates of the six kinds of steel.

(2) The relation between the width of the plates and their strength.

(3) The relation between the temperature of the plates and their strength and energy-absorbing capacity.

(4) The relation between the type of fracture and energy-absorbing capacity of the plates.

(5) The correlation of the V-notch impact test and the wide plate test.

There was a total of 76 wide plates tested. The details of the results are given in Appendix A of this report and of the previous reports.[1][2] The results are discussed on pages 9 to 40 and the conclusions are given on pages 40 to 43, inclusive.

FINAL REPORT

NAVY BUREAU OF SHIPS CONTRACT NObs-31224
PROJECT SR-93

"CLEAVAGE FRACTURE OF SHIP PLATES
AS INFLUENCED BY SIZE EFFECT."
September 30, 1946

From: University of Illinois
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Wilbur M. Wilson
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Walter H. Bruckner

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INTRODUCTION

The object of the investigation covered by this report was to determine the factors that influence the formation of cleavage fractures in ship plates. Because ship plates are much wider than plates that can be tested in a testing machine, tests were made on plates with nominal widths of 72-in., 48-in., 24-in., and 12-in. in order to obtain information on which to base extrapolations that might indicate the behavior of still wider plates. The information obtained relative to the behavior of wide plates containing severe stress-raisers may be divided into six major divisions, as follows:

A. The average static strength.

B. The energy-absorbing capacity.

C. The V-notch impact value of the steels as an indicator of the performance of the wide plate test.

D. The distribution of plastic deformation at the ends of the stress-raiser prior to maximum load.

E. The temperature-elongation relation.

F. The reduction in thickness of the plates.

The standard stress-raiser consisted of a transverse slot 1/2-in. wide with a hacksaw cut at each end which terminated in a jeweler's-saw cut 1/8-in. long, and which had an $\frac{L}{W}$ ratio $\left(\frac{\text{length of stress-raiser}}{\text{width of plate}}\right)$ of 0.25.

In order to determine the relation between the behavior of the wide plates and the mechanical properties of the material, tests were made at room temperature on both flat and round coupon specimens cut from the plates, from which the specimens were made, to determine the ultimate strength, yield point, elongation, and the reduction of area. Likewise, impact tests were made at various temperatures on standard Charpy V-notch specimens cut from some of the plates.

The following steels were used in this investigation.

Rimmed-Steel as-rolled, designated as Steel E As-Rolled.

Rimmed-Steel normalized, designated as Steel E Normalized.*

Killed-Steel as-rolled, designated as Steel D As-Rolled.

Killed-Steel normalized, designated as Steel D Normalized.*

Killed-Steel as-rolled, designated as Steel F As-Rolled.

Killed-Steel as-rolled, designated as Steel G As-Rolled.

The mechanical properties and chemical compositions of these steels are given in Appendix B.

EXPERIMENTAL WORK

1. Procedure.

The procedure followed in the tests of this report is described on pages 3 to 8, and the data for one test, together with a fairly complete description of the manner in which it was obtained, are presented on pages 13 to 21, inclusive, of a previous report.[1]

A 72-in. plate mounted in the testing machine is shown in the photograph of Fig. 1. Figure 2 gives the general dimensions of the wide plate specimens and the location of the electric gages and of the gage points for the mechanical gages. All wide plate specimens were loaded in the direction of rolling except where noted.

2. Data.

The tests included in this report and similar tests in the previous reports[1][2] are listed in Table I. There were a large number of tests and the amount of data obtained for each was so great that the whole is quite voluminous; and its presentation in a brief but understandable form is quite

* The normalizing treatment is described in Appendix B, Table IIIb, page 7b.

difficult. The data are presented in the form of tables and graphs that either accompany the discussion of the results or are given in Appendix A. The tensile properties and the Charpy impact values of the plates are given in Appendix B and in the two previous reports.[1][2]

The terms used in presenting these data are defined as follows:

The average strength of the wide plates is taken as the maximum load divided by the original net section. The energy-absorbing capacity is taken as the area under the load-strain curve for a gage length equal to 3/4 of the gross width of the plate. Two values are reported. One is the energy absorbed up to the maximum load, the other is the energy absorbed up to failure.

The percentages of the area of fracture that were cleavage, single shear, double shear, given in Table II, were obtained by macroscopic examination of the fractured edges of the plates. A microscopic examination would undoubtedly have revealed small amounts of cleavage in shear fractures or of shear in cleavage fractures.

Unless otherwise designated, the term, impact test, is used to designate the Charpy type impact test of a standard V-notch specimen made in accordance with A.S.T.M. specifications. The energy absorption in foot-pounds is designated as the V-notch impact value, or simply the impact value.

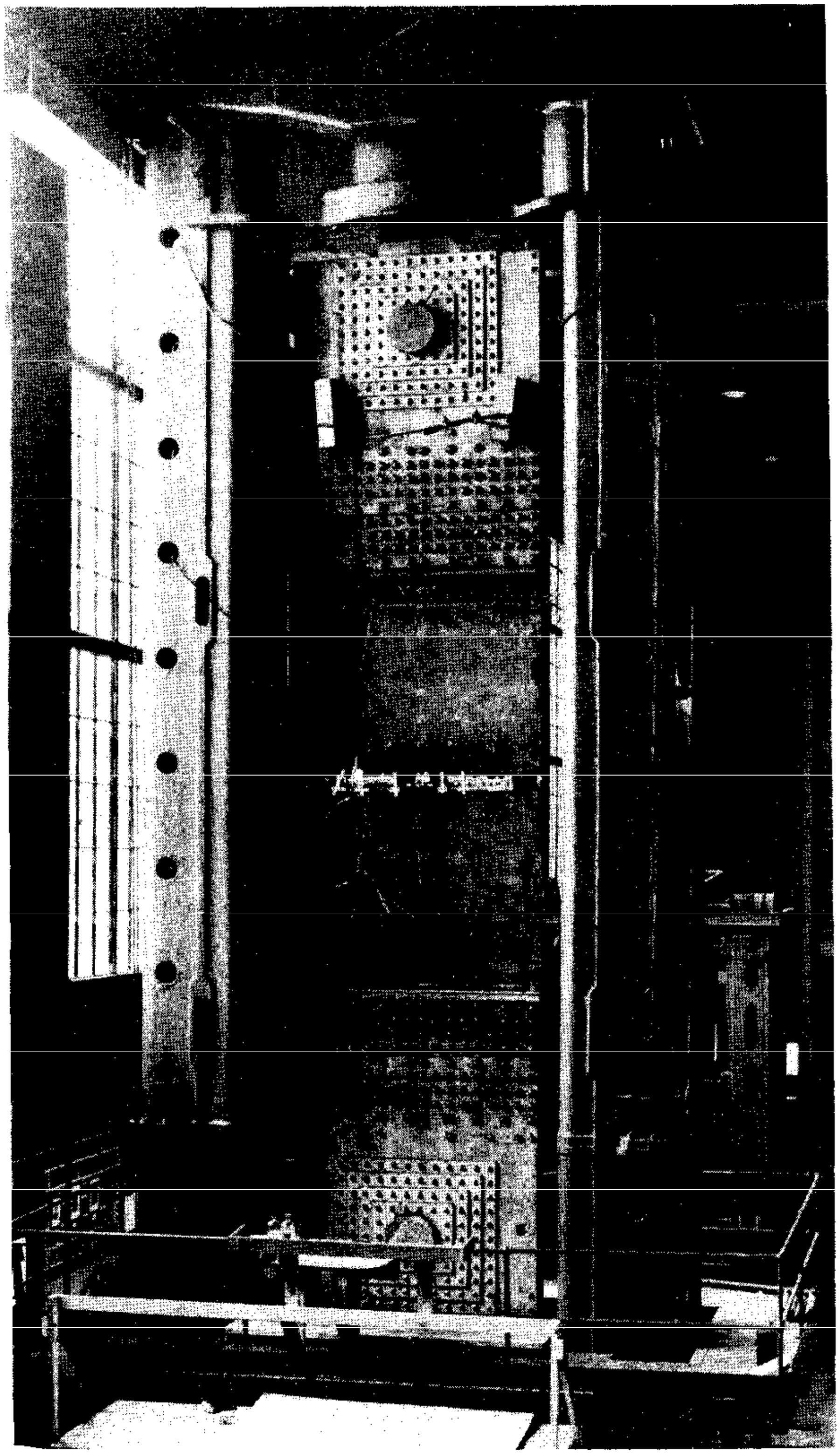
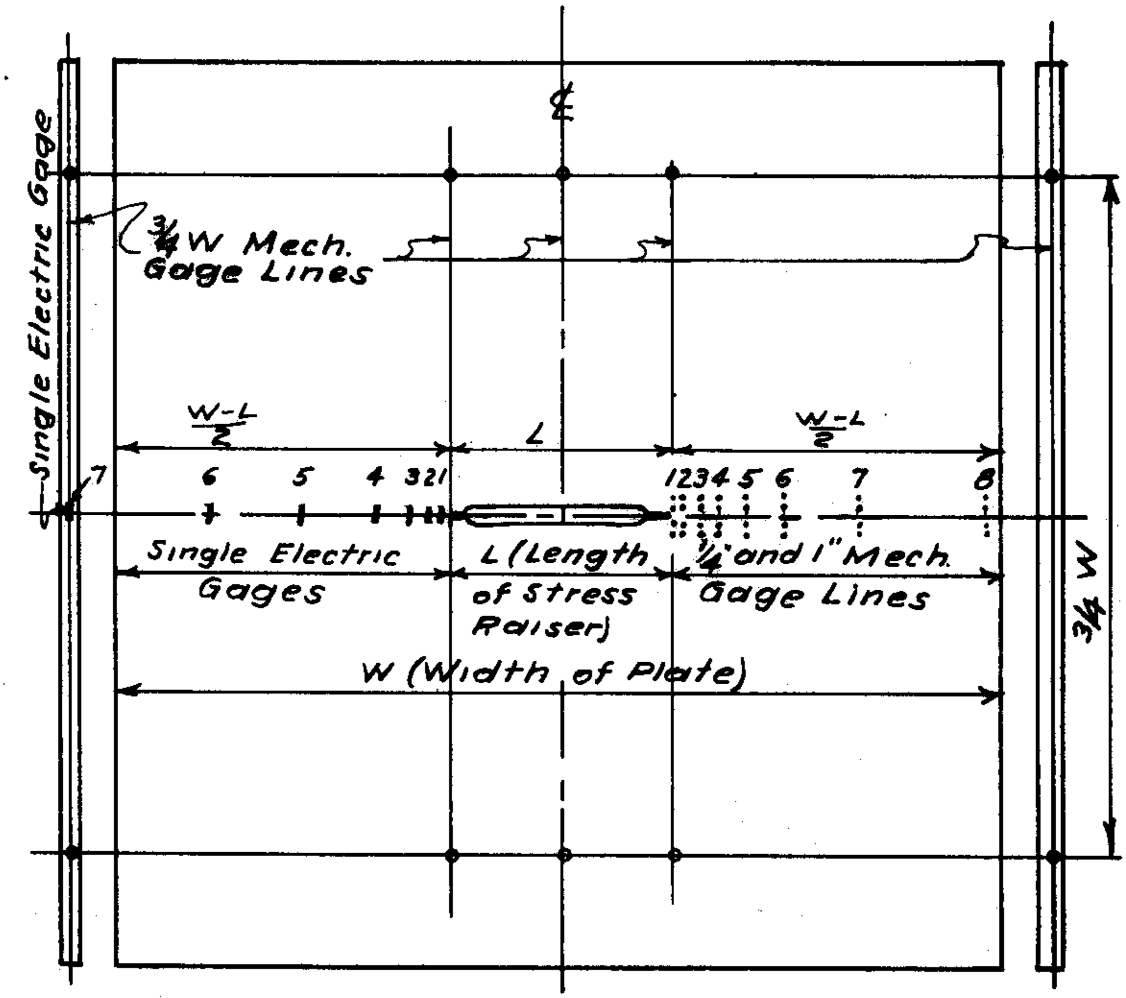


FIG. 1.

72-IN. SPECIMEN IN 3 000 000-LB. TESTING MACHINE.



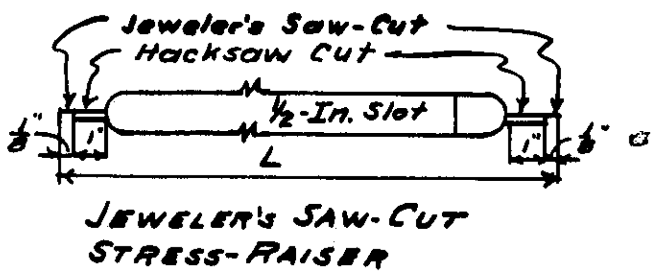


FIG. 2 SKETCH OF WIDE PLATE SPECIMENS AND TYPE OF STRESS-RAISER

TABLE I.

DESCRIPTION OF SPECIMENS.*

Stress-Raiser: Jeweler's-Saw Cut. L/W = 0.25

SPECIMEN NO.	TEMPERATURE OF STEEL WHEN TESTED Degrees F.	KIND OF STEEL	NOMINAL WIDTH OF SPECIMEN, In.
18A-1	141	Rimmed-Steel E As-Rolled	72
13A-7	110		
CG-1	74		
23-7	38		
18A-1	59	Killed-Steel D As-Rolled	72
22-1	59		
17A-7	31		
5-1	15		
17-7	0		
12A-1	60	Killed-Steel D Normalized	72
15-7	32		
11-1	15		
5-7	0		
14-7	-38		
13-7	123	Rimmed-Steel E As-Rolled	48
18-8	110		
22-7	84		
22A-7	38		
17B-7	43	Killed-Steel D As-Rolled	48
18-2	39		
5-4	32		
18-1	18		
15A-1	42	Killed-Steel D Normalized	48
5A-2	31		
5A-5	15		

* All specimens stressed parallel to direction of rolling unless otherwise noted.

TABLE I. (Cont'd)
DESCRIPTION OF SPECIMENS.

SPECIMEN NO.	TEMPERATURE OF STEEL WHEN TESTED Degrees F.	KIND OF STEEL	NOMINAL WIDTH OF SPECIMEN, In.
20A-13	111	Rimmed-Steel E As-Rolled	24
20A-3	89		
22-9	86		
20-9	-36		
18B-3	58	Killed-Steel D As-Rolled	24
17B-6	37		
17B-4	30		
17B-5	10		
3-1	40	Killed-Steel D Normalized	24
3-2	33		
3-3	16		
A-4	50	Killed-Steel F As-Rolled	24
A-2	32		
A-1	0		
A-3	-40		
18-9A	128	Rimmed-Steel E As-Rolled	12
23-3B	109		
13A-5B	74		
13A-5A	40		
20-2A	-73		
18A-5	78	Killed-Steel D As-Rolled	12
18A-3	59		
18B-2	41		
17-6B	41		
17-6A	40		
22A-2	17		
22B-2	-2		
17A-5A	-50		

TABLE I. (Concl'd)
DESCRIPTION OF SPECIMENS.

SPECIMEN NO.	TEMPERATURE OF STEEL WHEN TESTED Degrees F.	KIND OF STEEL	NOMINAL WIDTH OF SPECIMEN, In.
15-5A	41	Killed-Steel D Normalized	12
9-2	30		
15-6B	16		
10A-4	1		
13A-10	160	Rimmed-Steel E As-Rolled. Stressed transverse to direction of rolling	12
13A-9	140		
18-7B	121		
18-7A	81		
17-13	115	Rimmed-Steel E Normalized	12
23-3A	78		
16-5	50		
18A-3	30		
A-13	104	Killed-Steel F As-Rolled	12
A-12	55		
A-6	20		
A-10	-22		
B-10	54	Killed-Steel G As-Rolled	12
B-5	-5		
B-9	-26		
B-6	-47		

3. Discussion of Results

a. Strength:- The strength of the specimens with a jeweler's-saw cut type of stress-raiser and an $\frac{L}{W}$ value of 0.25, expressed as the average stress on the net section at the maximum load, is given in Table II. The relation between the strength and the temperature for 72-in., 48-in., and 24-in. plates made of various kinds of steel,* is shown by the diagrams of Fig. 3, and for 12-in. plates by the diagrams of Fig. 4. The numeral beside each point of a diagram is the total percentage of the fracture that is of the shear type. In general, the strength of the plates increased somewhat with an increase in the portion of the fracture that was of a shear type. For plates with an all-cleavage fracture, changes in temperature were not accompanied by any significant change in strength.

The relation between the strength and the width of wide plates is shown by the diagrams of Fig. 5. These diagrams indicate that the average strength decreased with an increase in the width of the plate for all kinds of steel, but the exact relation could not be determined. However, the tendency for the strength to decrease with an increase in width beyond a width of 72-in., would seem to be definitely established. Moreover, the rate of decrease would seem to be nearly as great for widths greater than 48 ins. as it is for widths less than 48 ins. The average strength of 72-in. wide plates was somewhat greater than the coupon yield-point strength of the material.

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*The letter designations and properties of all steels are given in Appendix B.

TABLE II.

STRENGTH OF WIDE PLATES.
Stress-Raiser: Jeweler's-Saw Cut, L/W = 0.25.
Loads in 1000's of lbs.; Stresses in 1000's of lb.per sq.in.;
Energy in 1000's of in. lb.

SPEC. NO.	TEMP. °F.	COUPON STRENGTH Y.P.	COUPON STRENGTH Ult.	ULTIMATE LOAD	FRACTURE* Percent C	FRACTURE* Percent SS	FRACTURE* Percent DS	ULTIMATE STRESS ON NET SECTION	ENERGY ABSORBED At Max. Load	ENERGY ABSORBED At Failure
72-IN. RIMMED-STEEL E AS-ROLLED PLATES.										
18A-1	141	29.8	57.9	1730	---	73	6	41.4	1898	3586
13A-7	110	28.8	54.6	1476	16	65	--	36.3	2361	3400
CG -1	74	30.5	61.3	1290	100	--	--	31.9	233	350
23 -7	38	32.2	59.9	1360	100	--	--	33.6	120	200
72-IN. KILLED-STEEL D AS-ROLLED PLATES.										
18A-1	59	40.0	66.9	1722	39	39	--	42.1	481	2054
22-1	59	37.3	65.1	1927	84	--	16	46.0	2163	2507
17A-7	31	39.4	66.0	1890	--	86	6	45.7	3024	4700
5-1	15	37.0	63.7	1730	100	--	--	41.5	476	563
17-7	0	38.8	65.4	1789	100	--	--	43.1	174	228
72-IN. KILLED-STEEL D NORMALIZED PLATES.										
12A-1	60	34.8	59.8	1765	--	81	1	42.4	2122	4550
15-7	32	34.8	59.2	1750	--	55	19	43.2	2738	4650
11-1	15	34.4	60.3	1507	100	--	--	37.4	238	298
5-7	0	36.2	60.9	1614	100	--	--	38.9	210	260
14-7	-38	35.5	59.7	1541	100	--	--	38.6	179	234
48-IN. RIMMED-STEEL E AS-ROLLED PLATES.										
13-7	123	31.1	59.1	1095	9	66	7	40.3	800	1683
18-8	110	30.4	59.3	1008	22	58	--	36.2	766	1446
22-7	84	33.9	60.5	987	100	--	--	35.7	245	361
22A-7	38	31.3	57.7	983	100	--	--	36.0	61	73
48-IN. KILLED-STEEL D AS-ROLLED PLATES.										
17B-7	43	39.0	65.4	1276	85	8	7	45.9	560	1081
18-2	39	39.1	65.1	1185	96	2	2	43.5	288	416
5-4	32	37.0	63.7	1207	79	21	--	43.7	890	1110
18-1	18	39.1	65.1	1185	100	--	--	43.6	226	304
48-IN. KILLED-STEEL D NORMALIZED PLATES.										
15A-1	42	34.9	59.5	1216	--	--	81	45.4	1340	2540
5A-2	31	34.5	60.7	1098	100	--	--	40.0	207	227
5A-5	15	34.5	60.7	1100	100	--	--	40.0	185	229

* C = Cleavage, SS = Single Shear, DS = Double Shear.
Portion of width not accounted for was flame-cut.

TABLE II (Cont'd)

STRENGTH OF WIDE PLATES.
Stress-Raiser: Jeweler's-Saw Cut. L/W = 0.25.
Loads in 1000's of lbs.; Stresses in 1000's of lb. per sq. in.;
Energy in 1000's of in.lb.

SPEC. NO.	TEMP. °F.	COUPON STRENGTH Y.P.	COUPON STRENGTH ULT.	ULTIMATE LOAD	FRACTURE * Percent C	FRACTURE * Percent SS	FRACTURE * Percent DS	ULTIMATE STRESS ON NET SECTION	ENERGY ABSORBED At Max. Load	ENERGY ABSORBED At Failure
24-IN. RIMMED-STEEL E AS-ROLLED PLATES.										
20A-13	111	32.3	59.6	563	98	--	2	41.0	159	246
20A-3	89	32.3	59.6	483.8	100	--	--	35.4	102	135
22-9	86	33.9	60.5	486.4	100	--	--	36.7	74	125
20-9	-36	29.3	56.8	510	100	--	--	37.6	16	21
24-IN. KILLED-STEEL D AS-ROLLED PLATES.										
18B-3	58	37.6	64.9	665	--	95	--	49.7	286	717
17B-6	37	39.0	65.4	618	98	1	1	45.7	112	148
17B-4	30	39.0	65.4	653	19	81	--	48.3	260	656
17B-5	10	39.0	65.4	643	97	1	2	47.3	158	188
24-IN. KILLED-STEEL D NORMALIZED PLATES.										
3-1	40	33.8	59.0	633	--	49	35	46.4	309	795
3-2	33	33.8	59.0	637	19	49	29	46.3	320	762
3-3	16	33.8	59.0	588	100	--	--	42.8	102	117
24-IN. KILLED-STEEL F AS-ROLLED PLATES.										
A-4	50	34.1	60.8	657	--	78	15	48.8	344	860
A-2	32	34.1	60.8	655	17	49	34	47.6	351	868
A-1	0	34.1	60.8	675	81	10	9	49.9	400	496
A-3	-40	34.1	60.8	626	98	1	1	45.8	124	161

* C = Cleavage, SS = Single Shear, DS = Double Shear.
Portion of width not accounted for was flame-cut.

TABLE II (Cont'd)

STRENGTH OF WIDE PLATES.
Stress-Raiser: Jeweler's-Saw Cut. L/W = 0.25
Loads in 1000's of lbs.; Stresses in 1000's of lb.per sq.in.;
Energy in 1000's of in.lb.

SPEC. NO.	TEMP. °F.	COUPON STRENGTH Y.P.	COUPON STRENGTH Ult.	ULTIMATE LOAD	FRACTURE * Percent C	FRACTURE * Percent SS	FRACTURE * Percent DS	ULTIMATE STRESS ON NET SECTION	ENERGY ABSORBED At Max. Load	ENERGY ABSORBED At Failure
12-IN. REMMED-STEEL E AS-ROLLED PLATES.										
18-9A	128	30.4	59.3	324.8	6	94	--	49.5	66	214
23-3B	109	32.2	59.9	310.9	13	76	11	48.9	60	199
13A-5B	74	28.7	54.6	254.8	100	--	--	40.5	40	53
13A-5A	40	28.7	54.6	236.2	100	--	--	37.6	17	17
20-2A	-73	29.3	56.8	245	100	--	--	37.9	10	12
12-IN. KILLED-STEEL D AS-ROLLED PLATES.										
18A-5	78	40.0	66.9	342.7	10	90	--	52.9	87.6	240
18A-3	59	40.0	66.9	350.8	25	49	26	54.6	99	234
18B-2	41	37.6	64.9	312	100	--	--	48.0	27	36.9
17-6B	41	38.8	65.4	346.5	10	90	--	53.4	85	224
17-6A	40	38.8	65.4	356.4	100	--	--	54.3	50	56.5
22A-2	17	36.6	64.0	370.1	15	85	--	54.8	94.2	254
22B-2	-2	36.5	64.4	318.5	100	--	--	48.4	25.1	35
17A-5A	-50	39.4	66.0	320	100	--	--	47.8	13.4	23.6
12-IN. KILLED-STEEL D NORMALIZED PLATES.										
15-5A	41	34.8	59.2	327.6	13	66	21	50.5	100	242
9-2	30	35.0	60.0	336.3	20	49	31	51.9	109	251
15-6B	16	34.8	59.2	337.4	54	31	15	52.4	99	213
10A-4	1	35.0	59.4	316.3	100	--	--	48.0	36.3	42.2
12-IN. RIMMED-STEEL E AS-ROLLED PLATES. Transverse to direction of rolling.										
13A-10	160	28.7	54.6	304.7	--	74	19	47.3	76	176
13A-9	140	28.7	54.6	294.5	21	54	25	45.4	30	153
18-7B	121	30.4	59.3	319.3	32	41	27	47.8	83	188
18-7A	81	30.4	59.3	257.9	100	--	--	39.0	22	45

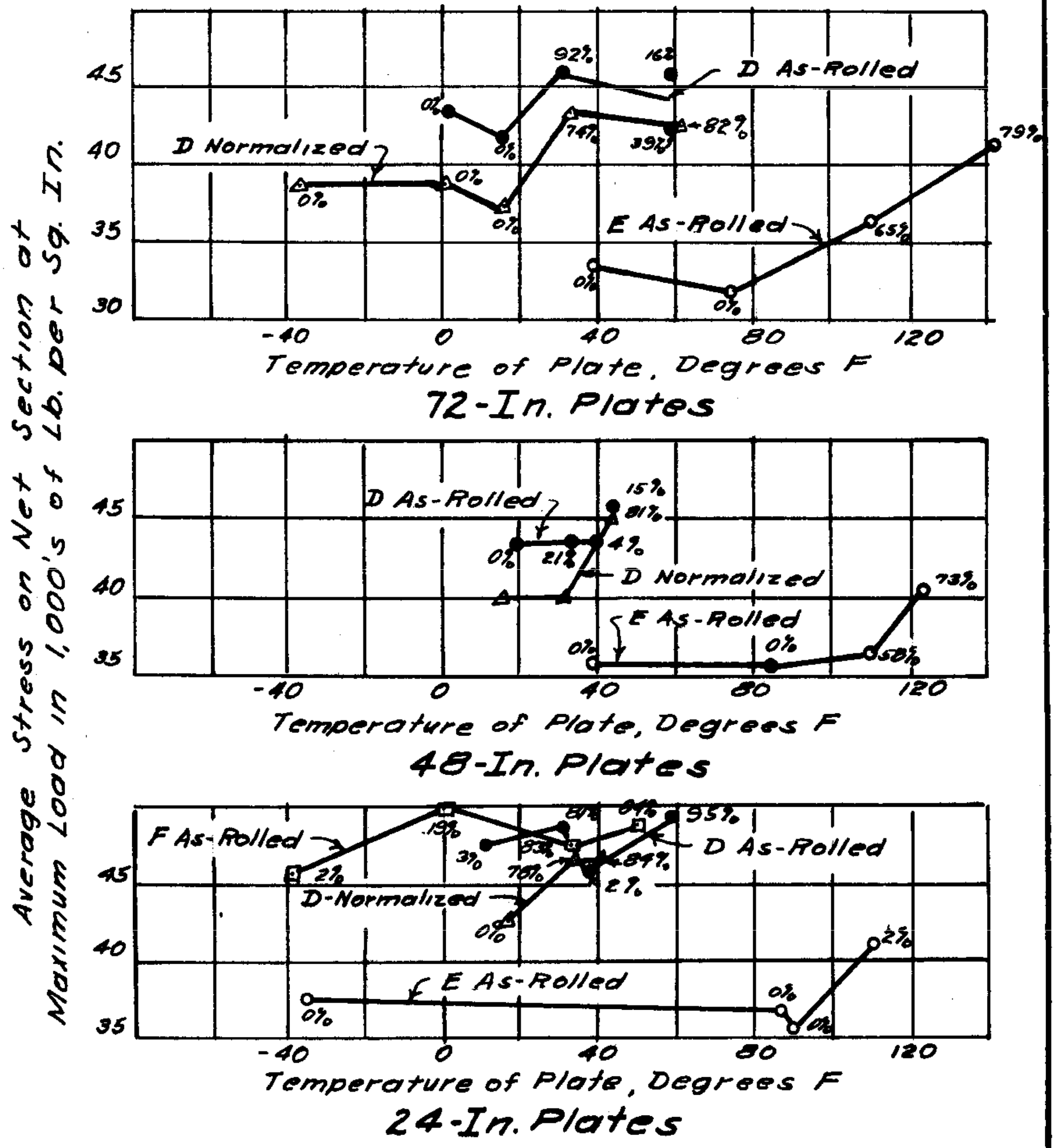
* C = Cleavage, SS = Single Shear, DS = Double Shear.
Portion of width not accounted for was flame-cut.

TABLE II (Concl'd)

STRENGTH OF WIDE PLATES.
Stress-Raiser: Jeweler's-Saw Cut. L/W = 0.25.
Loads in 1000's of lbs.; Stresses in 1000's of lb.per sq.in.;
Energy in 1000's of in.lb.

SPEC. NO.	TEMP. °F.	COUPON STRENGTH		ULTI-MATE LOAD	FRACTURE * Percent			ULTIMATE STRESS ON NET SECTION	ENERGY ABSORBED	
		Y.P.	Ult.		C	SS	DS		At Max. Load	At Fail-ure
				12-IN. RIMMED-STEEL E NORMALIZED PLATES.						
17-13	115	--	--	307.4	--	52	40	47.0	71	213
23-3A	78	--	--	306.0	--	93	--	47.5	88	204
16-5	50	35.1	57.7	291.4	98	--	2	45.2	33	39
18A-3	30	--	--	288.2	100	--	--	44.0	35	41
				12-IN. KILLED-STEEL F AS-ROLLED PLATES.						
A-13	104	34.1	60.8	339.8	--	17	73	51.5	107	295
A-12	55	34.1	60.8	348.0	20	49	31	52.3	117	290
A-6	20	34.1	60.8	362.1	72	8	20	55.3	114	217
A-10	-22	34.1	60.8	331.0	100	--	--	50.0	49	57
				12-IN. KILLED-STEEL G AS-ROLLED PLATES.						
B-10	54	41.3	70.1	366.0	10	22	68	58.0	81	243
B-5	-5	41.3	70.1	377.7	80	--	20	60.4	106	162
B-9	-26	41.3	70.1	381.7	93	7	--	60.4	85	95
B-6	-47	41.3	70.1	336.2	100	--	--	53.2	23	32

* C = Cleavage, SS = Single Shear, DS = Double Shear.
Portion of width not accounted for was flame-cut.



Note: Numerals beside points indicate percentage of shear fracture

Fig. 3

Comparison of Average Strength of Wide Plates and Temperature. $L/w = 0.25$, Jeweler's-Saw Cut Stress-Raiser. 72-In., 48-In. and 24-In. Plates

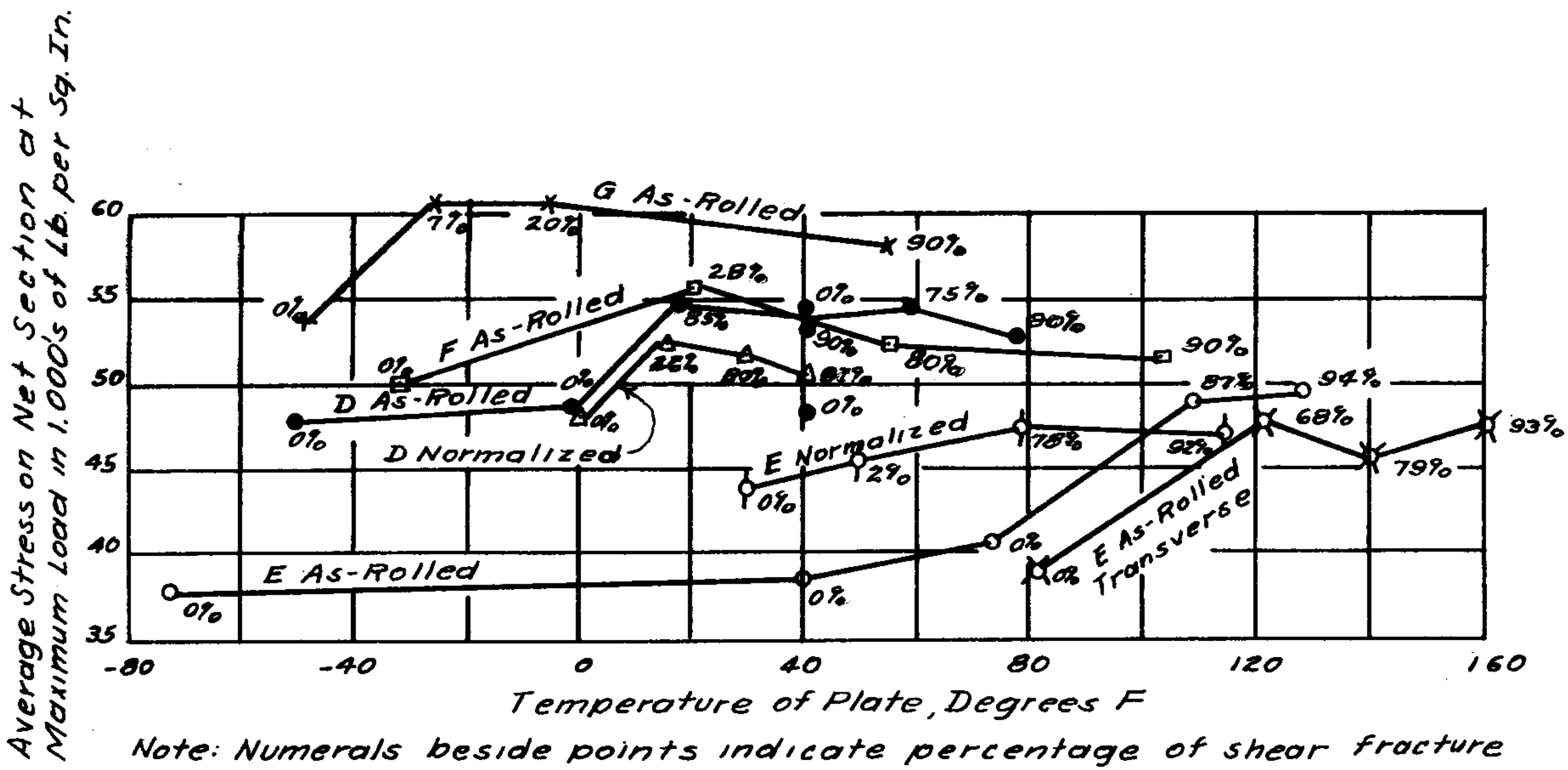
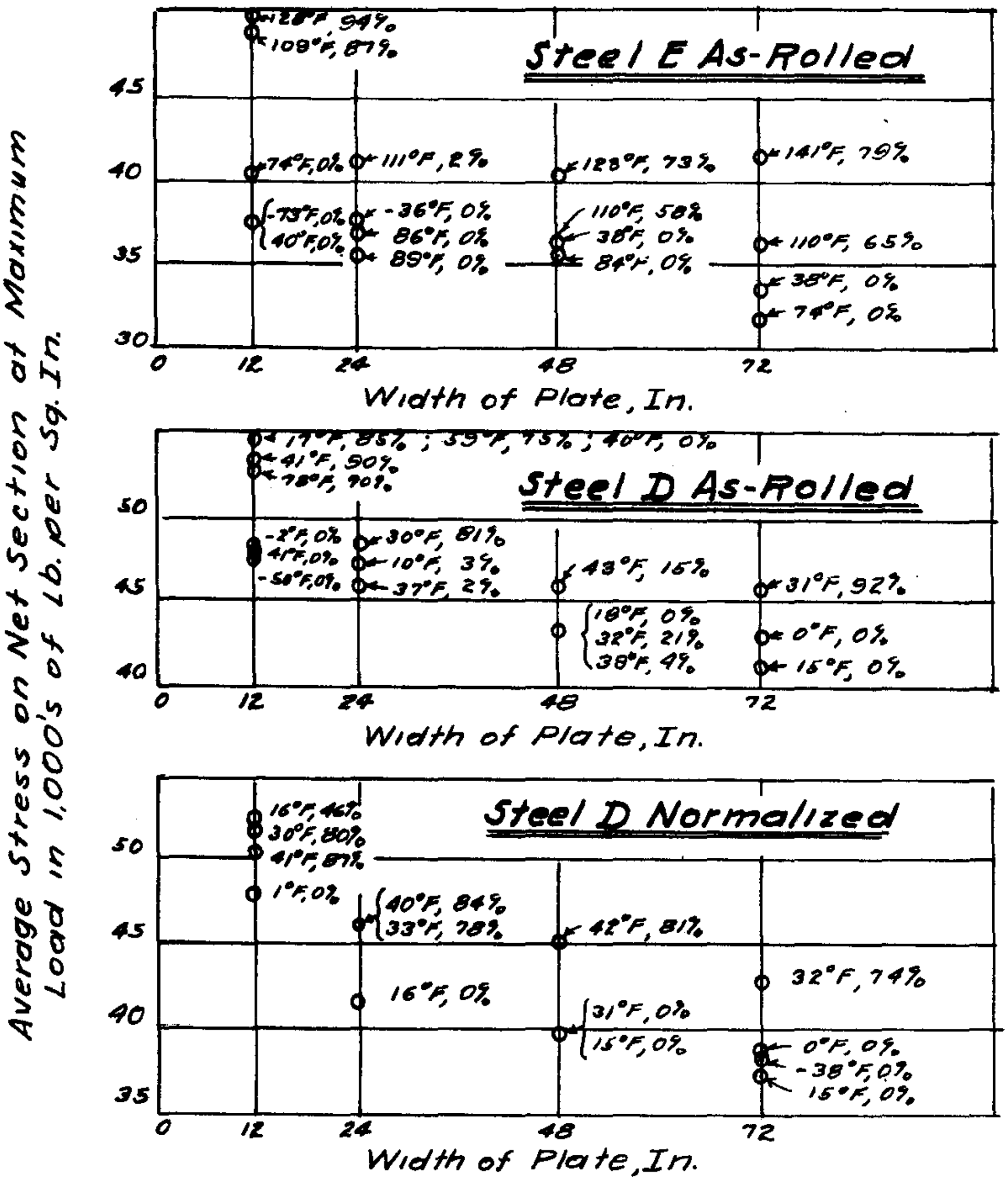


Fig. 4

Comparison of Average Strength of Wide Plates and Temperature.
12-In. Plates, $a/w = 0.25$, Jeweler's-Saw Cut Stress-Raiser.



Note: Numerals beside points indicate temperature of test, and percentage of shear fracture.

Fig. 5
Comparison of Average Strength and Width of Wide Plates. Jeweler's-Saw Cut Stress-Raiser. $l/w = 0.25$. Steels: D As-Rolled, E As-Rolled, D Normalized

The relative strengths of the various kinds of steel are shown in Figs. 6, 7, and 8. In these figures, the strengths of 72-in., 48-in., 24-in., and 12-in. plates are shown separately.

The average strength of wide plates was somewhat greater for killed-steel D as-rolled, killed-steel D normalized, and killed-steel F as-rolled than for rimmed-steel E as-rolled, all plates being of the same width. The first three steels above had approximately the same average strength for wide plates of the same width. The average strength of wide plates of killed-steel G as-rolled was somewhat greater than the strength of the plates of other steels. The average strength of plates of rimmed-steel E normalized was approximately the same as for rimmed-steel E as-rolled.

Plates of rimmed-steel E as-rolled, 12-in. wide, tested both parallel and transverse to the rolling direction showed no appreciable influence of the rolling direction upon the average strength.

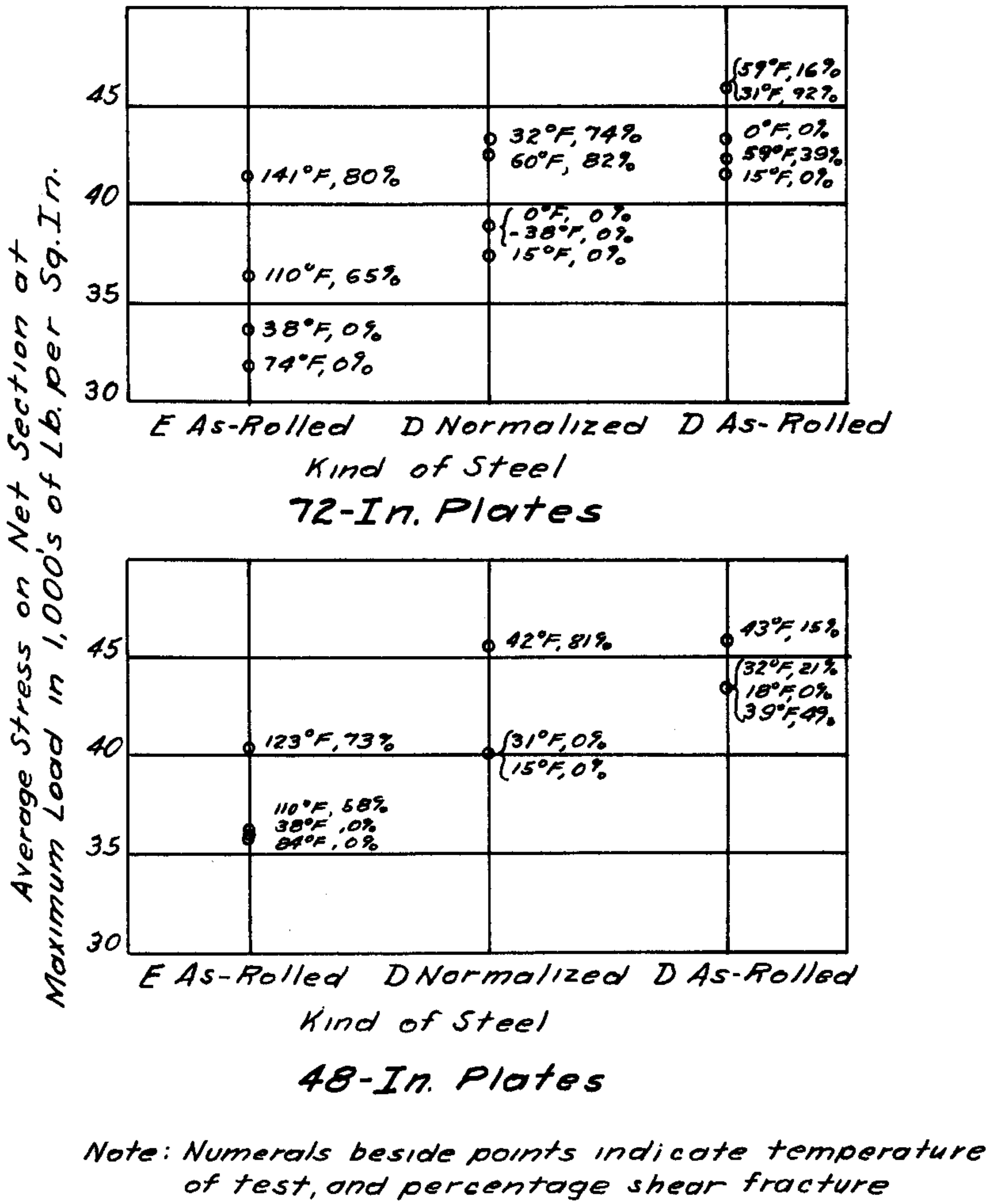
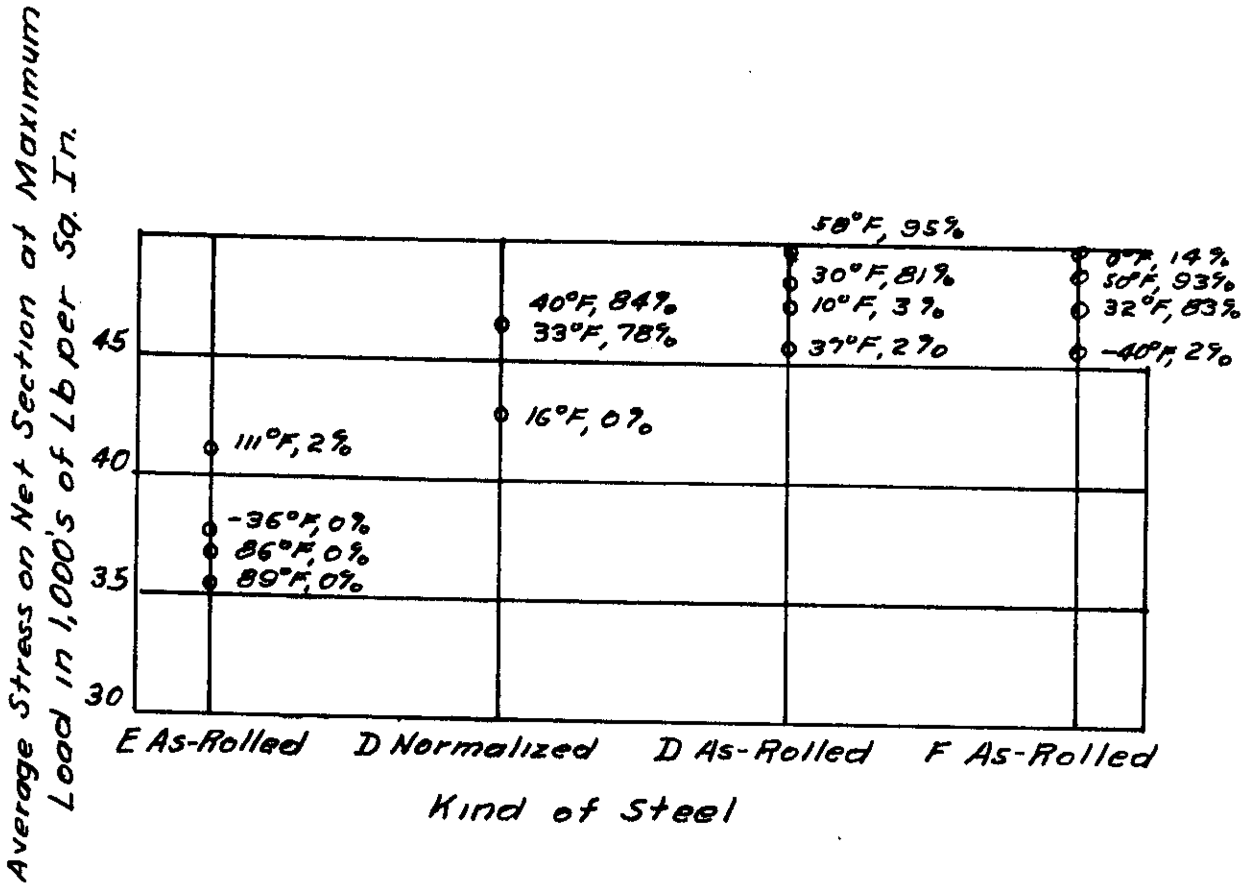
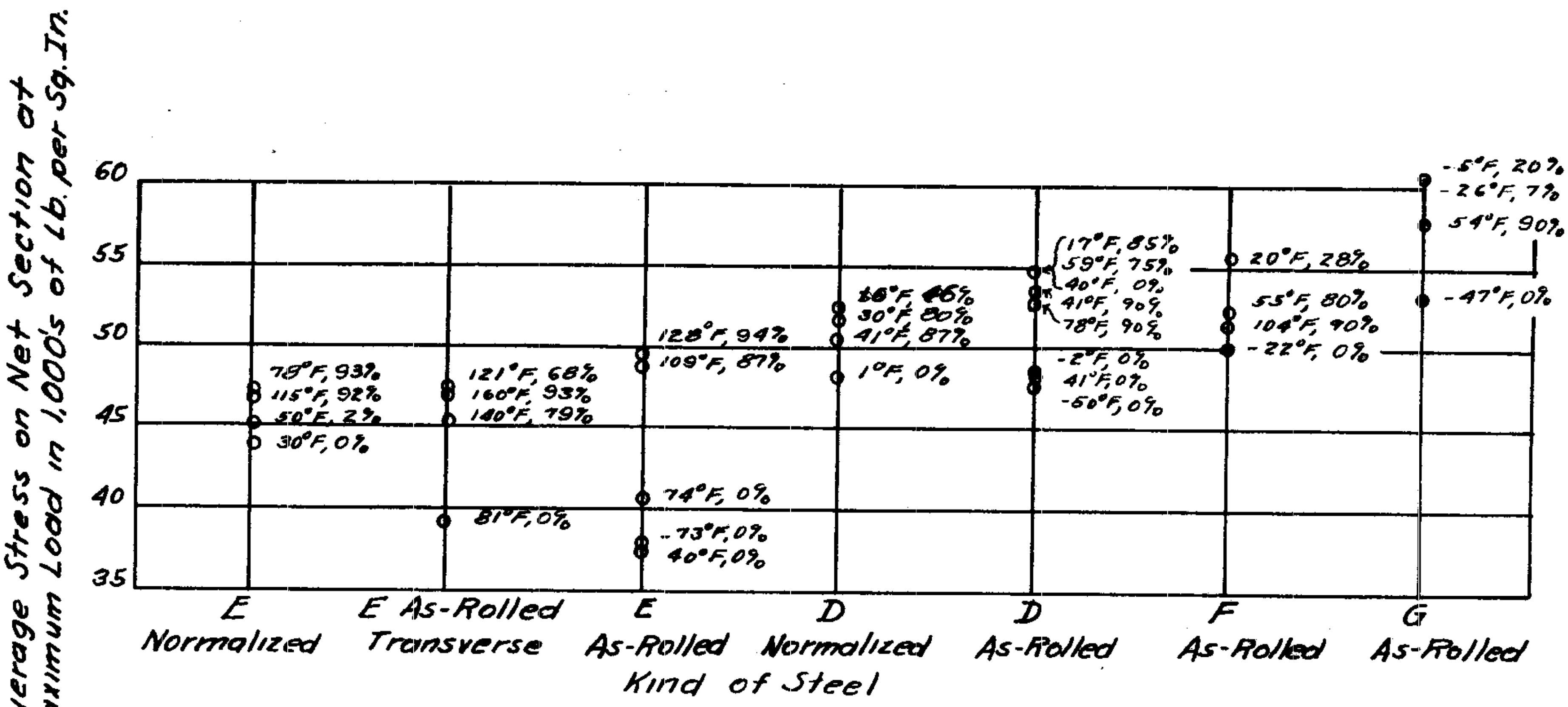


Fig. 6
Average Strength of Three Kinds of Steel. 72-In. and 48-In. Plates.



Note: Numerals beside points indicate temperature of test, and percentage shear fracture

Fig. 7
Average Strength of Four Kinds of Steel.
24-In. Plates.



Note: Numerals beside points indicate temperature of test, and percentage of shear fracture

Fig. 8
Average Strength of Six Kinds of Steel.
12-In. Plates.

b. <u>Distribution Across Plate of Longitudinal Strain</u>: The distribution across the plate of the longitudinal strain was discussed in previous reports(1)(2). Similar studies were made of the data obtained from the tests described in this report.

Diagrams showing the longitudinal strain at the transverse centerline, are given in Appendix A, pages 12a to 36a, inclusive. Measurements were made with 13/16-in. electric strain gages in the elastic and early plastic ranges; with 1-in. and 1/4-in. mechanical gages up to the load where the first cracks appeared at the ends of the stress-raisers; and with the mechanical gages having a gage length of 3/4 W at all loads and after failure. As noted in the reports referred to above, the average strain on a 13/16-in. gage length was many times greater at the end of the stress-raiser than at the edge of the plate. Moreover, as stated in the above mentioned reports, the unit plastic strain at the end of the stress-raiser was very much greater on the 1/4-in. gage length than it was on the 1-in. gage length, for loads up to the load at which initial fracture at the end of the stress-raiser occurred, but the unit strains on the two gage lengths were very nearly equal at the edge of the plates. The strain on the gage lines equal to 3/4 W was quite uniform across the plate at low loads, but in general, it was greater near the central portion than at the edges of the plates at loads near the ultimate.

c. <u>Energy Absorption</u>: The energy absorbed to failure by a wide plate has been taken as the area under its load-elongation diagram.* The curve showing the relation between the temperature and the energy-absorbing capacity of steel plates is made up of three parts: (1) A nearly horizontal portion at the left, which corresponds to a low-energy absorbing capacity. (2) A nearly

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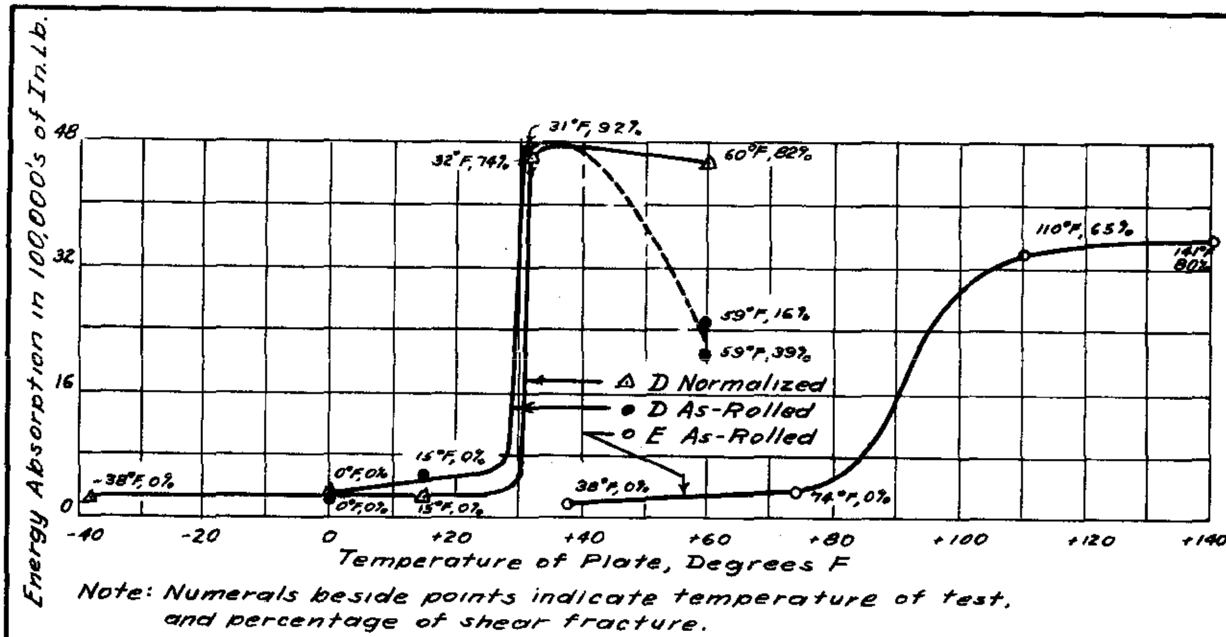
* The load-elongation diagrams are given in Appendix A of this report and of previous reports.(1)(2)

horizontal portion at the right, which corresponds to a high-energy-absorbing capacity. (3) A transition portion extending upward to the right and connecting (1) and (2).

The relation between the energy-absorbing capacity and the temperature for 72-in., 48-in., 24-in., and 12-in plates made of various steels is shown by the diagrams of Figs. 9, 10, 11 and 12. All specimens had a jeweler's-saw cut type of stress-raiser and an $\frac{L}{W}$ value of 0.25. These diagrams indicate that, for the 72-in. plates: (1) The energy-absorbing capacity of killed-steel D plates in the as-rolled and in the normalized conditions was greatly reduced when the temperature was reduced from 32 to 25 degrees F. (2) The energy-absorbing capacity of rimmed-steel E plates in the as-rolled condition was greatly reduced when the temperature was reduced from 110 to 80 degrees F. (3) Killed-steel D plates in the as-rolled and in the normalized conditions had very nearly the same energy-absorbing capacity when tested at the same temperature for a temperature range from 0 to 30 degrees F. (4) Rimmed-steel E as-rolled plates had a much lower energy-absorbing capacity than either killed-steel D as-rolled plates or killed-steel D normalized plates at temperatures from 32 to 80 degrees F. The maximum energy-absorption for the rimmed-steel E as-rolled plates corresponded to a temperature of the order of 120 degrees F.

As stated above, the killed-steel D plates in the as-rolled and in the normalized conditions had very nearly the same energy-absorbing capacity when tested at the same temperature for a temperature range from 0 to 30 degrees F. But for the killed-steel D normalized plate, the energy absorbed was approximated the same at 60 degrees F. as at 32 degrees F., whereas, for the killed-steel D as-rolled plate the energy absorbed was very much less at 59 degrees F than at 31 degrees F. This latter result was so unusual that Charpy notch impact specimens were cut from the unstressed portion of the killed-steel D as-rolled plate which had been tested at 59°F. The resulting Charpy notch impact value, the average of four tests, was found to be in line with the values obtained from other killed-steel D as-rolled plates from the same heat. Another 72-in. specimen of killed-steel D as-rolled plate was then tested at 59°F., and the results from this test were very nearly the same as for the previous tests at the same temperature. Charpy impact values for the plate of this specimen were also in line with corresponding values of other plates from the same heat. It would seem, therefore, that the relation between the temperature and the energy absorbed by 72-in. killed-steel as-rolled plates was quite erratic. The results of tests of 48-in., 24-in., and 12-in. killed-steel as-rolled plates, given by the diagrams on Figs. 10, 11 and 12, indicate that the same statement applies to plates of this steel for all widths from 12-in. to 72-in., inclusive.



Note: Numerals beside points indicate temperature of test, and percentage of shear fracture.

Fig. 9
Comparison of Energy Absorption to Failure and Temperature of Test. 72-In. Plates. $\frac{L}{W}$ = 0.25, Jeweler's-Saw Cut Stress-Raiser

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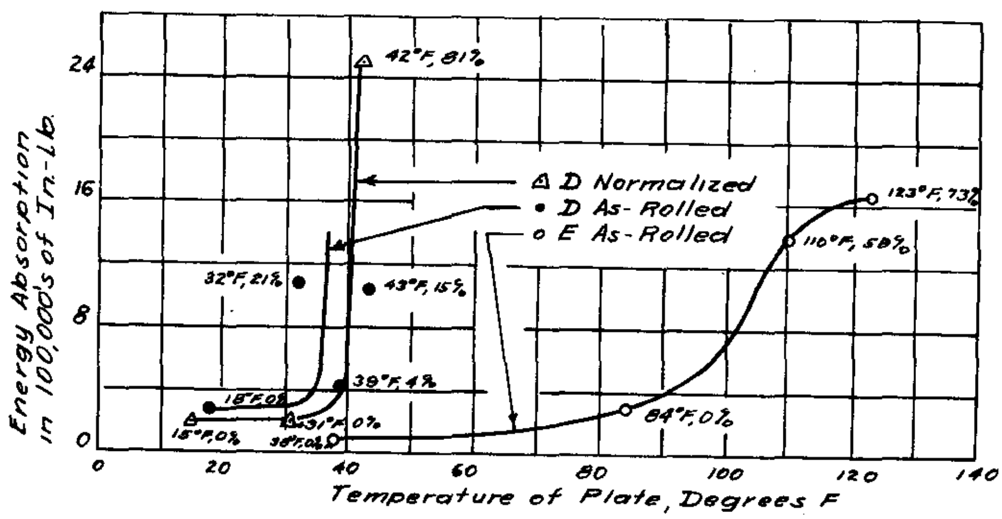
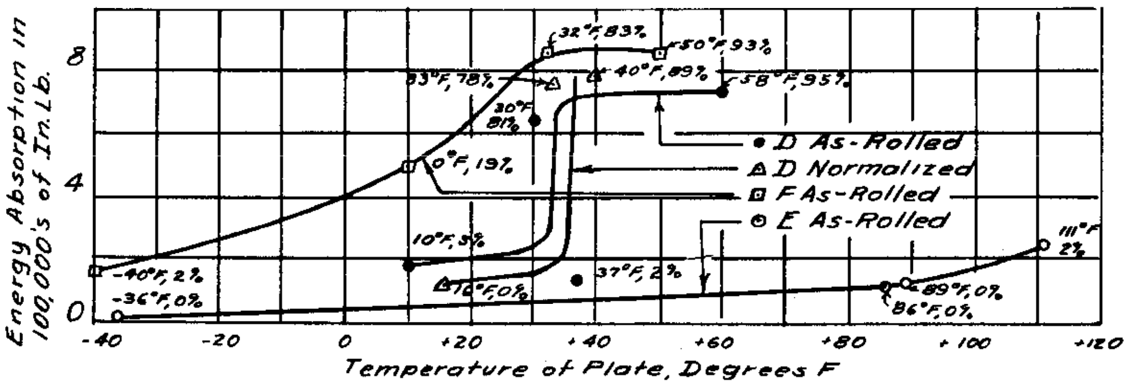


Note: Numerals beside points indicate temperature of test, and percentage of shear fracture

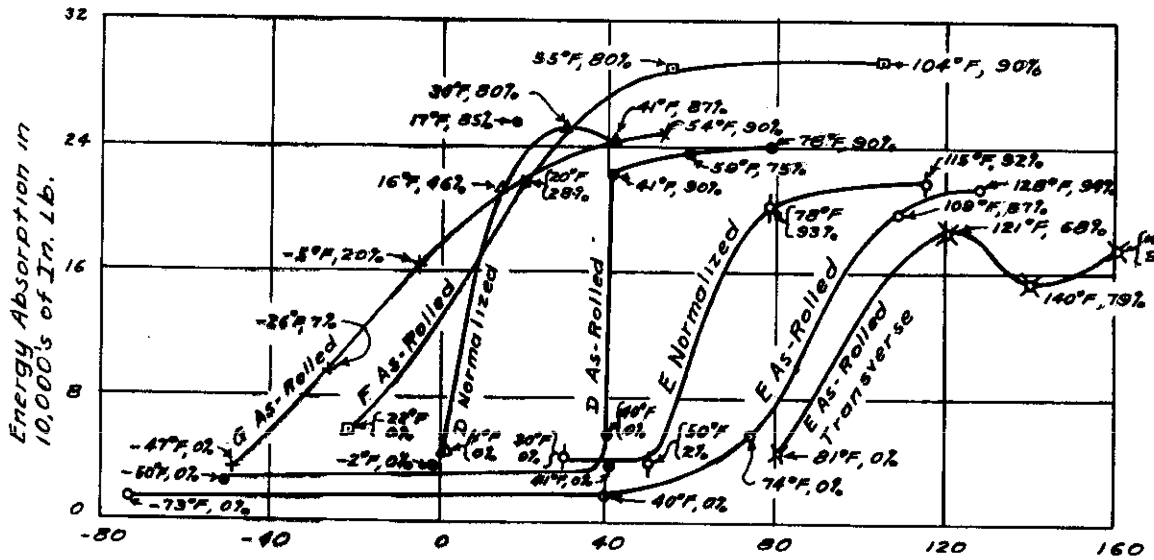
Fig. 10
Comparison of Energy Absorption to Failure and Temperature of Test. 48-In. Plates $\frac{L}{W}$ = 0.25, Jeweler's-Saw Cut Stress-Raiser



Note: Numerals beside points indicate temperature of test, and percentage of shear fracture

Fig. 11

Comparison of Energy Absorption to Failure and Temperature of Test. 24-In. Plates. $l/w = 0.25$ Jeweler's-Saw Cut Stress-Raiser



Note: Numerals beside points indicate temperature of test, and percentage of shear fracture.

Fig. 12

Comparison of Energy Absorption to Failure and Temperature of Test. 12-In. Plates. $l/w = 0.25$, Jeweler's-Saw Cut Stress-Raiser

The temperature-energy absorption relation shown by the diagrams of Figs. 9 to 12, inclusive, indicate that this relation was quite erratic for the killed-steel D as-rolled for all plate widths, but was fairly consistant for the killed-steel D normalized and the rimmed-steel E as-rolled.

The transition temperature for each kind of steel was approximately the same for the four widths of plates except for plates of killed-steel D normalized. For the latter, the transition temperature was lower for the 12-in. than for the 72-in., 48-in. and 24-in. wide plates. This is the only evidence indicating that the transition temperature-range for wide plates with the type of stress-raisers used in these tests, was materially influenced by the width of the plate.

The relation between the energy absorption and temperature for various 12-in. rimmed-steel E plates, is shown in Fig. 12. The improvement of this rimmed steel by normalizing is indicated by the accompanying shift of the transition portion of the diagram to a lower temperature range. Tests of 12-in. rimmed-steel E as-rolled plates, some loaded parallel and others transverse to the direction of rolling, indicated, as shown in Fig. 12, that the transition temperature is somewhat higher for plates loaded transverse than for plates loaded parallel to the direction of rolling.

Tests of 24-in. and 12-in. wide plates of killed-steel F as-rolled indicated that, for these widths, this steel had a greater energy-absorbing capacity and a lower transition temperature range than killed-steel D and rimmed-steel E as-rolled. This is apparent from the diagrams of Figs. 11 and 12. These diagrams also show that, of all the 12-in. wide plates tested, those of killed-steel G as-rolled had the lowest transition temperature range. Moreover, the maximum energy-absorbing capacity of 12-in. wide plates of killed-steel G as-rolled, was nearly as great as the maximum for any of the 12-in. plates tested. The normalizing treatment improved the 12-in. plates of rimmed-steel E as-rolled in that it lowered the transition temperature about 30°F., as shown in Fig. 12. These diagrams also indicated that the transition temperature of this steel was about 10°F higher when tested transverse than when tested parallel to the direction of rolling.

It was observed that the energy absorbed by the wide-plate specimens, increased with the amount of shear present in the fracture. This is shown by the diagrams of Figs. 13, 14, 15 and 16. Moreover, the energy-absorbing capacity was many times greater under conditions that produced a shear-type fracture than it was under conditions that produced a cleavage-type fracture.

The various energy diagrams indicate that, for the steels used in these tests, the relation between the energy absorbed and the percentage shear in the fracture, did not vary greatly for any of the four plate-widths tested. This was true even though the temperature corresponding to a given percentage shear in the fracture. differed greatly for the various steels. The results are especially interesting for the steels tested in the 72-in. and 12-in. widths, shown in Figs. 13 and 16, since all three steels were tested at temperatures high enough to give a percentage of shear in the fracture of the order of 80 to 90. And, at these percentages, of shear fracture as well as at lower values, the energy absorption for the three steels, was approximately the same for these two extreme widths. It would seem. therefore, that the type of fracture is a fairly accurate indication of the energy absorbed by the steel up to the time it failed. This suggests that a visual inspection of a field fracture will make possible a fairly accurate estimate of the energy absorbed before failure occurred.

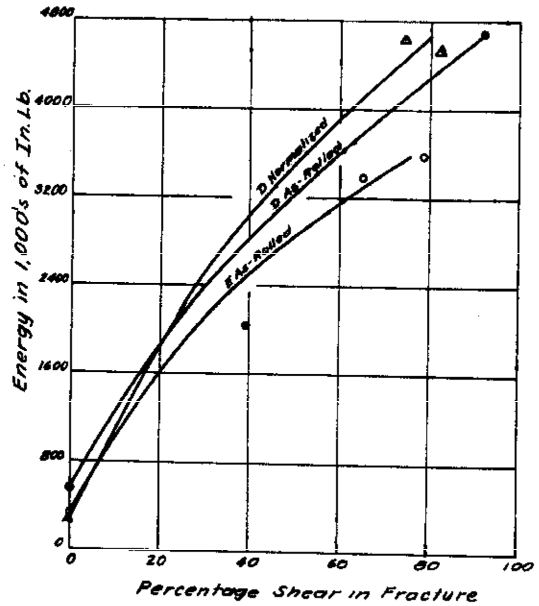


Fig. 13
Comparison of Energy Absorption to Failure and Percentage Shear in Fracture. 72-In. Plates $\frac{L}{W}$ = 0.25, Jeweler's-Saw Cut Stress Raiser

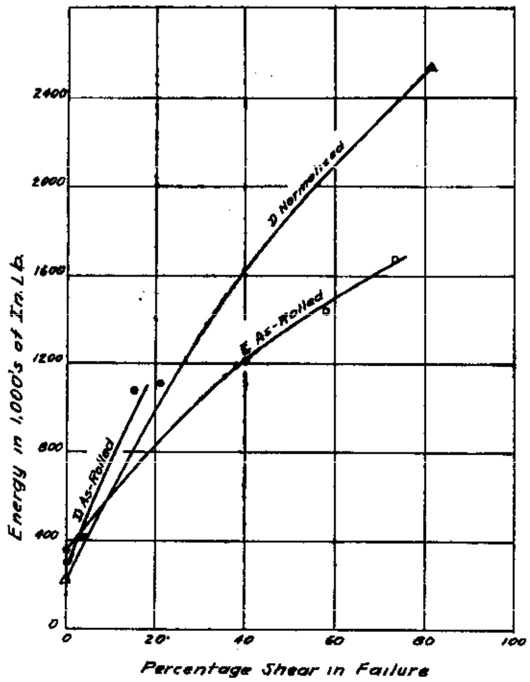


Fig. 14
Comparison of Energy Absorption to Failure and Percentage Shear in Fracture. 48-In. Plates $\frac{L}{W}$ = 0.25, Jeweler's-Saw Cut Stress-Raiser

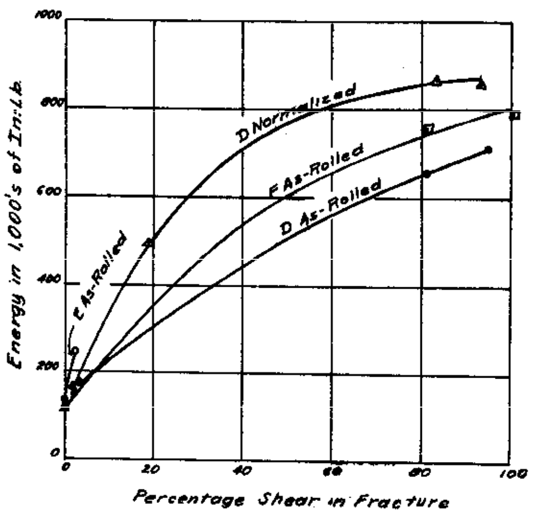


Fig. 15
Comparison of Energy Absorption to Failure and Percentage Shear in Fracture for 24-In Plates $\frac{L}{W}$ = 0.25, Jeweler's-Saw Cut Stress-Raiser

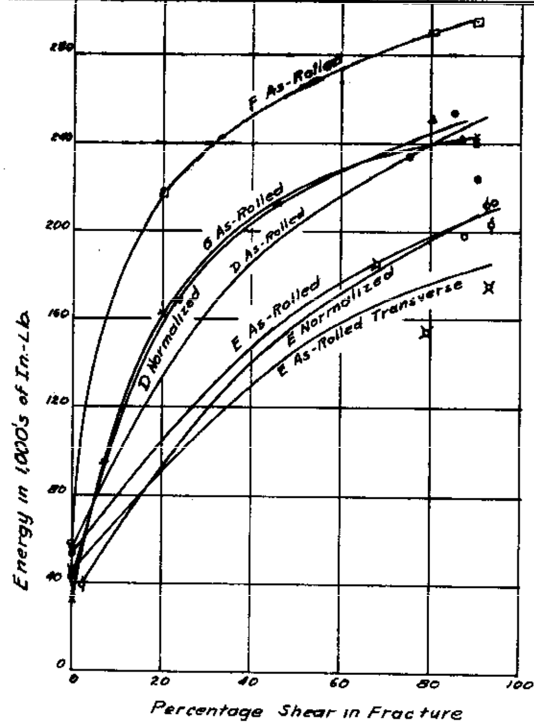


Fig. 16
Comparison of Energy Absorption to Failure and Percentage Shear in Fracture. 12-In. Plates $\frac{L}{W}$ = 0.25, Jeweler's-Saw Cut Stress-Raiser

d. Various Methods of Determining the Transition Temperature-Ranges: Four relations for determining the transition temperature-range of the various steels were used. Three of these relations are based upon the behavior of wide plates with jeweler's-saw cut stress-raisers, and one is based upon the Charpy V-notch impact values. These relations are described in the following paragraphs.

(1) Temperature-Energy Absorption Relation: The relation between the temperature and energy absorption of wide plates of various widths and made of various steels, is presented in Section 3c, and is shown by the diagrams of Figs. 9, 10, 11 and 12.

(2) Temperature-Percentage Shear in the Fracture Relation: The relation between the temperature of the wide plates and the percentage shear in the fracture is shown in Fig. 17 for the 12-in. wide plates of various steels.

(3) Temperature-Elongation Relation: The relation between the temperature and the average elongation to failure is shown by the diagrams of Figs. 18, 19, 20 and 21. In these figures, the ordinates represent the average elongation across the plate on a gage length equal to 3/4 W, and the absiccas represent the temperature of the plate when tested.

(4) Temperature V-notch Impact Relation: The relation between the temperature and the V-notch impact value for the various steels is shown by the diagrams of Fig. 22.

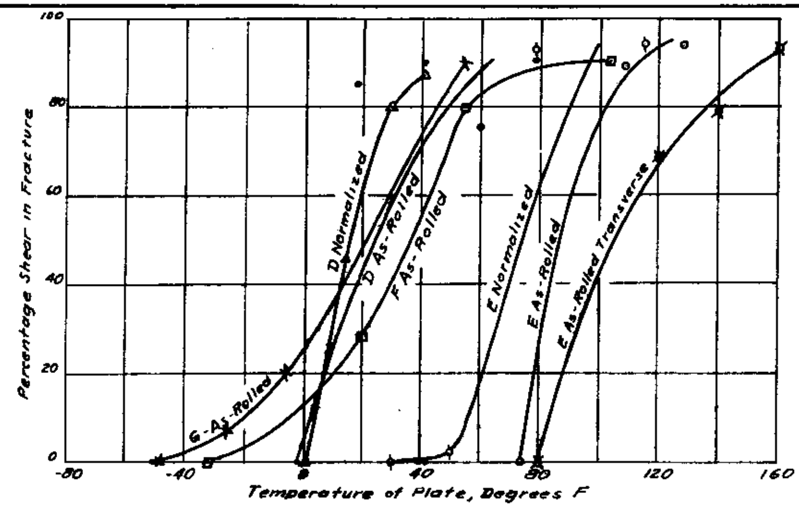
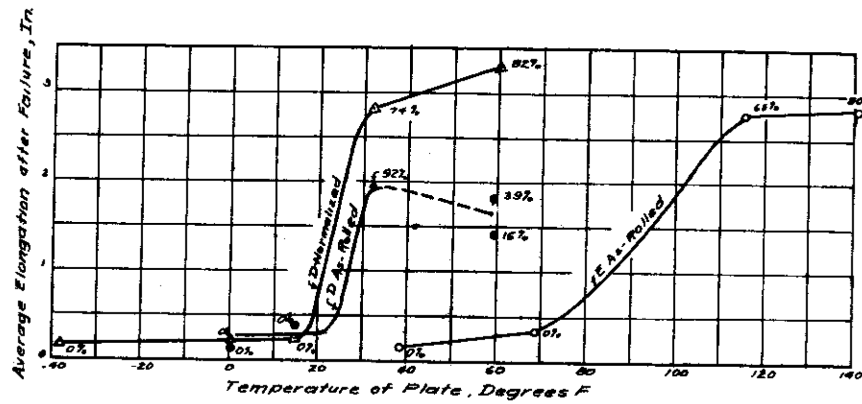
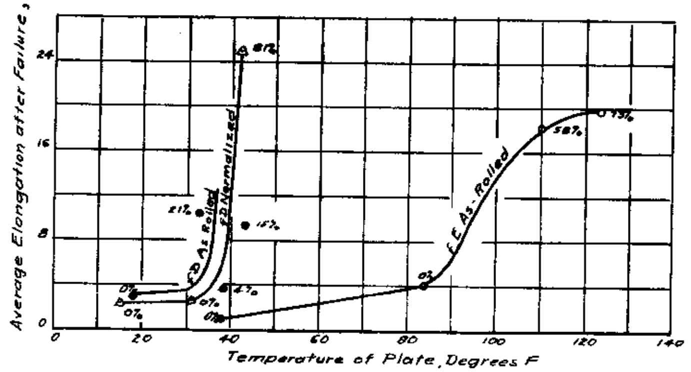


Fig. 17
Comparison of Percentage Shear in Fracture and Temperature 12-In. Plates, t/w = 0.25, Jeweler's-Saw Cut Stress-Raiser



Note: Numerals beside points indicate percentage of shear fracture

Fig. 18
Comparison of Average Elongation After Fracture on 54-In. Gage Length and Temperature of Test. 72-In. Plates. t/w = 0.25. Jeweler's-Saw Cut Stress-Raiser



Note: Numerals beside points indicate percentage of shear fracture

Fig. 19
Comparison of Average Elongation After Fracture on 36-In. Gage Length and Temperature of Test. 48-In. Plates. t/w = 0.25 Jeweler's-Saw Cut Stress-Raiser

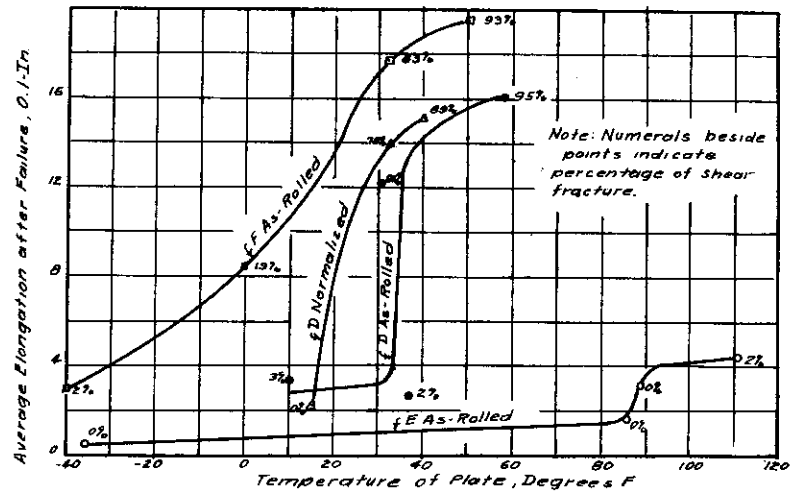


Fig. 20
Comparison of Average Elongation After Fracture on 17$\frac{5}{8}$-In Gage Length and Temperature of Test. 24-In. Plates, t/w = 0.25, Jeweler's-Saw Cut Stress-Raiser

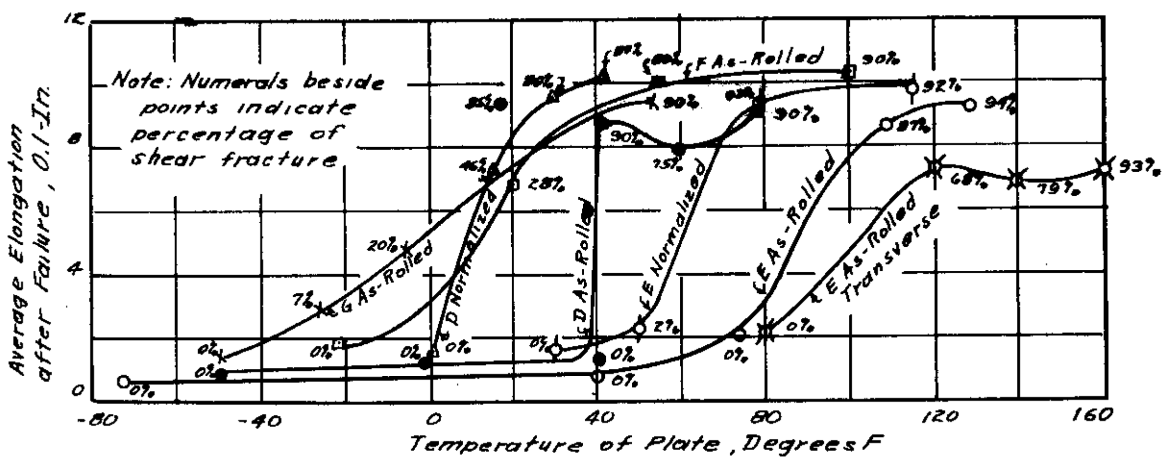
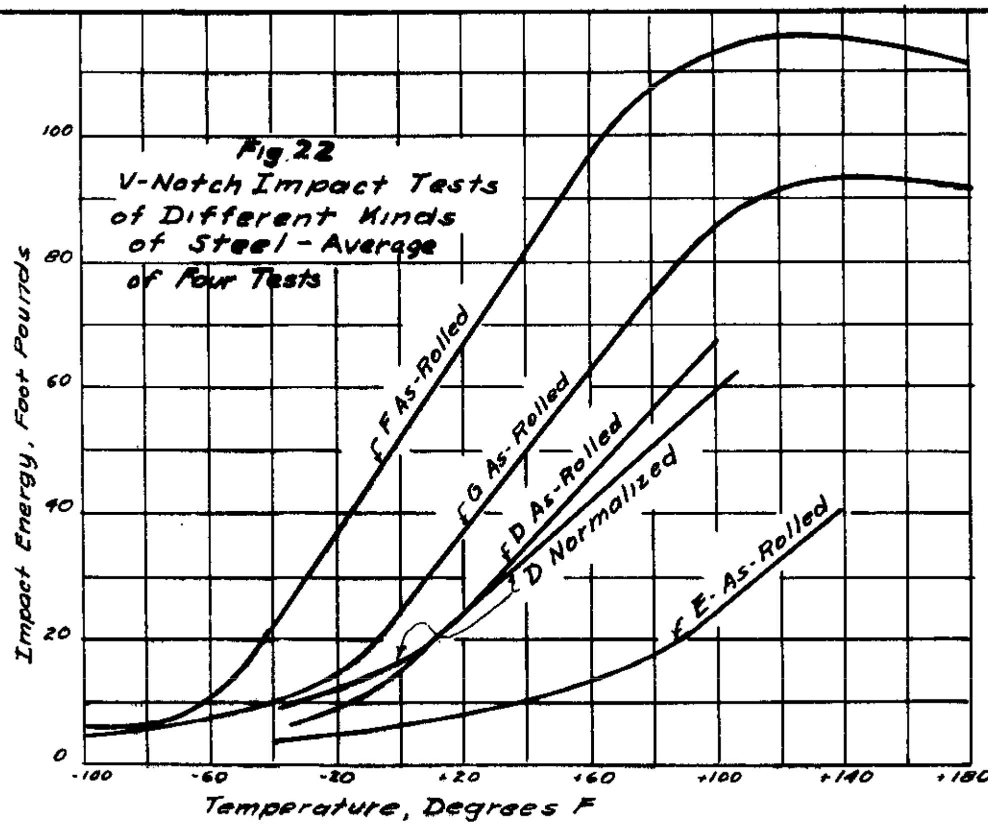


Fig 21
Comparison of Average Elongation After Fracture on 8⅝-In. Gage Length and Temperature of Test. 12-In. Plates, $a/w = 0.25$, Jeweler's-Saw Cut Stress-Raiser



Each of these four methods utilizes a diagram similar to the diagram described in the last sentence of the last paragraph on page 21. The temperature ranges of the intermediate portion of each of these diagrams, have been taken as the transition temperature-range. The transition temperature-ranges of the various steels, as determined by all methods, are somewhat indefinite.

The values of the transition temperature-ranges, as determined by the four methods, are listed in Table III. These values are of interest from two view-points: first, as absolute values of transition temperature-ranges, and second, as values determining the order in which the steels are segregated.

The absolute values of the transition temperature-range determined by the Charpy V-notch impact tests differed considerably from the values determined by the wide-plate tests. In general, however, the absolute values determined from the wide-plate tests by the various methods did not differ greatly from each other. The values determined from the temperature-elongation relation agreed most nearly with the values obtained from the temperature energy-absorption relation. The range of the transition portion of the diagrams was much less as determined by the wide-plate tests than as determined by the Charpy V-notch test.

The segregation of the steels by the Charpy V-notch-impact test and by the wide-plate test is shown in Table IV. The segregation from the wide-plate test is based upon the temperature-energy-absorption relation. In this table, the steels are indicated by the letters D, DN, E, F and G as noted at the bottom of the table. The sequence of the steels in the order of their transition temperature-range, is indicated by the order in which the steels are listed. There are two lines for each plate width. The steels are listed according to the results of the wide-plate tests in the upper line, and according to the results of the Charpy V-notch-impact test in the lower line. The arrangement of the steels in this table indicate that, for 72-in., 48-in., and 24-in. plates, all steels tested are segregated in the same order by the wide-plate test and the Charpy V-notch-impact test, but for the 12-in. plates, the F and G steels and the DN and D steels are segregated in the reverse orders of sequence by the two tests.

e. Reduction in Thickness of Plates: The reduction of thickness of the wide plate tests may be found for part of the tests in the previous reports(1)(2), and for the remainder on pages 37a to 53a inclusive of Appendix A of this report.

TABLE III.

TRANSITION TEMPERATURE-RANGES OF VARIOUS STEELS AS DETERMINED BY DIFFERENT RELATIONS.

Relation Used for Determination	Transition Temperature Range, Degrees F. D Killed As-Rolled	D Killed Normalized	E Rimmed As-Rolled	E Rimmed Normalized	E Rimmed As-Rolled Trans.	F Killed As-Rolled	G-Killed As-Rolled
12-IN. PLATES							
V-Notch Imp. Test	-40 to 100+	-40 to 110+	20 to 140+			-70 to 110	-40 to 120
Temp.-Energy Absorp.	38 to 42	0 to 30	80 to 120	50 to 90	80 to 140	-20 to 55	-40 to 40
Temp.-Percent.Shear	0 to 60	0 to 30	75 to 120	50 to 100	80 to 160	-20 to 55	-40 to 60
Temp.-Elongation	38 to 42	0 to 40	60 to 110	40 to 80	60 to 120	-20 to 60	-50 to 50
24-IN. PLATES.							
V-Notch Imp. Test	-40 to 100+	-40 to 110+	20 to 140+			-70 to 110	
Temp.-Energy Absorp.	28 to 37	30 to 40	110 to			-50 to 35	
Temp.-Elongation	30 to 50	15 to 40	85 to 105			-50 to 50	
48-IN. PLATES							
V-Notch Imp. Test	-40 to 100+	-40 to 110+	-20 to 140+				
Temp.-Energy Absorp.	30 to 36+	30 to 42	90 to 115				
Temp.-Elongation	30 to 36+	30 to 42	80 to 120				
72-IN. PLATES							
V-Notch Imp. Test	-40 to 100+	-40 to 110+	20 to 140+				
Temp.-Energy Absorp.	25 to 32	28 to 32	80 to 110				
Temp.-Elongation	20 to 58	15 to 32	70 to 110				

TABLE IV.

SEGREGATION OF STEELS BY WIDE-PLATE TEST AND

CHARPY V-NOTCH IMPACT TEST.

Plate Width, In.	Kind of Steel Steels Listed in order of Increasing Transition Temperature-Range from Left to Right.					
72			D	DN	E	Sequence the same by both tests
			D	DN	E	
48			D	DN	E	Sequence the same by both tests
			D	DN	E	
24		F	D	DN	E	Sequence the same by both tests
		F	D	DN	E	
12	G	F	DN	D	E	
	F	G	D	DN	E	

Upper line based upon wide-plate test. Temperature-energy absorption relation.

Lower line based upon Charpy V-notch-impact test.

D = Killed-Steel D As-Rolled.

DN = Killed-Steel D Normalized.

E = Rimmed-Steel E As-Rolled.

F = Killed-Steel F As-Rolled.

G = Killed-Steel G As-Rolled.

4. Tests of Plates with Punched Holes and of Plates with Sheared Edges As Stress-Raisers: In the previous Progress Report,(2) there was reported the failure of a pulling plate and of a tensile specimen, both having sheared edges. To further determine the effects of shearing and, in addition, punching, two 24-in. wide plates of rimmed-steel E as-rolled with 13/16-in. punched holes, and one 24-in. wide plate of the same steel with sheared edges were tested. The holes were punched and the plate edges were sheared in a bridge shop to insure standard fabricating conditions, and were tested in the as-received condition, but after being stored in the laboratory for several months at a temperature of 70 to 80 degrees F. The parallel edges of the plates with punched holes were machined to remove possible cracks which would act as stress-raisers on the edges. The details of these plates are shown in the upper parts of Figs. 23 and 24.

The results of these three tests and of previous tests[2] of comparable specimens with other types of stress-raisers, are given in Table V and shown in Figs. 25 and 26. The energy absorbed per inch of net width was obtained by dividing the total energy absorbed to fracture by the net width of the specimen on the section through the stress raiser. The net width of the sheared edge plate was its full width. The method of obtaining the energy per inch of net width for the sheared edge plate is explained on pages 39 and 40.

The load-elongation diagrams for the plates with punched holes are shown on page. 11a of Appendix A of this report. The diagrams of thickness after fracture, for the plates with punched holes and for those with sheared edges, are shown on pages 53a to 54a inclusive, of Appendix A.

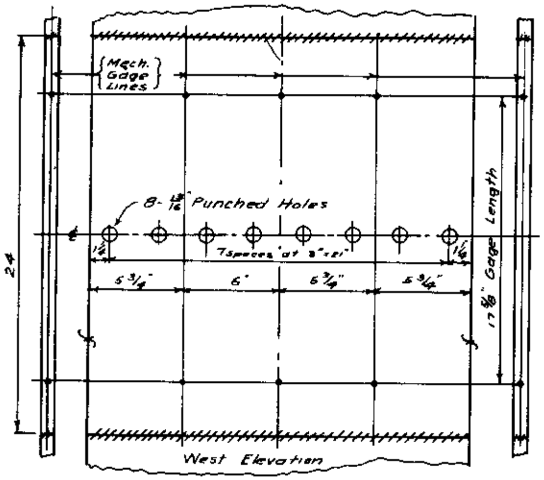
TABLE V.

TESTS OF 24-IN. RIMMED-STEEL E AS-ROLLED PLATES.
Five Types of Stress-Raisers.

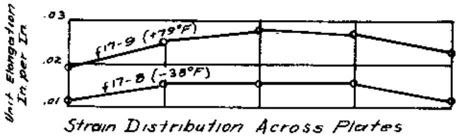
Loads in 1000's of lbs.; Stresses in 1000's lb. per sq. in.; Energy in 1000's of in. lb.

SPEC. NO.	TEMP. °F.	COUPON STRENGTH Y.P.	COUPON STRENGTH ULT.	$\frac{L}{W}$	ULTIMATE LOAD	ULTIMATE STRESS ON NET SECTION	FRACTURE* percent C	SS	DS	ENERGY ABSORBED per inch of Net Width** At Max. Load	At Failure
	$\frac{13}{16}$-IN. DIAMETER PUNCHED HOLE STRESS-RAISER.										
17-9	+79	30.1	56.3	0.291	694.0	54.5	91	6	3	14.8	15.5
17-8	-38	30.1	56.3	0.303	644.0	51.3	100	-	-	7.5	8.0
	SHEARED EDGE STRESS-RAISER										
17-12	-43	30.1	56.3	-	792.0	44.7	100	-	-	-	10.0#
	JEWELER'S-SAW CUT STRESS-RAISER										
20A-3	89	32.3	59.6	0.25	483.3	35.4	100	-	-	5.78	7.66
22-9	86	33.9	60.5	0.25	486.4	36.7	100	-	-	4.17	7.15
20-9	-36	29.3	56.8	0.25	510.0	37.6	100	-	-	0.92	1.21
	NO. 47 DRILL-HOLE STRESS-RAISER										
20A-8	86	32.3	59.6	0.25	534.0	39.0	50	47	3	5.68	15.17
20-14	-40	29.3	56.8	0.25	546.0	39.8	100	-	-	3.43	3.63
	1/4-IN. DRILL-HOLE STRESS-RAISER										
22A-9	83-95≁	31.3	57.7	0.25	602.0	45.4	13	79	8	11.90	37.80
20A-14	-37	32.3	59.6	0.25	635.0	46.0	100	-	-	9.10	12.50

* C = Cleavage, SS = Single Shear, DS = Double Shear
** Gage Lengths shown on Figs. 23 and 24.
# Refer to page 39.
≁ Temperature increased to 95° F. due to plastic deformation.

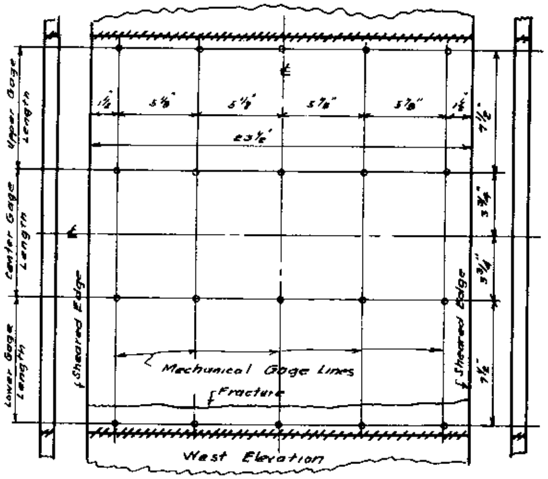


Sketch of Punched Hole Plates

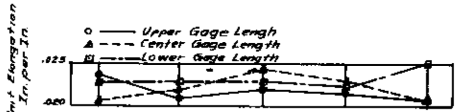


Strain Distribution Across Plates After Fracture

Fig. 23
Strain Distribution Across Plate
24-In. Rimmed Steel E As-Rolled Plates with 13/16-In. Punched Holes as Stress-Raisers



Sketch of Sheared Edge Plate



Strain Distribution Across Plate After Fracture

Fig. 24
Strain Distribution Across Plate
24-In Rimmed Steel E As-Rolled Plate with Sheared Edges.

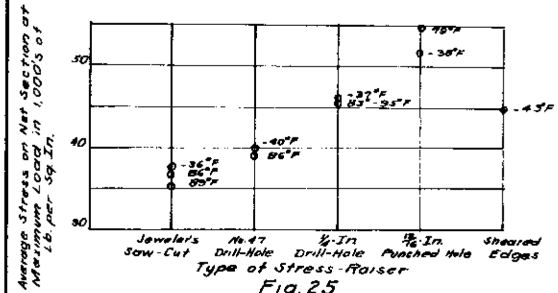


Fig. 25
Average Strength of 24-In. Rimmed Steel E As-Rolled Plates with Five Types of Stress-Raisers

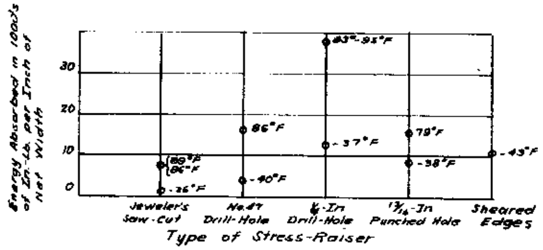


Fig. 26
Energy Absorption to Failure of 24-In. Rimmed Steel E As-Rolled Plates with Five Types of Stress-Raisers.

The strain distribution across these plates after fracture, is shown at the bottom of Figs. 23 and 24. It is notable that, for the plate with sheared edges, the unit elongation on the gage lines bridging the fracture is of the same relative magnitude as the elongation on gage lines in the portion of the plate away from the fracture, and is of the order of 2.3 percent. Failure of this plate occurred at a temperature of -43°F. with no appreciable reduction of thickness and with a 100 percent cleavage fracture.

The strengths of plates with the following types of stress-raisers, 13/16-in. punched holes, sheared edges, jeweler's-saw cut, No. 47 drill-hole, and 1/4-in. drill-hole, are plotted in Fig. 25. The temperature at which a test was made is indicated by the numeral adjacent to the small circle representing the results of the test. The average strength of the plates with punched holes was greater than the average strength of plates with other types of stress-raisers, while the average strength of the plate with sheared edges was about the same as the average strength of the plates with the 1/4-in. drill-hole stress-raiser.

The energy absorptions of the plates with different types of stress-raisers are compared in Fig. 26. The energy absorption of the plates with the punched holes is of about the same magnitude as the energy absorption of the plates with No. 47 drill-hole stress-raisers and less than that of the plates with 1/4-in. drill-hole stress-raisers. The low energy absorption of the plates with punched holes may be attributed to the type of fracture, since these plates had 0 percent and 9 percent shear in the fracture for tests at temperatures of -38°F. and 79°F., respectively.

The energy absorption of the plate with sheared edges was not measured. However, if it is assumed that the ratio of the product of the maximum load and the elongation at failure to the energy absorption was the same for the plate with sheared edges as it was for the plate with punched holes, the value of the energy absorption at failure for the plate with sheared edges would be 237,000 in/lb. which is equivalent to 10,050 in/lbs. per inch of net width. The energy absorption of the plate with sheared edges is of about the same magnitude as the energy absorption of the plate with the punched holes and of the plates with the 1/4-in. drill-hole stress-raisers.

Thus, the plates with 13/16-in. diameter punched holes had a higher average strength than the plates with the other types of stress-raisers but had a low energy absorption. The plate with sheared edges had approximately the same strength and approximately the same energy absorption as the plate with 1/4-in. drill-hole stress-raisers.

CONCLUSIONS

Tests of 3/4-in. plates with widths of 72-in, 48-in., 24-in., and 12-in. containing a jeweler's-saw cut type of stress-raiser and with an $\frac{L}{W}$ ratio of 0.25, are described in this and previous[1][2] reports. The results of these tests appear to justify the following conclusions.

1. For all kinds of steel, the average strength decreased with an increase in the width of the plate. Moreover, the tendency to decrease in strength with an increase in the width beyond 72-in., would seem to be definitely established. The average strength of 72-in. plates was somewhat greater than the coupon yield-point strength of the material.

2. The strength of the plates increased somewhat with an increase in the portion of the fracture that was of a shear type. For plates with an all cleavage fracture, changes in temperature were not accompanied by any significant change in strength.

3. The average strength of wide plates was somewhat greater for killed-steel D as-rolled, killed-steel D normalized, and killed-steel F as-rolled than for rimmed-steel E as-rolled, all plates being of the same width. The first three steels above had approximately the same average strength for wide plates of the same width. The average strength of wide plates of killed-steel G as-rolled was somewhat greater than the strength of the plates of other steels. The average strength of plates of rimmed-steel E normalized was approximately the same as for rimmed-steel E as-rolled.

4. Tests of 12-in. rimmed-steel E as-rolled plates indicated that, for this steel, the direction of rolling had no appreciable effect upon the average strength.

5. The energy-absorbing capacity of plates with severe stress-raisers was many times greater under conditions that produced a shear-type fracture than it was under conditions that produced a cleavage-type fracture. It would seem, therefore, that the type of fracture is a dependable indication of the energy-absorbing capacity of plates.

6. When in the form of wide plates with severe stress-raisers, all of the steels tested, with the possible exception of killed-steel F as-rolled and killed-steel G as-rolled, had a low energy-absorbing capacity at the sub-zero temperatures which may be encountered in ship navigation.

7. The transition temperature-range of rimmed-steel E as-rolled plates was slightly higher when tested transverse than when tested parallel to the direction of rolling.

8. Values of the transition temperature-range of the various steels were determined from four relations. The absolute values of the transition temperature-ranges determined by the V-notch Charpy impact tests differed

considerably from the values determined by the wide-plate tests. In general, however, the absolute values determined from the wide-plate tests by the various methods did not differ greatly from each other. The values determined from the temperature-elongation relation agreed most nearly with the values obtained from the temperature energy-absorption relation. The range of the transition portion of the diagrams was much less as determined by the wide-plate tests than as determined by the Charpy V-notch test.

9. The range of the transition portion of the diagram was much less as determined by the wide-plate test than as determined by the Charpy V-notch impact test.

10. For 72-in., 48-in., and 24-in. plates all steels tested are segregated in the same order by the wide-plate test and by the Charpy V-notch impact test, but for the 12-in. plates, the F and G steels and the Dn and D steels are segregated in the reverse orders of sequence by the two tests.

11. The unit strain at the end of the stress-raiser was many times greater than the average strain over the net section for loads up to the load where fracture started. This was true for both the elastic and the plastic strains.

12. The unit plastic strain at the end of the stress-raiser was very much greater on the 1/4-in. gage length than it was on the 1-in. gage length, for loads up to the load where fracture started.

13. The fracture of all the wide plates started at the end of the stress-raiser and at the mid-thickness of the plate.

Tests of 24-in. wide rimmed-steel E as-rolled plates 3/4-in. thick with punched-hole, and others with sheared-edge stress-raisers, appear to justify the following conclusions for this steel.

1. Punched holes and sheared edges were apparently severe stress-raisers, causing some reduction of strength and a very great reduction in the energy absorption.

2. Rimmed-steel E as-rolled plates with 13/16-in. punched holes as stress-raisers, failed at room temperature with a brittle fracture and with a very low energy absorption.

RECOMMENDATIONS FOR FUTURE WORK

Plans for future work include a group of tests to give more complete knowledge relative to the relation between the temperature of the steel plates and their energy-absorbing capacity. The curve showing the relation between the temperature and the energy-absorbing capacity of steel plates is made up of three parts: (1) A nearly horizontal portion at the left, which corresponds to a low-energy-absorbing capacity. (2) A nearly horizontal portion at the right, which corresponds to a high energy-absorbing capacity. (3) A nearly vertical transition portion connecting (1) and (2). The tests necessary to define the three parts of this diagram within a somewhat limited range of temperature have been made for 12-in. and 72-in. plates of rimmed-steel E as-rolled, killed-steel D as-rolled, and killed-steel D normalized.

Considerable work has already been done to establish the temperature energy-absorbing capacity of 24-in. and 48-in. plates made of the three steels designated above but time will not permit the completion of this work. It is desirable that the necessary tests be made to complete the temperature-energy-absorbing curves for 24-in. and 48-in. plates of the three kinds of steel, rimmed-steel E as-rolled, killed-steel D as-rolled, and killed-steel D normalized.

Tests of killed-steel G as-rolled in 72-in., 48-in., and 24-in. widths and killed-steel F as-rolled in 72-in. and 48-in. widths were not made and would appear desirable because of the high energy-absorbing capacity and low transition temperature range of these steels.

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Wilson, W. M., Hechtman, R. A., and Bruckner, W. H.

2. Progress Report, "Cleavage Fracture of Ship Plates as Influenced by Size Effect," NObs-31224, Serial No. SSC-3, dated August 20, 1946 by
Wilson, W. M., Hechtman, R. A., and Bruckner, W. H.

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APPENDIX A

EXPERIMENTAL DATA FROM TESTS

OF WIDE PLATE TESTS.

From:

University of Illinois
College of Engineering

Report Prepared by:

Wilbur M. Wilson
Robert A. Hechtman
Walter H. Bruckner

<u>LIST OF DATA</u>

Data for the tests listed in Tables I and II of the body of this Final Report and not included in Appendix A are contained in Appendix A of the Final Report(1) and Appendix A of the Progress Report.(2)

APPENDIX A

EXPERIMENTAL DATA FROM WIDE PLATE TESTS.

ABSTRACT

Experimental data from the wide plate tests described in this report are given in the following pages.

- -

DESCRIPTION OF SPECIMENS.

All of the specimens, the tests of which are described in this Final Report, are described in Table I, pages 6, 7 and 8, respectively.

RELATION BETWEEN LOAD AND AVERAGE ELONGATION ON A GAGE LENGTH EQUAL TO 3/4 W.

The relation between total load and average elongation on a gage length equal to three-quarters of the width of the specimen, is shown for all specimens on pages 1a to 11a , inclusive. The plastic elongation on a gage length equal to 3/4 W was measured with a mechanical strain gage with conical points at both extremities, which engaged No. 54 drill holes on the inner faces of pins projecting from the specimen on the gage lines 3/4 W apart. The elongation was read on five gage lines on each side of the specimen, as shown on page 13a. The elongation thus measured includes the opening between the two parts of the plate after fracture had begun. The area under the load-elongation diagrams thus determined represents the energy absorbed over the length of the plate equal to 3/4 W.

The unusual shape of the load-elongation diagram, page 1a, specimen 18A-1, steel D as-rolled plate 72" wide, tested at 59°F., would seem to call for some explanation. The corresponding diagram for specimen 22-1, page 2a, steel D as-rolled plate 72" wide, tested at 59°F. is more typical. The difference is the more unusual because the two specimens were geometrically identical, were made of the same steel, were tested at the same temperature, and the energy which they absorbed to failure differed by only 20%. The difference in the shape of the two load-elongation diagrams is believed to be due to the difference in the fractures. For specimen 18A-1, page 1a, the load increased steadily up to 1,722,000 lbs. and then there was a sudden drop in the load accompanied by a cleavage fracture approximately 8.5 inches long at each end of the stress raiser. The load was then increased and each portion of the fracture was extended as a shear fracture until the load reached a second maximum of 1,250,000 lbs. after which the shear fracture was extended and the load fell off, as shown by the diagram on page 1a.

The load-elongation diagram, page 2a, for specimen 12A-1, a 72-in. steel D normalized plate tested at 60°F., had a somewhat different shape. For it, the load increased gradually up to 1,765,000 lbs. when shear fractures approximately 5.5 in. long formed at the ends of the stress-raiser. As the testing-machine pulling-heads were still further separated, the shear fractures extended, the load fell off and the extensions of the plate increased, as shown on page 2a.

The load-elongation diagram, page 4a, for specimen 17-6A, a 12-in. steel D as-rolled plate tested at 40°F., is shown on page 4a. Although the fracture was 100% cleavage, the elongation increased considerably before fracture occurred and there was an abrupt increase in load just before the maximum load was reached. Fracture was sudden and cleavage fractures extend simultaneously and instantaneously from each end of the stress raiser to the adjacent edge of the plate.

STRAIN DISTRIBUTION ACROSS PLATE ON GAGE LENGTH EQUAL TO 3/4 W.

The strain distribution across the plate as measured by mechanical strain gages on a gage length equal to three-quarters of the actual width of the specimens is shown on pages 12a to 20a, inclusive, for the tests described in this report.

STRAIN DISTRIBUTION ACROSS PLATE FROM ELECTRIC STRAIN GAGES

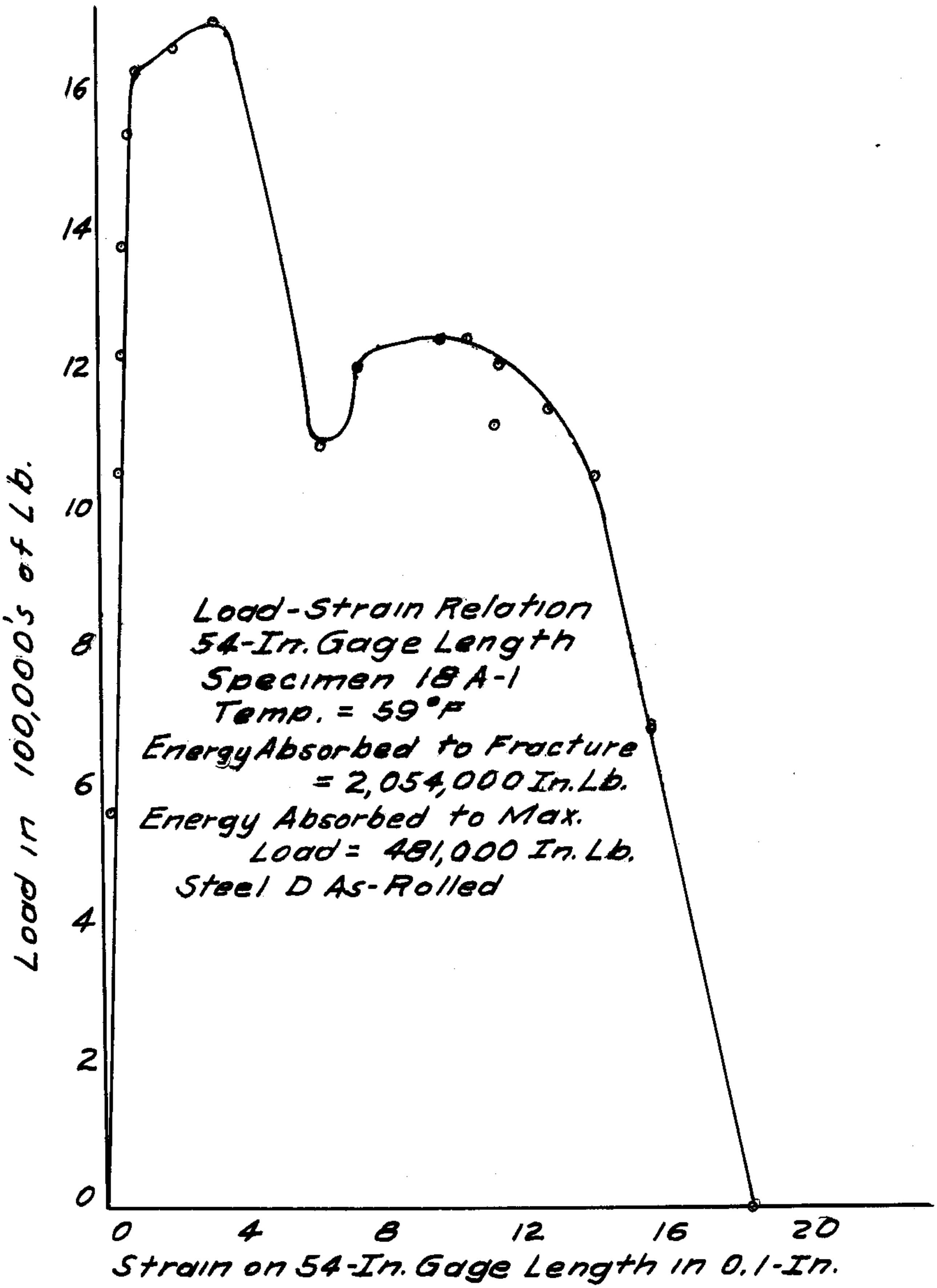
The strain distribution across one-half of the plate as measured by SR-4 electric strain gages is shown on pages 20a to 28a, inclusive, for the tests described in this report. All electric strain gages had a gage length of 13/16 in. except one gage of 1/4-in. gage length located next to the stress-raiser on 24-in. specimens. Strain readings with the electric strain gages were taken only in the elastic and early plastic ranges of the specimen.

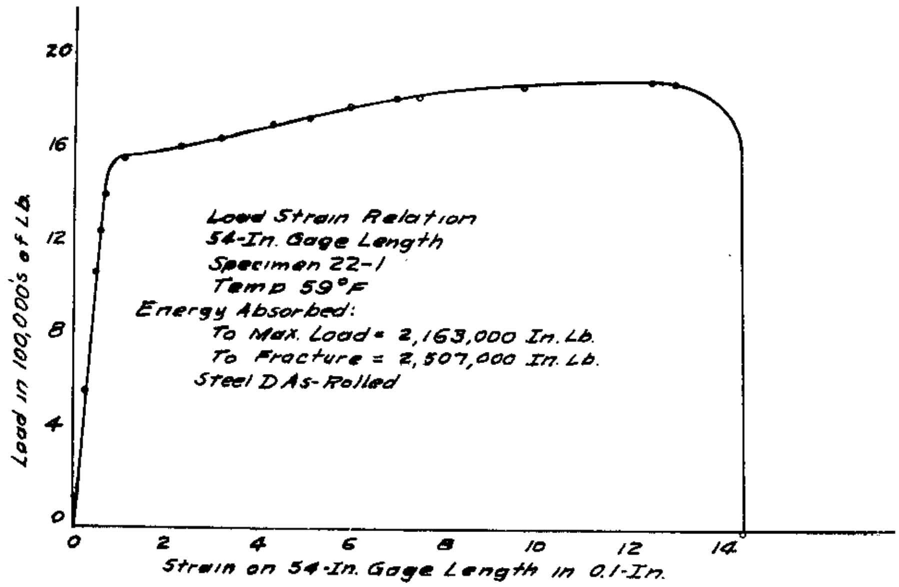
PLASTIC DEFORMATION ACROSS PLATE ON 1/4-IN. AND 1-IN. GAGE LENGTHS.

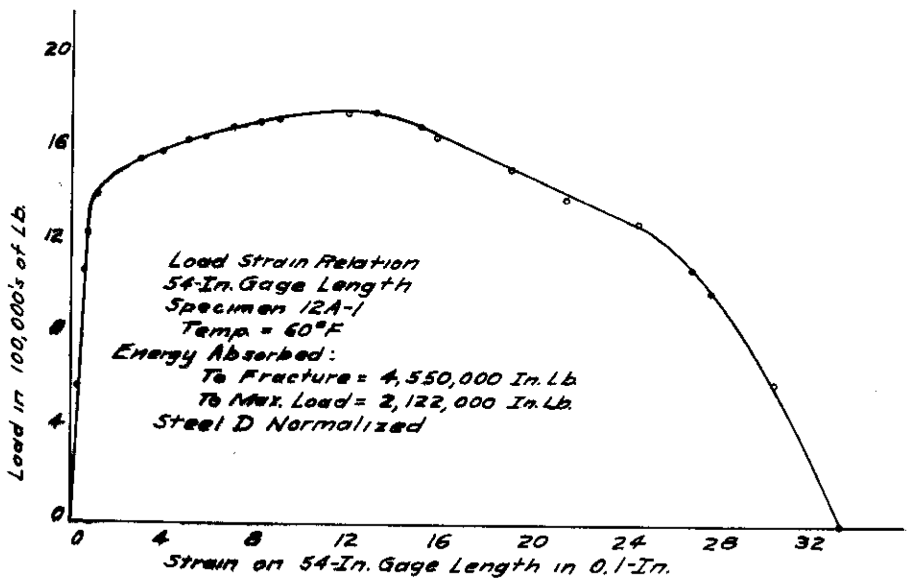
The plastic strain distribution across one-half of the plate as measured on 1/4-in. and 1-in. gage lengths by mechanical strain gages is shown on pages 28a to 36a, inclusive, for the tests of this report. These mechanical gage readings were taken up to the load at which the initial crack at the end of the stress-raiser appeared.

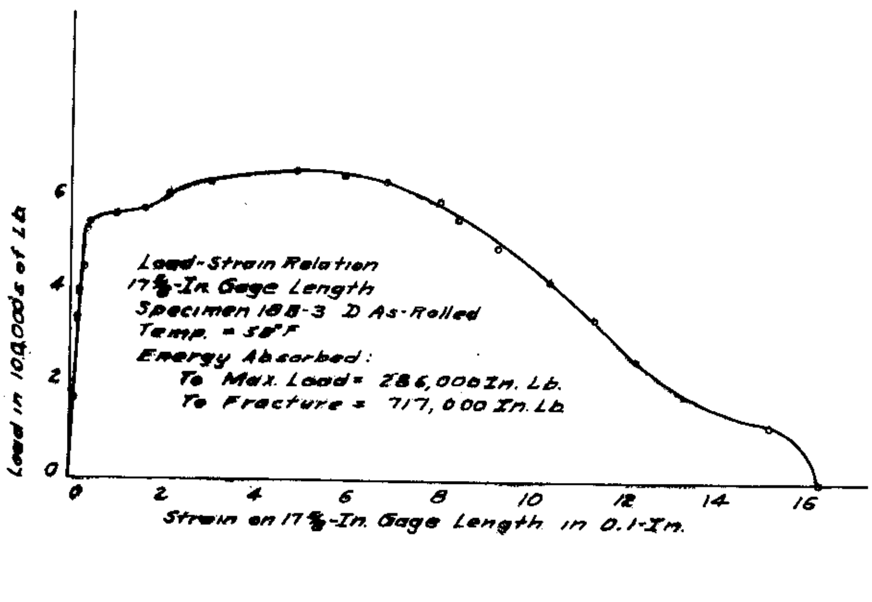
THICKNESS OF PLATE AT FRACTURE

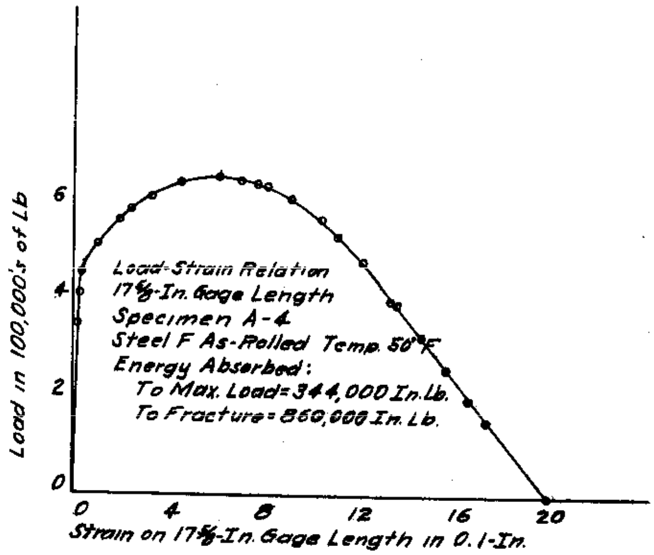
The thickness and profile of the plate at the fractured edge is shown on pages 37a to 54a, inclusive, for the specimens of this report.

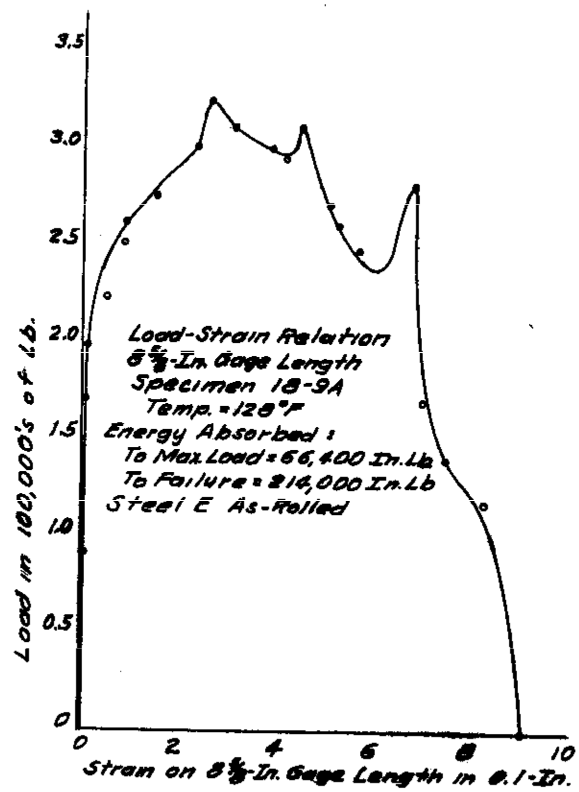

Load-Strain Relation
54-In. Gage Length
Specimen 18A-1
Temp. = 59°F
Energy Absorbed to Fracture
= 2,054,000 In. Lb.
Energy Absorbed to Max.
Load = 481,000 In. Lb.
Steel D As-Rolled
Load in 100,000's of Lb.
0
2
4
6
8
10
12
14
16
0
4
8
12
16
20
Strain on 54-In. Gage Length in 0.1-In.

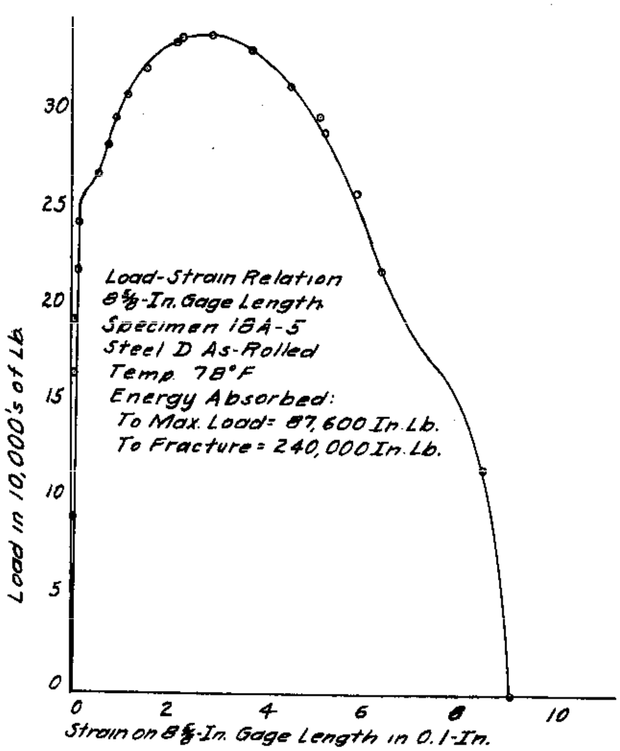

Load Strain Relation
54-In. Gage Length
Specimen 22-1
Temp 59°F
Energy Absorbed:
To Max. Load = 2,163,000 In. Lb.
To Fracture = 2,507,000 In. Lb.
Steel D As-Rolled
Load in 100,000's of Lb.
Strain on 54-In. Gage Length in 0.1-In.

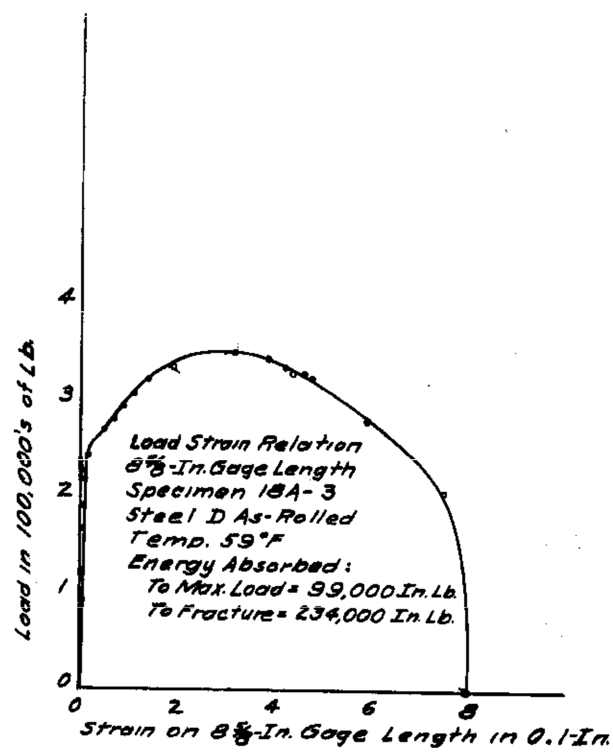

Load Strain Relation
54-In. Gage Length
Specimen 12A-1
Temp. = 60°F
Energy Absorbed:
To Fracture = 4,550,000 In. Lb.
To Max. Load = 2,122,000 In. Lb.
Steel D Normalized
Load in 100,000's of Lb.
Strain on 54-In. Gage Length in 0.1-In.

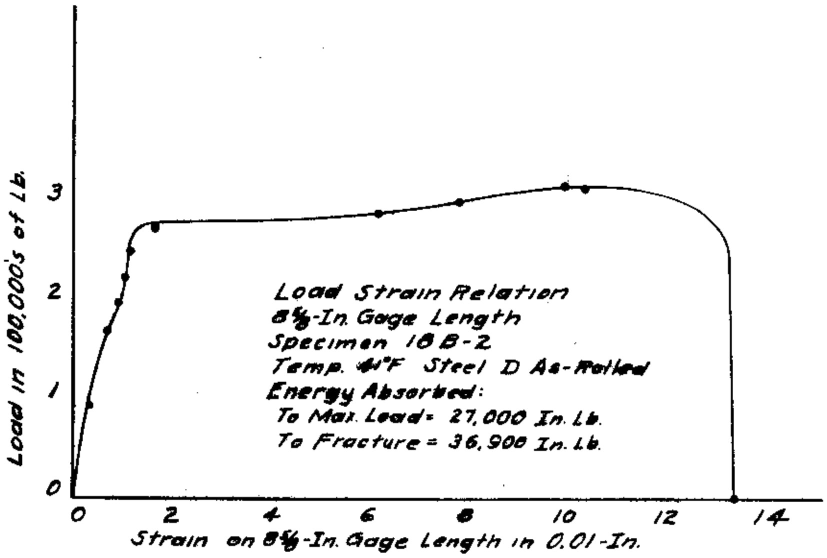

Load-Strain Relation
17⅝-In. Gage Length
Specimen 18B-3 D As-Rolled
Temp. = 58°F
Energy Absorbed:
To Max. Load = 286,000 In. Lb.
To Fracture = 717,000 In. Lb.
Load in 100,000's of Lb.
Strain on 17⅝-In. Gage Length in 0.1-In.

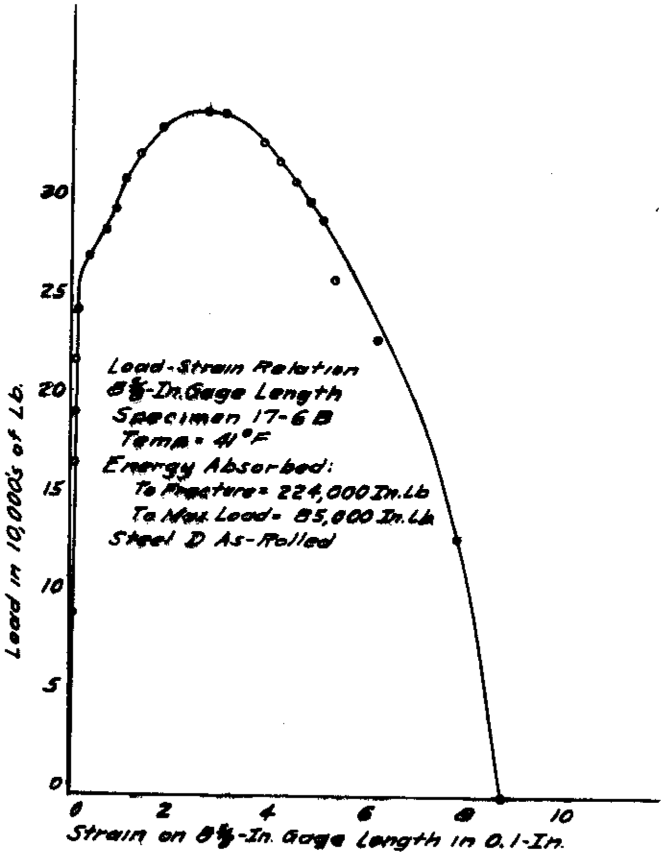

Load-Strain Relation
17⅝-In. Gage Length
Specimen A-4
Steel F As-Rolled Temp. 50°F
Energy Absorbed:
To Max. Load = 344,000 In. Lb.
To Fracture = 860,000 In. Lb.
Load in 100,000's of Lb
0
2
4
6
0
4
8
12
16
20
Strain on 17⅝-In. Gage Length in 0.1-In.

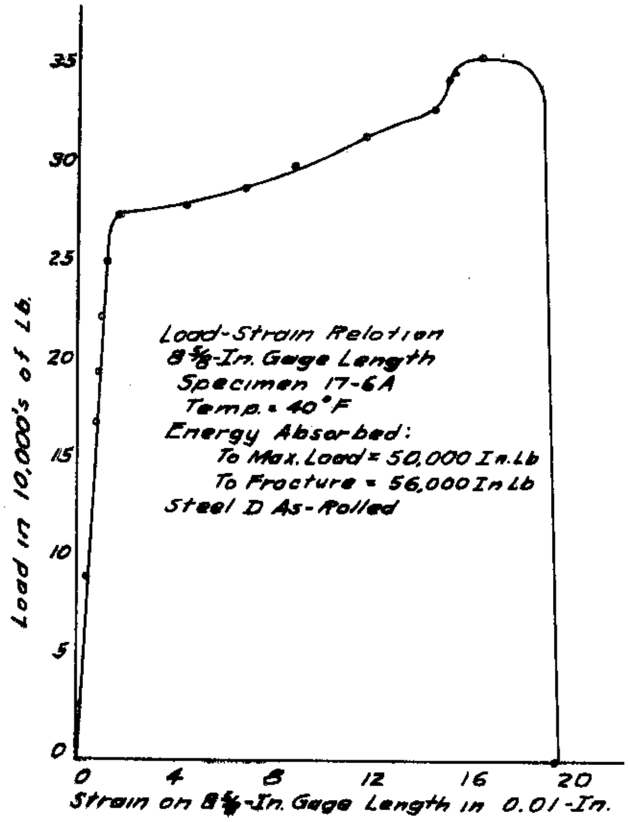

Load-Strain Relation
8⅝-In. Gage Length
Specimen 18-9A
Temp. = 128°F
Energy Absorbed:
To Max. Load = 66,400 In. Lb.
To Failure = 214,000 In. Lb.
Steel E As-Rolled
Load in 100,000's of Lb.
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
2
4
6
8
10
Strain on 8⅝-In. Gage Length in 0.1-In.

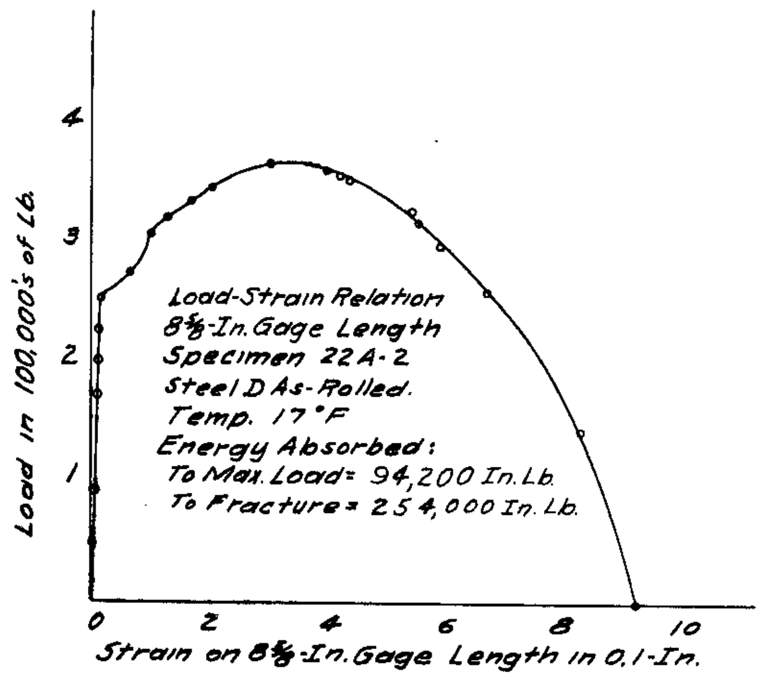

Load-Strain Relation
8⅝-In. Gage Length
Specimen 18A-5
Steel D As-Rolled
Temp. 78°F
Energy Absorbed:
To Max. Load = 87,600 In. Lb.
To Fracture = 240,000 In. Lb.
Load in 10,000's of Lb
0
5
10
15
20
25
30
0
2
4
6
8
10
Strain on 8⅝-In. Gage Length in 0.1-In.

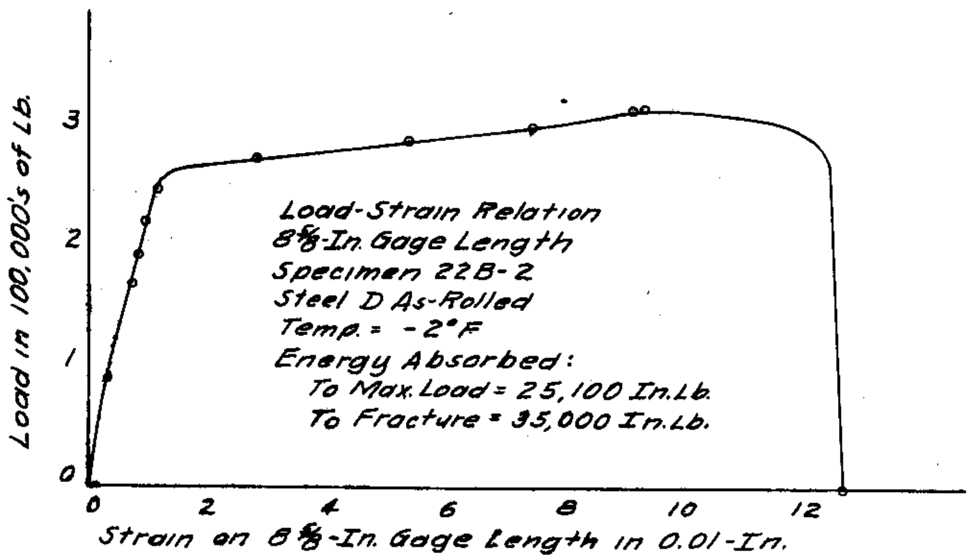

Load Strain Relation
8⅝-In. Gage Length
Specimen 18A-3
Steel D As-Rolled
Temp. 59°F
Energy Absorbed:
To Max. Load = 99,000 In. Lb.
To Fracture = 234,000 In. Lb.
Load in 100,000's of Lb.
0
1
2
3
4
0
2
4
6
8
Strain on 8⅝-In. Gage Length in 0.1-In.

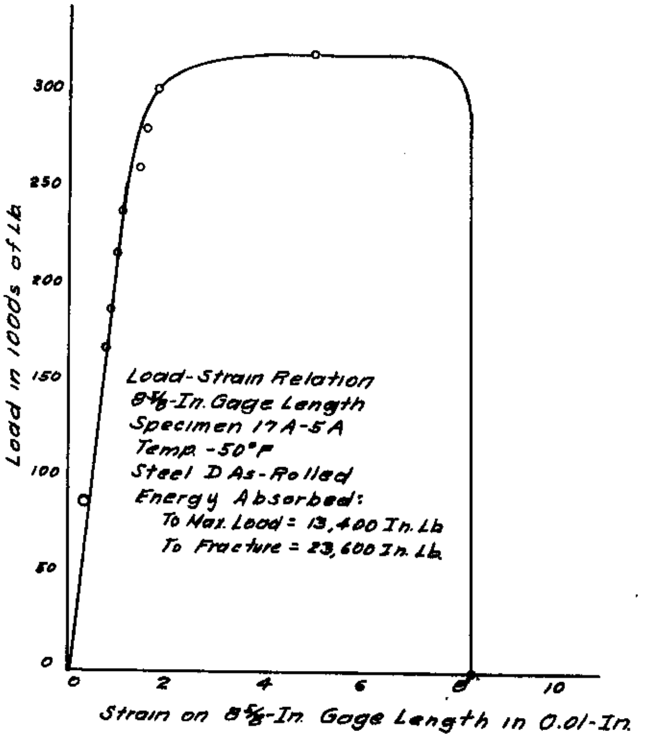

Load Strain Relation
8⅝-In. Gage Length
Specimen 18B-2
Temp. 41°F Steel D As-Rolled
Energy Absorbed:
To Max. Load = 27,000 In. Lb.
To Fracture = 36,900 In. Lb.
Load in 100,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.01-In.

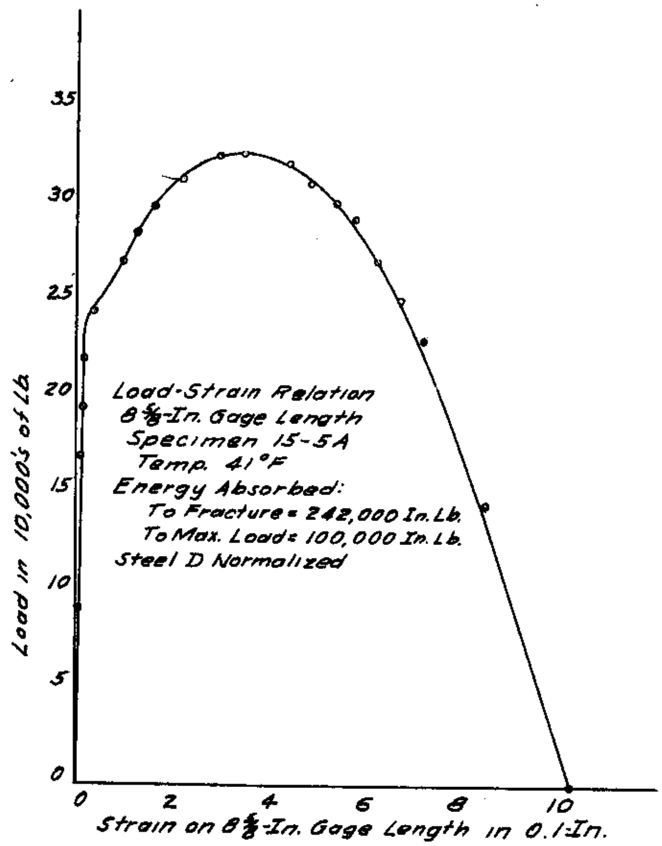

Load-Strain Relation
8⅝-In. Gage Length
Specimen 17-6B
Temp. = 41°F
Energy Absorbed:
To Fracture = 224,000 In. Lb
To Max. Load = 85,000 In. Lb
Steel D As-Rolled
Load in 10,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.1-In.

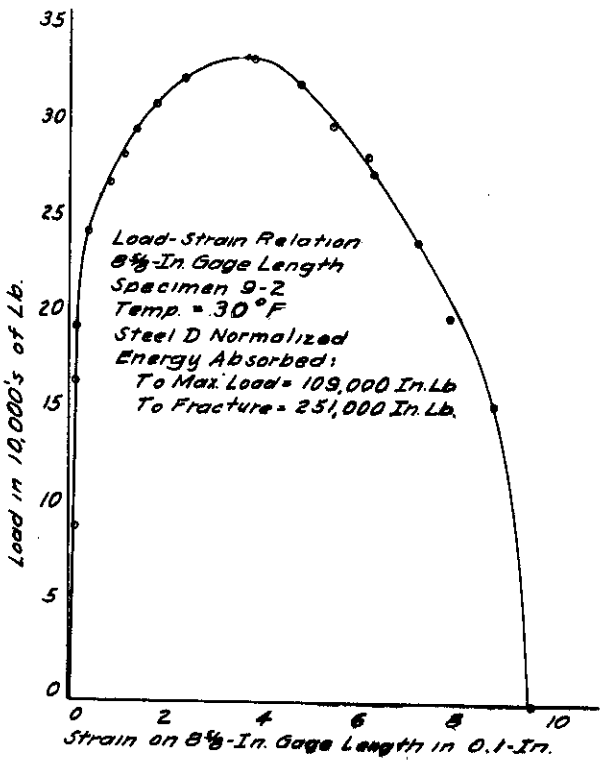

Load-Strain Relation
8⅝-In. Gage Length
Specimen 17-6A
Temp. = 40°F
Energy Absorbed:
To Max. Load = 50,000 In. Lb
To Fracture = 56,000 In Lb
Steel D As-Rolled
Load in 10,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.01-In.

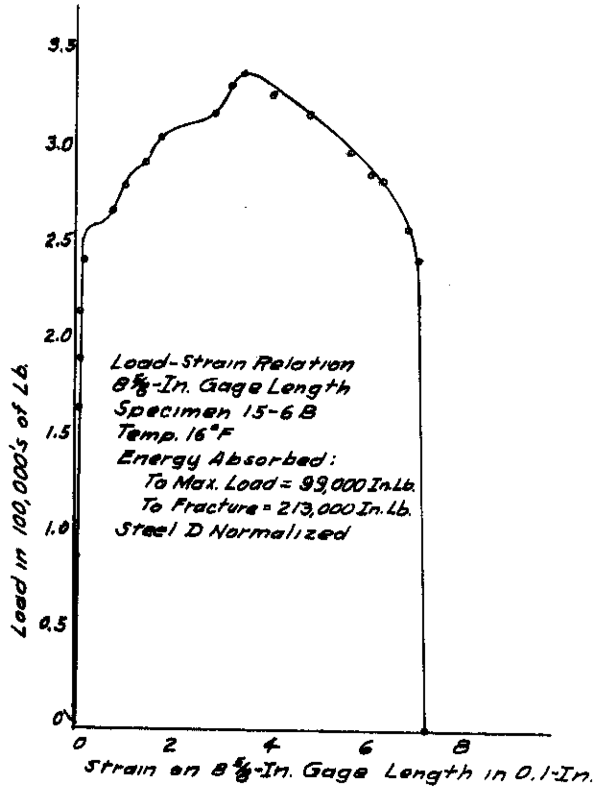

Load-Strain Relation
8⅝-In. Gage Length
Specimen 22A-2
Steel D As-Rolled.
Temp. 17°F
Energy Absorbed:
To Max. Load = 94,200 In. Lb.
To Fracture = 254,000 In. Lb.
Load in 100,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.1-In.
0
1
2
3
4
6
8
10

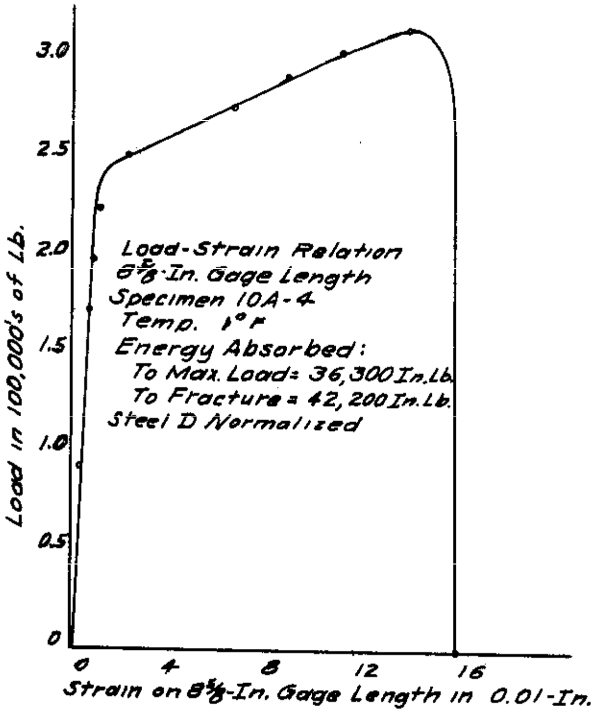

Load-Strain Relation
8⅝-In. Gage Length
Specimen 22B-2
Steel D As-Rolled
Temp. = -2°F
Energy Absorbed:
To Max. Load = 25,100 In. Lb.
To Fracture = 35,000 In. Lb.
Load in 100,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.01-In.
0
1
2
3
4
6
8
10
12

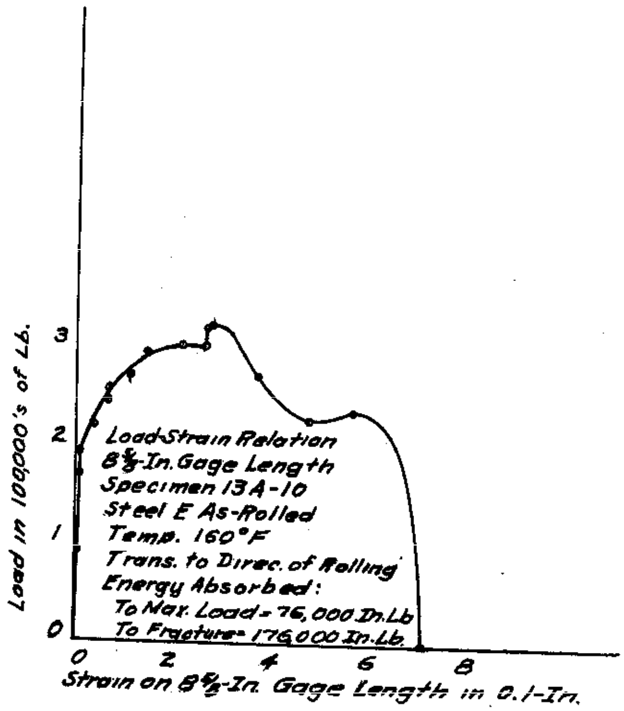

Load-Strain Relation
8⅝-In. Gage Length
Specimen 17A-5A
Temp. -50°F
Steel D As-Rolled
Energy Absorbed:
To Max. Load = 13,400 In. Lb
To Fracture = 23,600 In. Lb.
Load in 1000s of Lb.
Strain on 8⅝-In. Gage Length in 0.01-In.

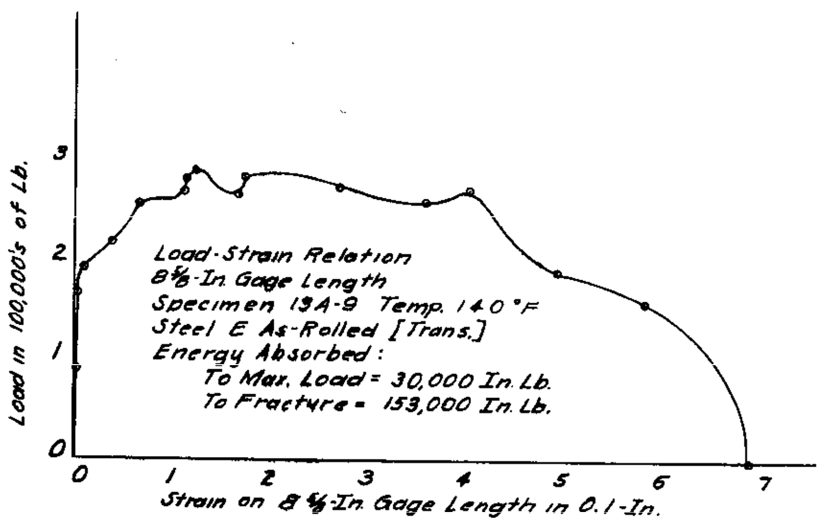

Load-Strain Relation
8⅝-In. Gage Length
Specimen 15-5A
Temp. 41°F
Energy Absorbed:
To Fracture = 242,000 In. Lb.
To Max. Load = 100,000 In. Lb.
Steel D Normalized
Load in 10,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.1-In.

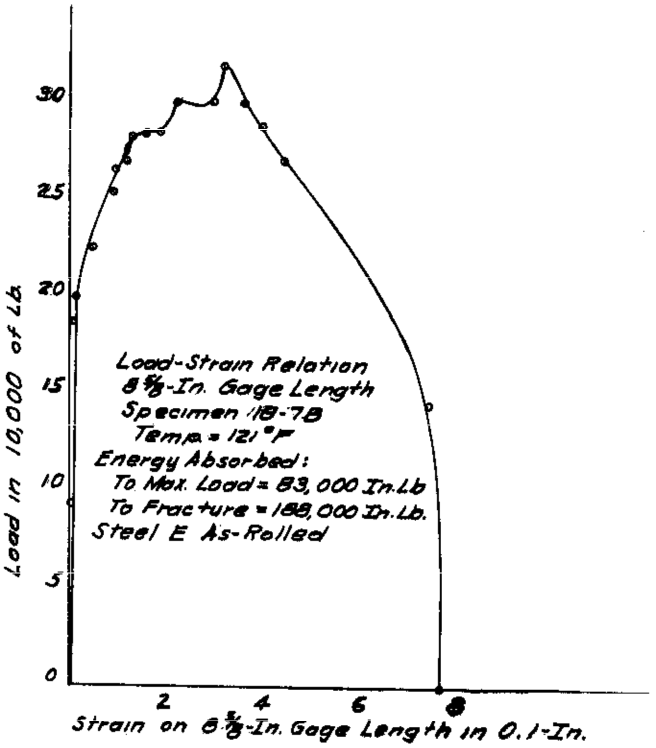

Load-Strain Relation
8⅝-In. Gage Length
Specimen 9-2
Temp. = 30°F
Steel D Normalized
Energy Absorbed:
To Max. Load = 109,000 In. Lb
To Fracture = 251,000 In. Lb.
Load in 10,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.1-In.

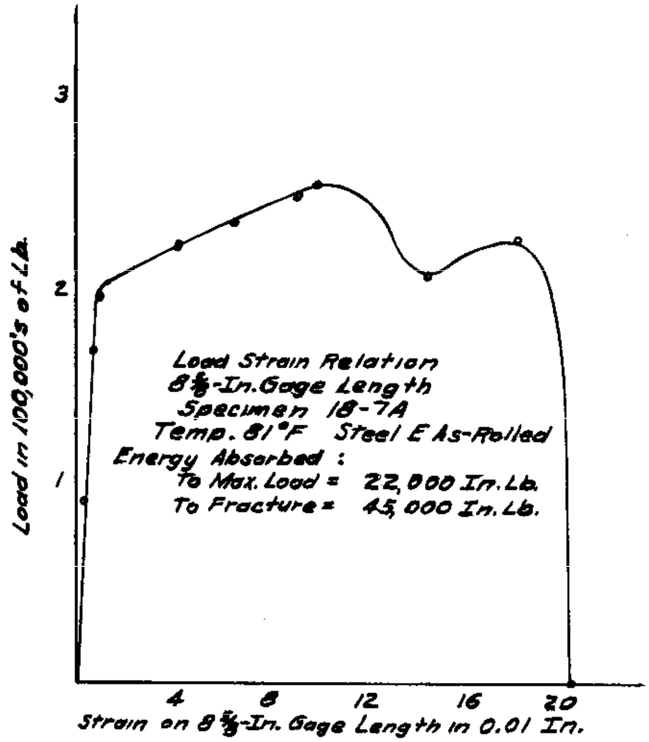

Load-Strain Relation
8⅝-In. Gage Length
Specimen 15-6B
Temp. 16°F
Energy Absorbed:
To Max. Load = 99,000 In. Lb.
To Fracture = 213,000 In. Lb.
Steel D Normalized
Load in 100,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.1-In.

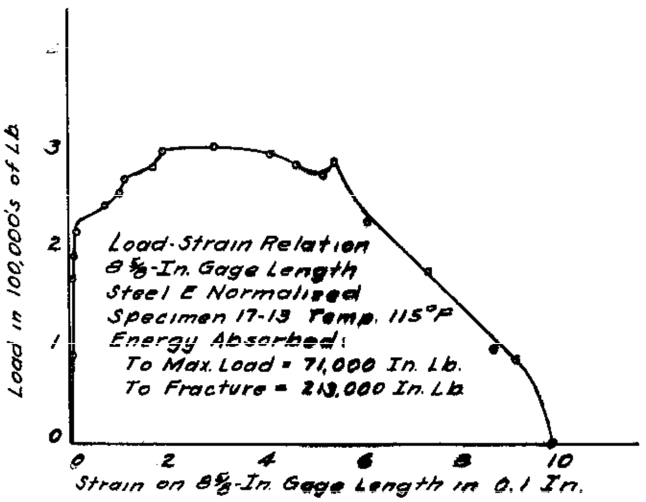

Load-Strain Relation
8⅝-In. Gage Length
Specimen 10A-4
Temp. 1°F
Energy Absorbed:
To Max. Load = 36,300 In. Lb.
To Fracture = 42,200 In. Lb.
Steel D Normalized
Load in 100,000's of Lb.
3.0
2.5
2.0
1.5
1.0
0.5
0
0
4
8
12
16
Strain on 8⅝-In. Gage Length in 0.01-In.

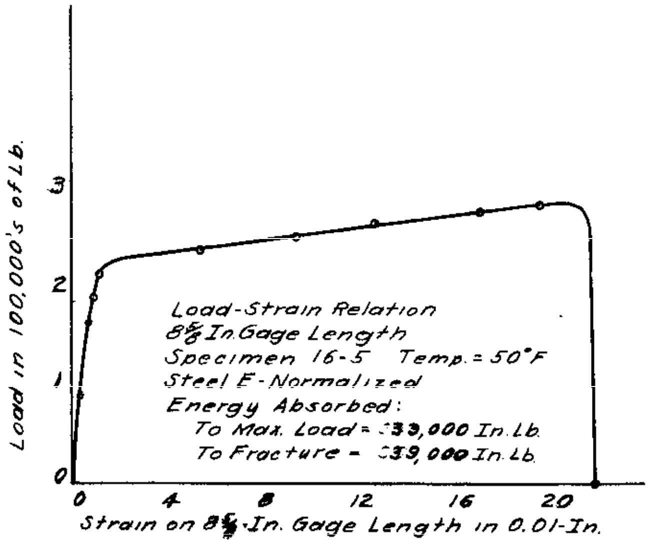

Load-Strain Relation
8⅝-In. Gage Length
Specimen 13A-10
Steel E As-Rolled
Temp. 160°F
Trans. to Direc. of Rolling
Energy Absorbed:
To Max. Load = 76,000 In. Lb.
To Fracture = 176,000 In. Lb.
Load in 100,000's of Lb.
3
2
1
0
0
2
4
6
8
Strain on 8⅝-In. Gage Length in 0.1-In.

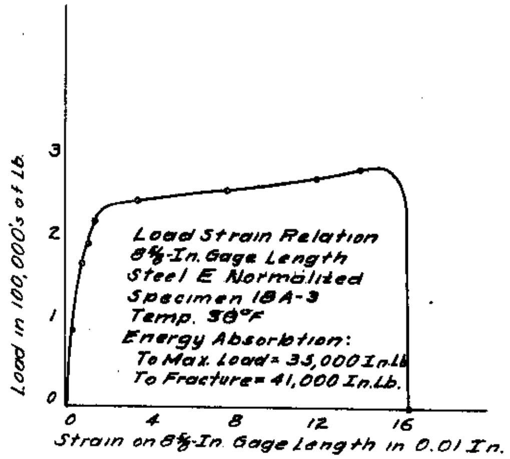

Load-Strain Relation
8⅝-In. Gage Length
Specimen 13A-9 Temp. 140°F
Steel E As-Rolled [Trans.]
Energy Absorbed:
To Max. Load = 30,000 In. Lb.
To Fracture = 153,000 In. Lb.
Load in 100,000's of Lb.
3
2
1
0
0
1
2
3
4
5
6
7
Strain on 8⅝-In. Gage Length in 0.1-In.

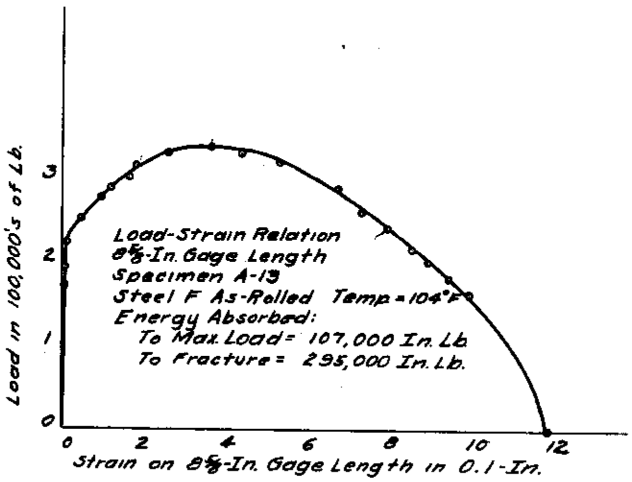

Load in 10,000 of Lb.
30
25
20
15
10
5
0
2
4
6
8
Strain on 8 5/8-In. Gage Length in 0.1-In.
Load-Strain Relation
8 5/8-In. Gage Length
Specimen 18-7B
Temp. = 121°F
Energy Absorbed:
To Max. Load = 83,000 In.Lb
To Fracture = 188,000 In.Lb.
Steel E As-Rolled

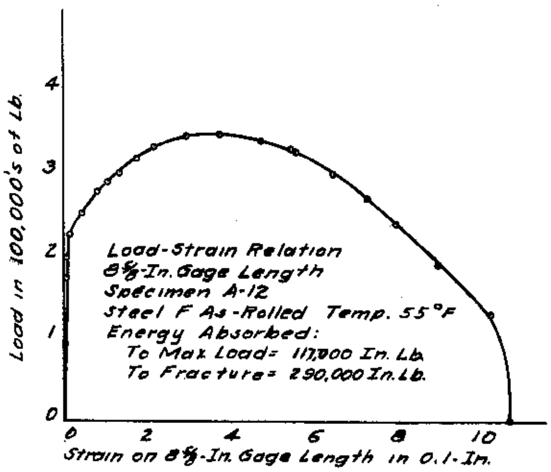

Load in 100,000's of Lb.
3
2
1
4
8
12
16
20
Strain on 8 5/8-In. Gage Length in 0.01 In.
Load Strain Relation
8 5/8-In. Gage Length
Specimen 18-7A
Temp. 81°F Steel E As-Rolled
Energy Absorbed :
To Max. Load = 22,000 In. Lb.
To Fracture = 45,000 In. Lb.

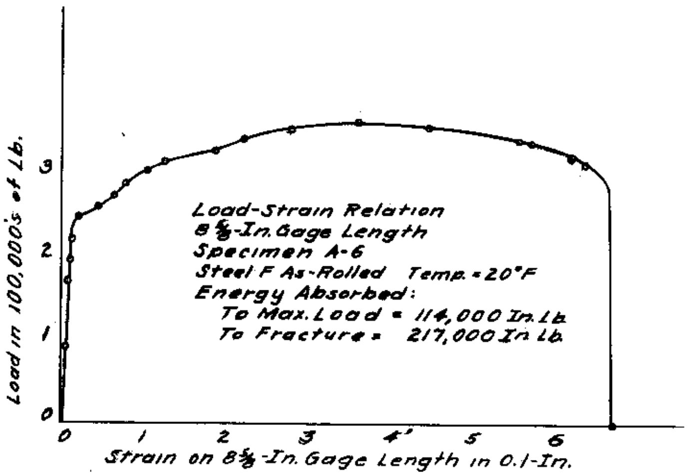

Load in 100,000's of Lb.
3
2
1
0
0
2
4
6
8
10
Strain on 8 5/8-In. Gage Length in 0.1 In.
Load-Strain Relation
8 5/8-In. Gage Length
Steel E Normalized
Specimen 17-13 Temp. 115°F
Energy Absorbed:
To Max. Load = 71,000 In. Lb.
To Fracture = 213,000 In. Lb.

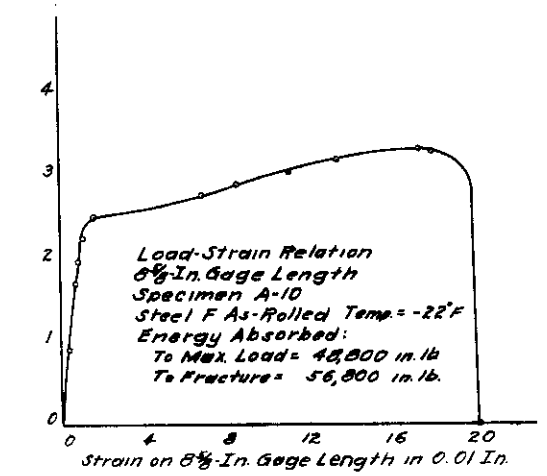

Load in 100,000's of Lb.
3
2
1
0
0
4
8
12
16
20
Strain on 8 5/8-In. Gage Length in 0.01-In.
Load-Strain Relation
8 5/8 In. Gage Length
Specimen 16-5 Temp. = 50°F
Steel E-Normalized
Energy Absorbed:
To Max. Load = 33,000 In. Lb.
To Fracture = 39,000 In. Lb.

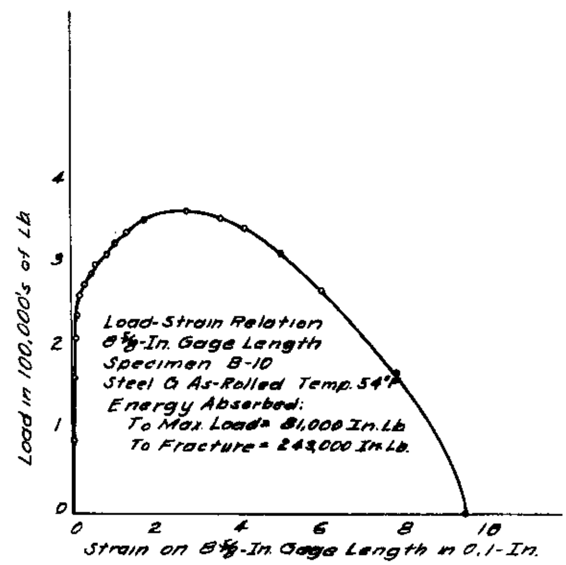

Load Strain Relation
8⅝-In. Gage Length
Steel E Normalized
Specimen 18A-3
Temp. 38°F
Energy Absorbtion:
To Max. Load= 35,000 In.Lb
To Fracture= 41,000 In.Lb.
Load in 100,000's of Lb.
0
1
2
3
0
4
8
12
16
Strain on 8⅝-In. Gage Length in 0.01 In.

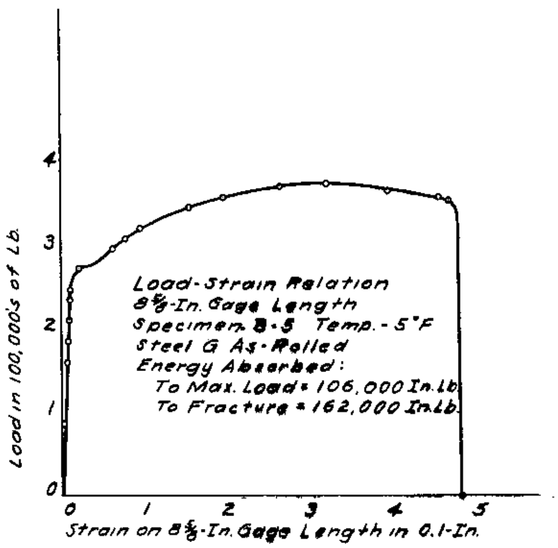

Load-Strain Relation
8⅝-In. Gage Length
Specimen A-13
Steel F As-Rolled Temp.=104°F
Energy Absorbed:
To Max. Load= 107,000 In. Lb
To Fracture= 295,000 In. Lb.
Load in 100,000's of Lb.
0
1
2
3
0
2
4
6
8
10
12
Strain on 8⅝-In. Gage Length in 0.1-In.

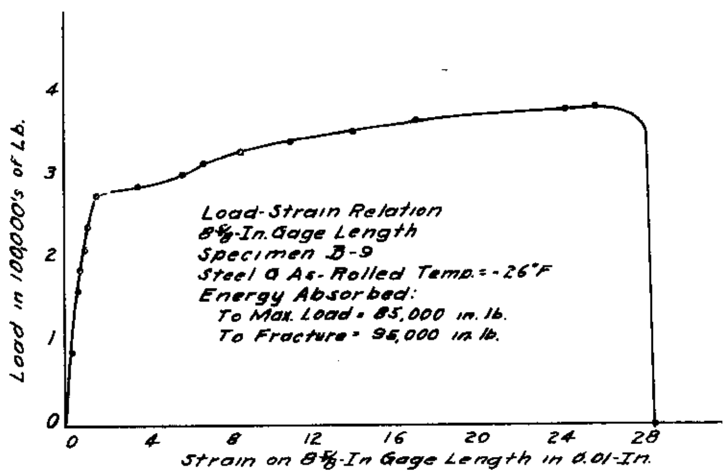

Load-Strain Relation
8⅝-In. Gage Length
Specimen A-12
Steel F As-Rolled Temp. 55°F
Energy Absorbed:
To Max. Load= 117,000 In. Lb.
To Fracture= 290,000 In. Lb.
Load in 100,000's of Lb.
0
1
2
3
4
0
2
4
6
8
10
Strain on 8⅝-In. Gage Length in 0.1-In.

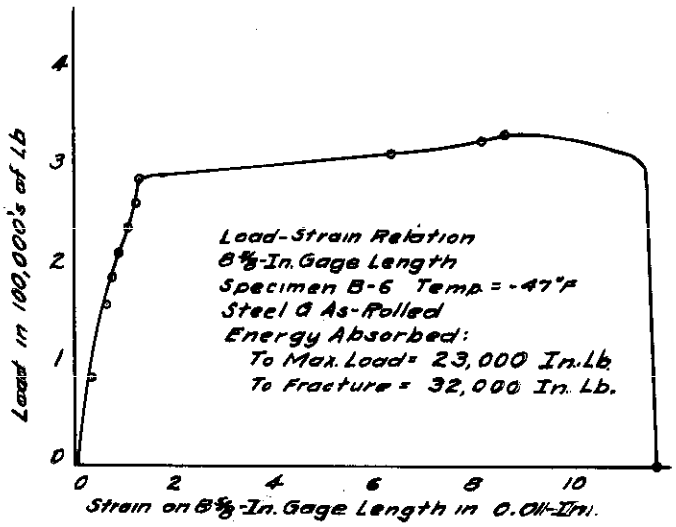

Load-Strain Relation
8⅝-In. Gage Length
Specimen A-6
Steel F As-Rolled Temp.=20°F
Energy Absorbed:
To Max. Load = 114,000 In. Lb
To Fracture = 217,000 In. Lb
Load in 100,000's of Lb.
0
1
2
3
0
1
2
3
4
5
6
Strain on 8⅝-In. Gage Length in 0.1-In.

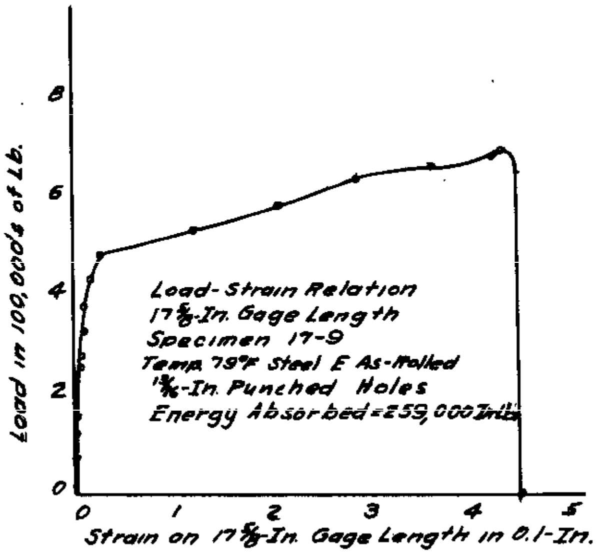

Load-Strain Relation
8⅝-In. Gage Length
Specimen A-10
Steel F As-Rolled Temp. = -22°F
Energy Absorbed:
To Max. Load = 48,800 in. lb
To Fracture = 56,800 in. lb.
Strain on 8⅝-In. Gage Length in 0.01 In.
0
1
2
3
4
8
12
16
20

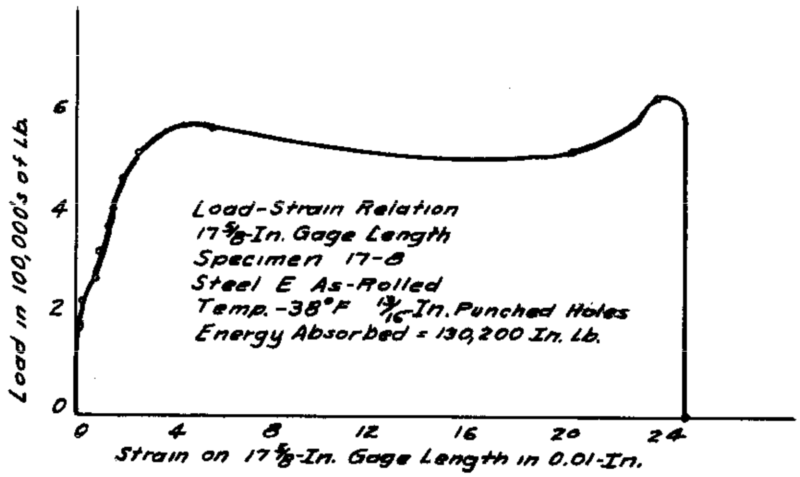

Load-Strain Relation
8⅝-In. Gage Length
Specimen B-10
Steel G As-Rolled Temp. 54°F
Energy Absorbed:
To Max. Load = 81,000 In. Lb
To Fracture = 243,000 In. Lb.
Load in 100,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.1-In.
0
1
2
3
4
6
8
10

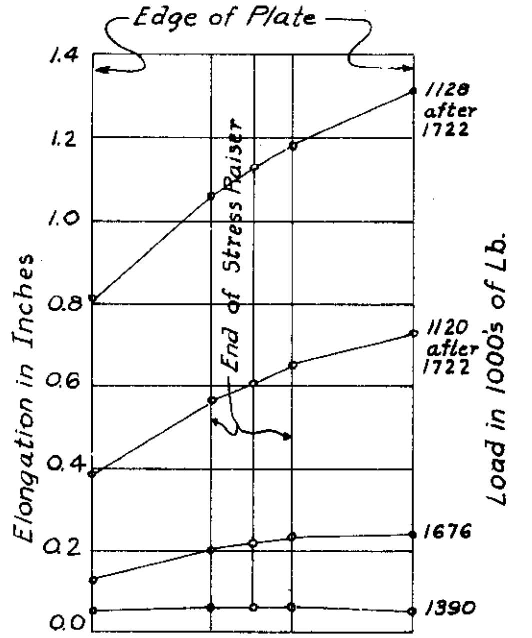

Load-Strain Relation
8⅝-In. Gage Length
Specimen B-5 Temp. -5°F
Steel G As-Rolled
Energy Absorbed:
To Max. Load = 106,000 In. Lb
To Fracture = 162,000 In. Lb.
Load in 100,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.1-In.
0
1
2
3
4
5


Load-Strain Relation
8⅝-In. Gage Length
Specimen B-9
Steel G As-Rolled Temp. = -26°F
Energy Absorbed:
To Max. Load = 85,000 in. lb.
To Fracture = 96,000 in. lb.
Load in 100,000's of Lb.
Strain on 8⅝-In Gage Length in 0.01-In.
0
1
2
3
4
8
12
16
20
24
28

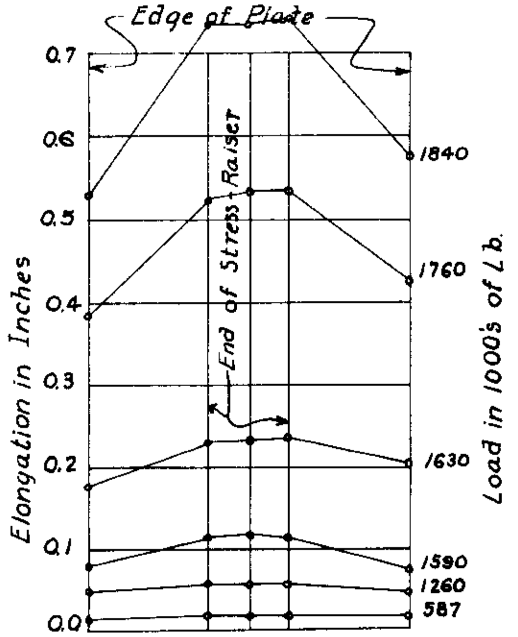

Load-Strain Relation
8⅝-In. Gage Length
Specimen 8-6 Temp. = -47°F
Steel G As-Rolled
Energy Absorbed:
To Max. Load = 23,000 In. Lb.
To Fracture = 32,000 In. Lb.
Load in 100,000's of Lb.
Strain on 8⅝-In. Gage Length in 0.01-In.


Load-Strain Relation
17⅝-In. Gage Length
Specimen 17-9
Temp. 79°F Steel E As-Rolled
13/16-In. Punched Holes
Energy Absorbed = 259,000 In. Lb.
Load in 100,000's of Lb.
Strain on 17⅝-In. Gage Length in 0.1-In.

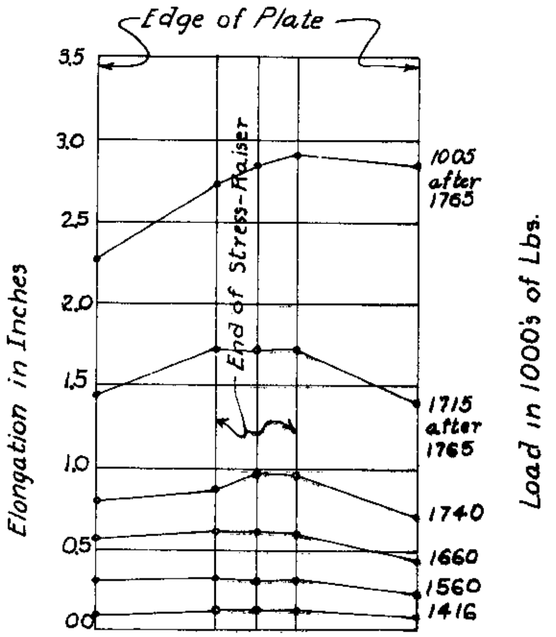

Load-Strain Relation
17⅝-In. Gage Length
Specimen 17-8
Steel E As-Rolled
Temp. -38°F 13/16-In. Punched Holes
Energy Absorbed = 130,200 In. Lb.
Load in 100,000's of Lb.
Strain on 17⅝-In. Gage Length in 0.01-In.



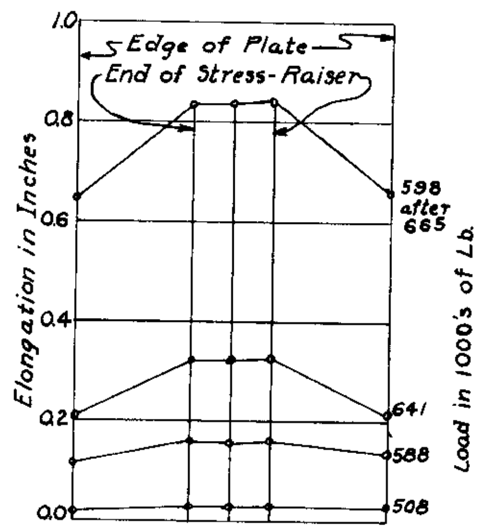
Strain Distribution Across 72-In. Plate
54-In. Gage Lines
Specimen 18A-1
Steel D As-Rolled



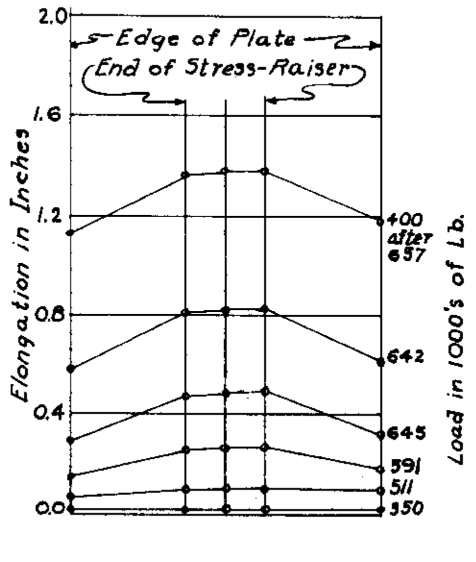
Strain Distribution Across 72-In. Plate
54-In. Gage Lines
Specimen 22-1
Steel D As Rolled



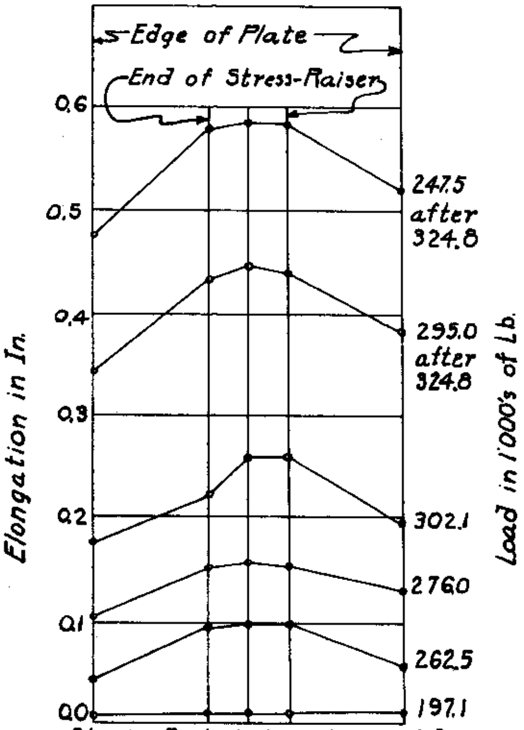
Strain Distribution Across 72-In. Plate
54-In. Gage Lines
Specimen 12A-1
Steel D Normalized



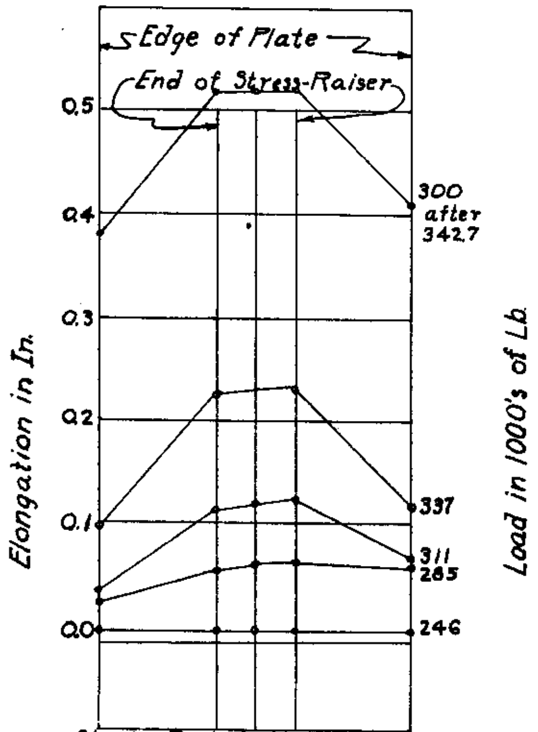
Strain Distribution Across 24-In. Plate
17⅝-In. Gage Length Specimen 18B-3
Steel D As Rolled



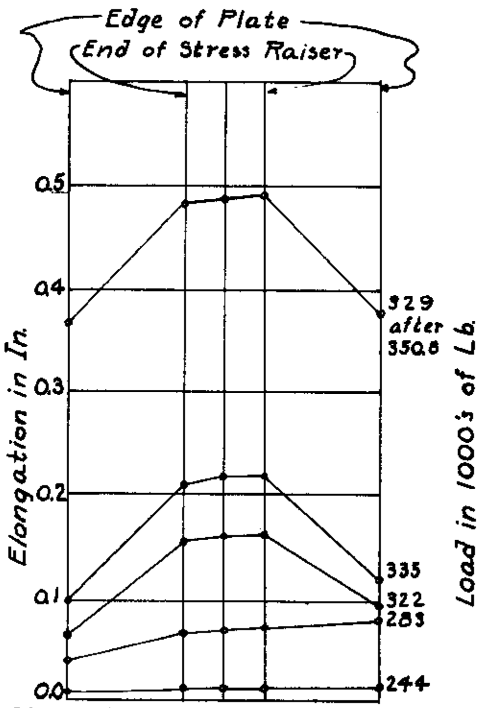
Strain Distribution Across 24-In. Plate
17⅞-In. Gage Length. Specimen A-4
Steel F As Rolled



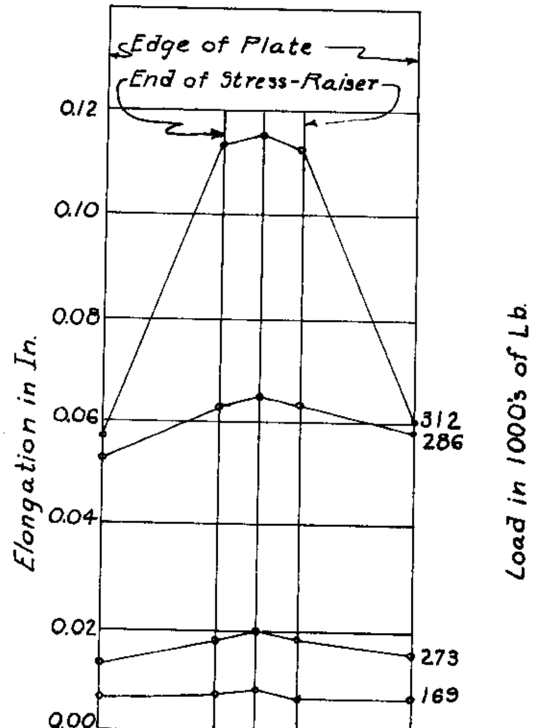
Strain Distribution Across 12-In Plate
8⅝-In. Gage Length.
Specimen 18-9A
Steel E As-Rolled.



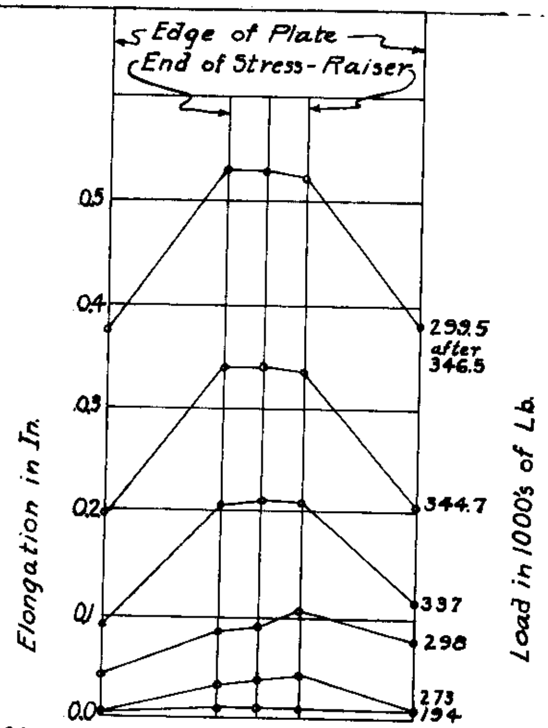
Strain Distribution Across 12-In Plate
8⅝-In. Gage Length
Specimen 18A-5
Steel D As-Rolled



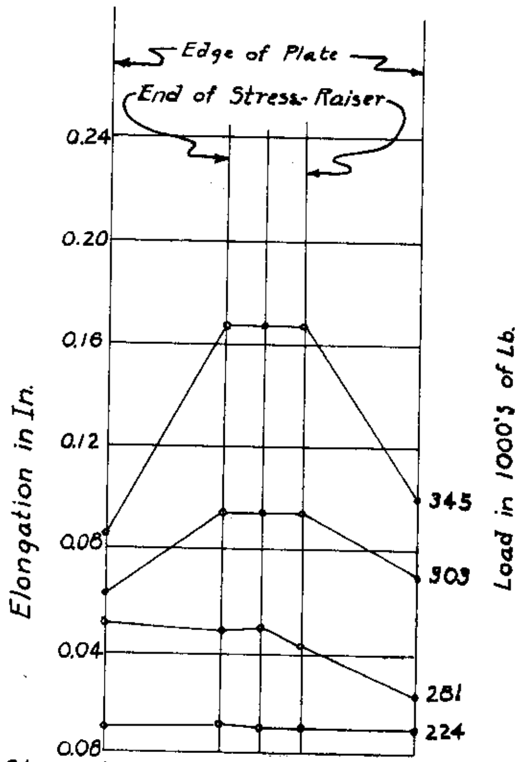
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length.
Specimen 18A-3
Steel D As-Rolled



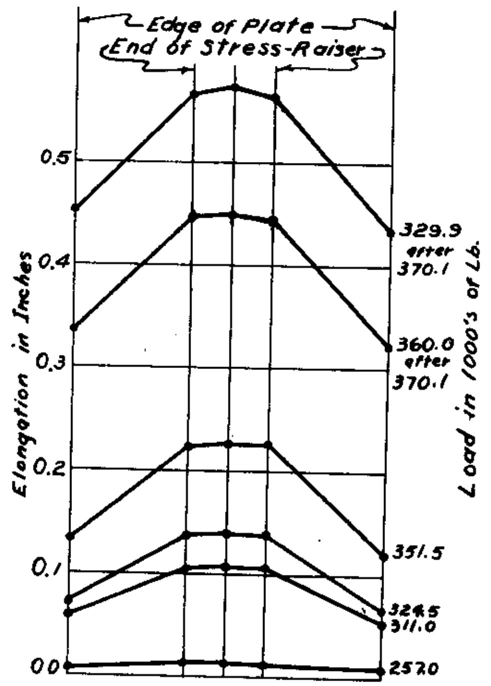
Strain Distribution Across 12-In Plate
8⅝-In. Gage Length
Specimen 18B-2
Steel D As-Rolled



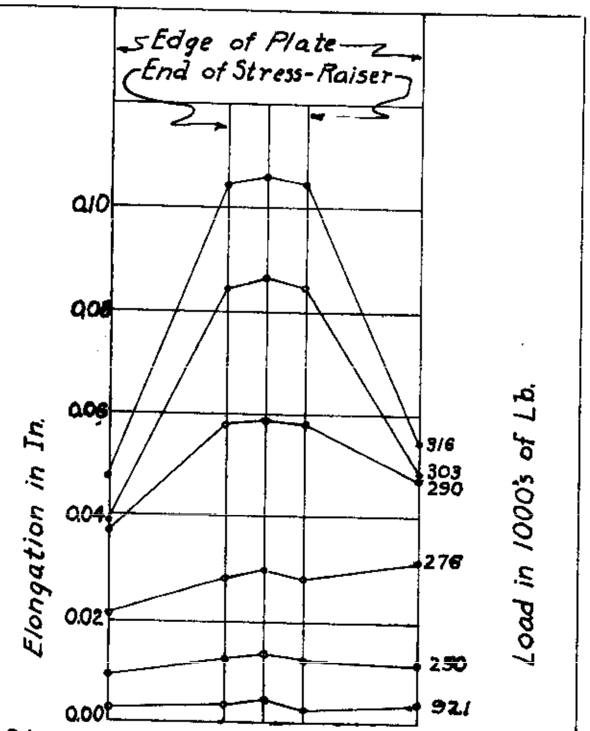
Strain Distribution Across 12-In. Plate.
8⅝-In. Gage Length Specimen 17-6B
Steel D As-Rolled



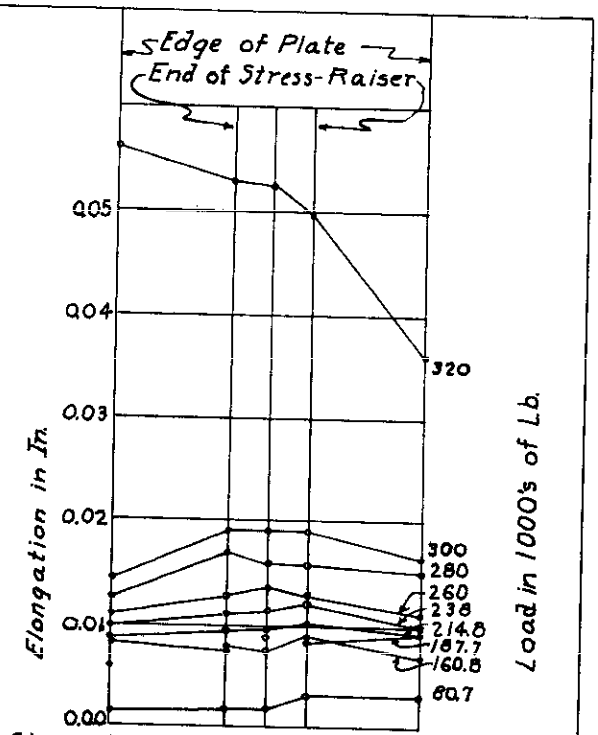
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length, Specimen 17-6A
Steel D As-Rolled.



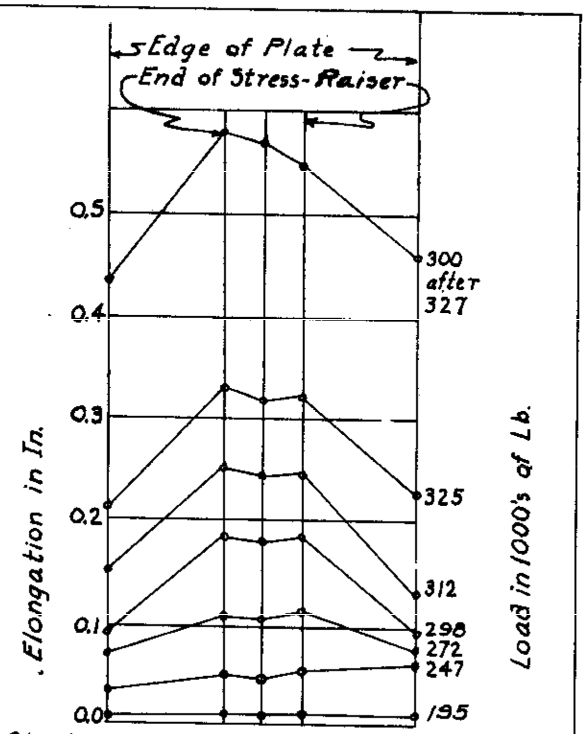
Strain Distribution Across 12-In Plate
8⅝-In Gage Length Specimen 22A-2
Steel D As-Rolled



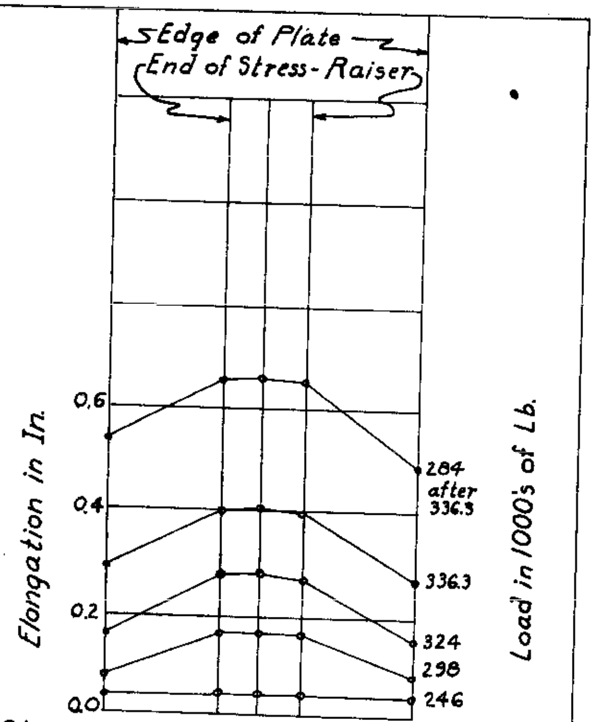
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length. Specimen 22B-2
Steel D As-Rolled



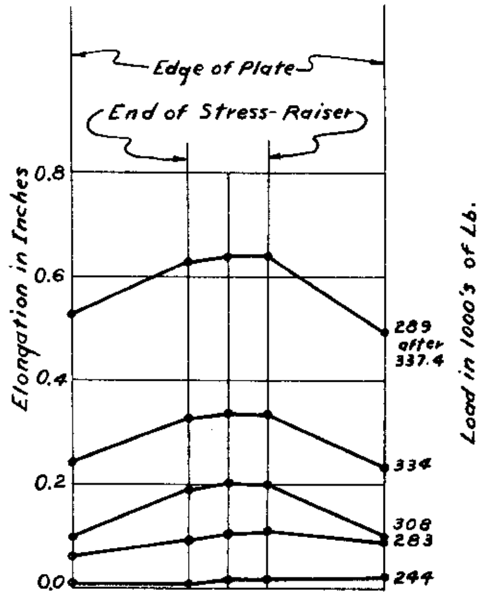
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length. Specimen 17A-5A
Steel D As-Rolled.



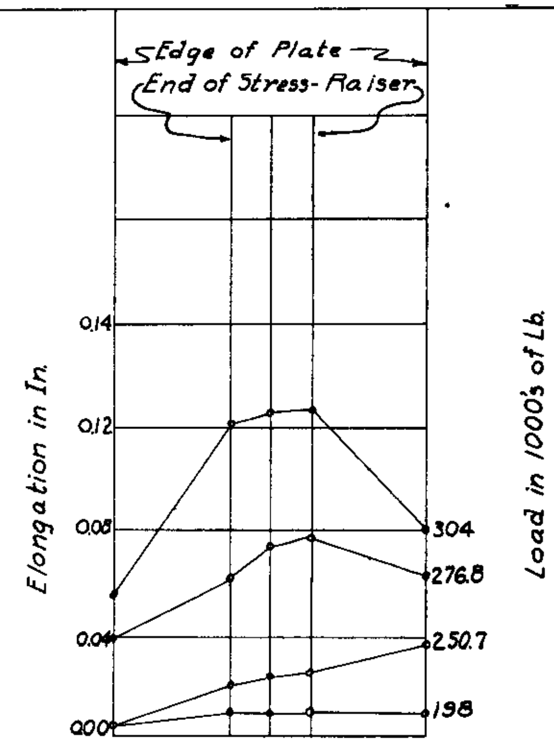
Strain Distribution Across 12-In Plate
8⅝-In. Gage Length. Specimen 15-5A
Steel D Normalized



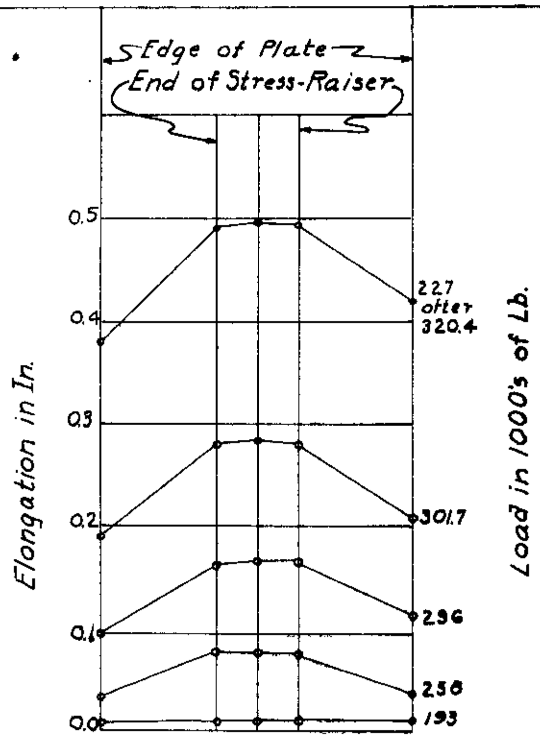
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length. Specimen 9-2
Steel D Normalized



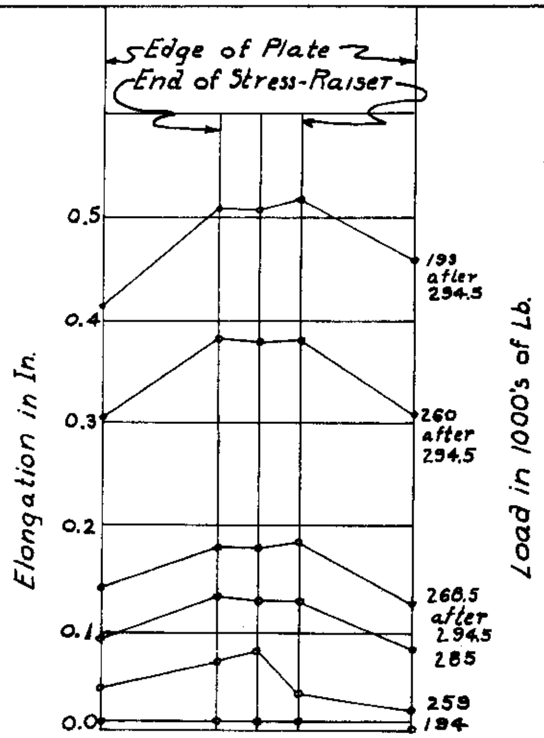
Strain Distribution Across 12-In. Plate
8⅝-In Gage Length Specimen 15-6B
Steel D Normalized



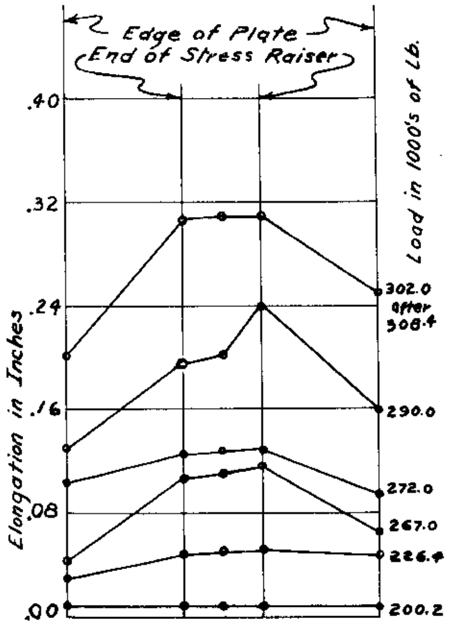
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length. Specimen 10-A4
Steel D Normalized.



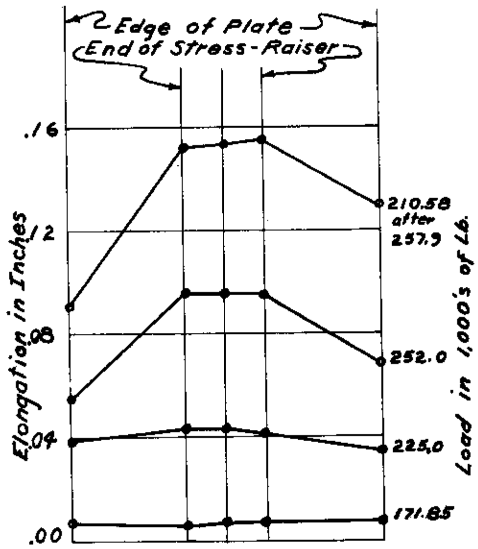
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length. Specimen 13A-10
Steel E As-Rolled



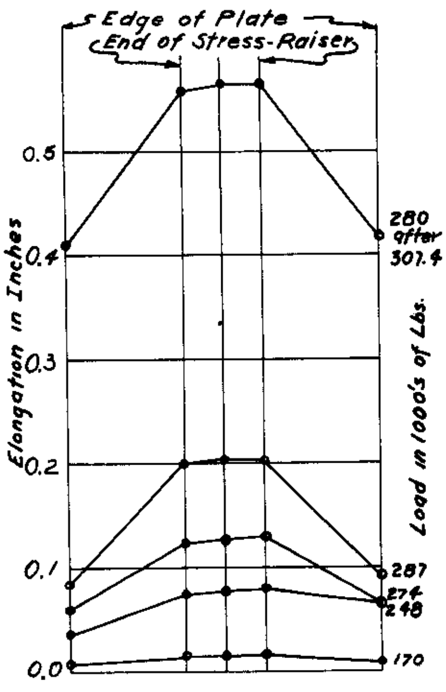
Strain Distribution Across 12-In. Plate
8⅝ In. Gage Length. Specimen 13A-9
Steel E As-Rolled



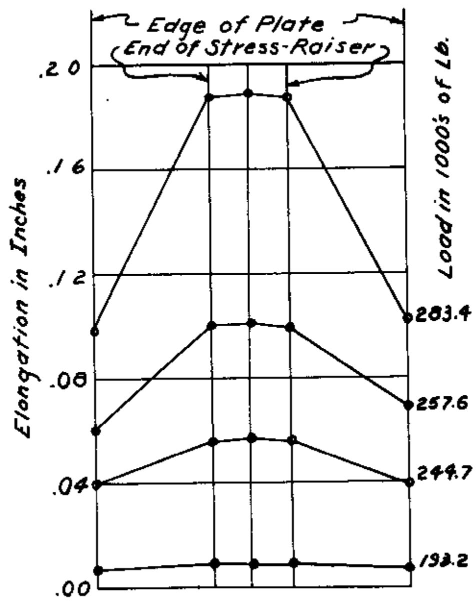
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length
Specimen 18-7B
Steel E As-Rolled



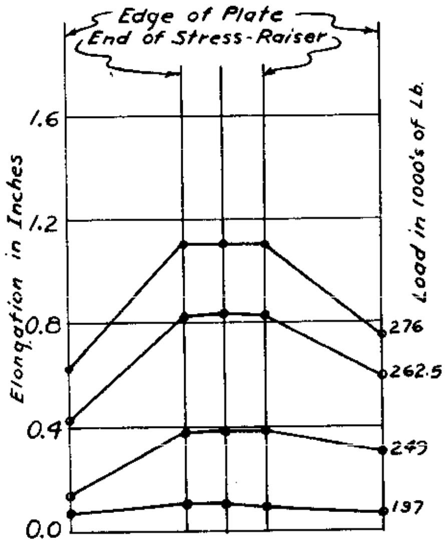
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length
Specimen 18-7A
Steel E As-Rolled



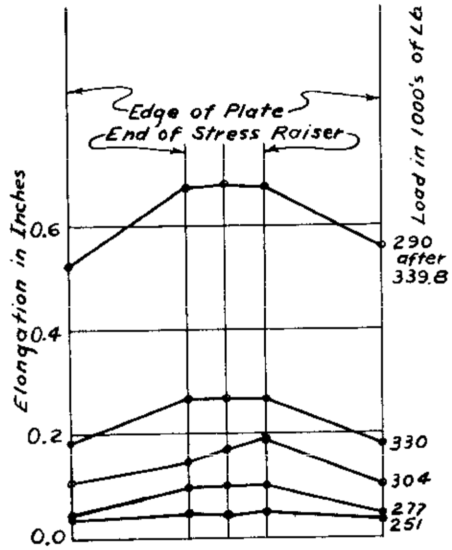
Strain Distribution Across 12-In Plate
8⅝-In Gage Length Specimen 17-13
Steel E Normalized



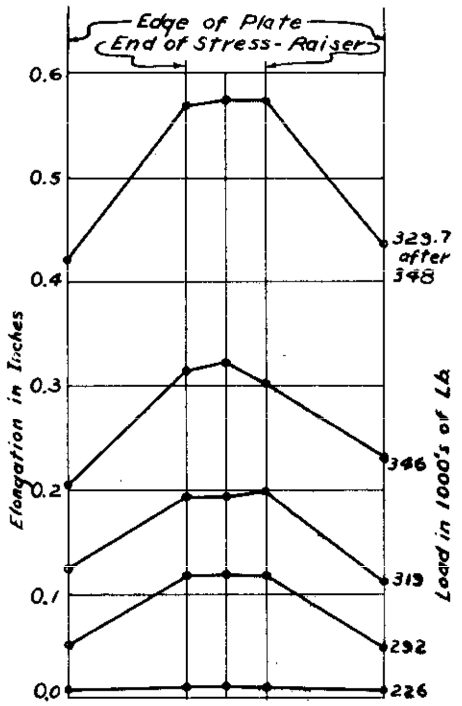
Strain Distribution Across 12-In. Plate
8⅝-In Gage Length Specimen 16-5
Steel E Normalized



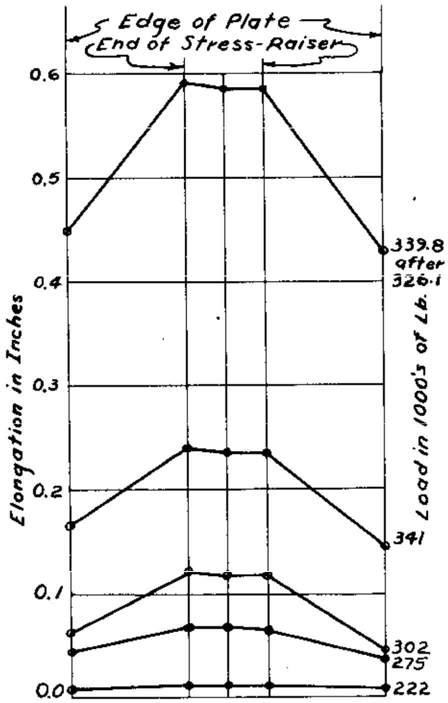
Strain Distribution Across 12-In Plate
8⅝-In. Gage Length Specimen 18 A-3
Steel E Normalized



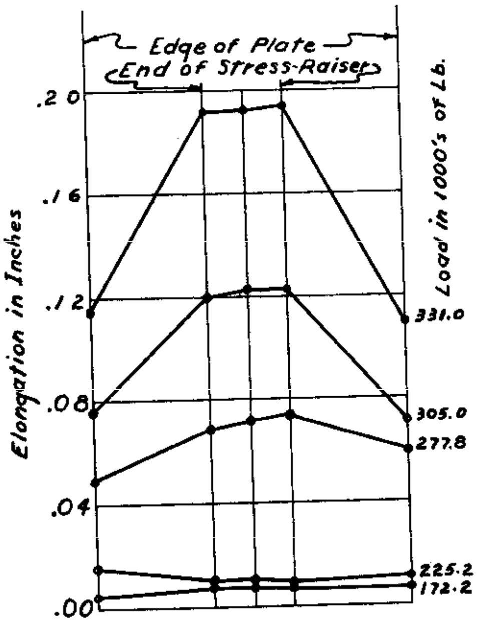
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length Specimen A-13
Steel F As rolled



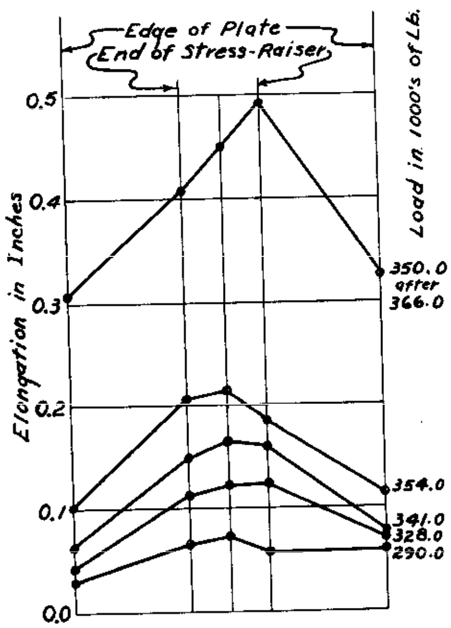
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length Specimen A-12
Steel F As-Rolled



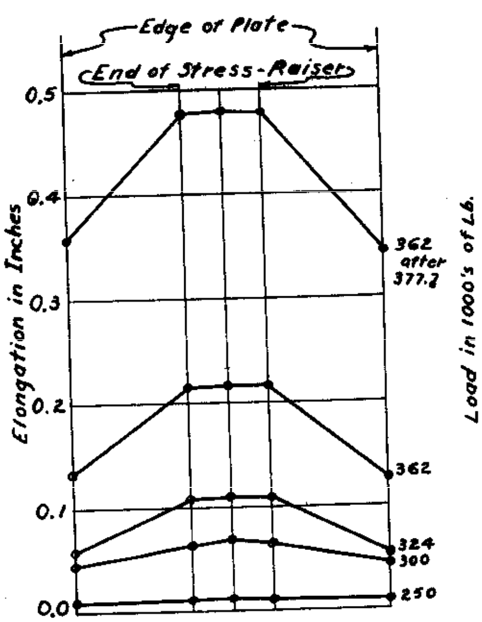
Strain Distribution Across 12 In. Plate
8⅝-In. Gage Length Specimen A-6
Steel F As-Rolled



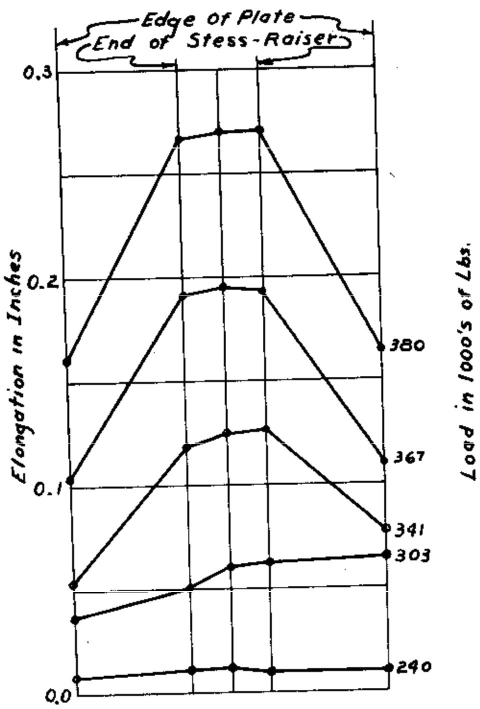
Strain Distribution Across 12-In. Plate
8⅝-In. Gage Length Specimen A-10
Steel F As-Rolled



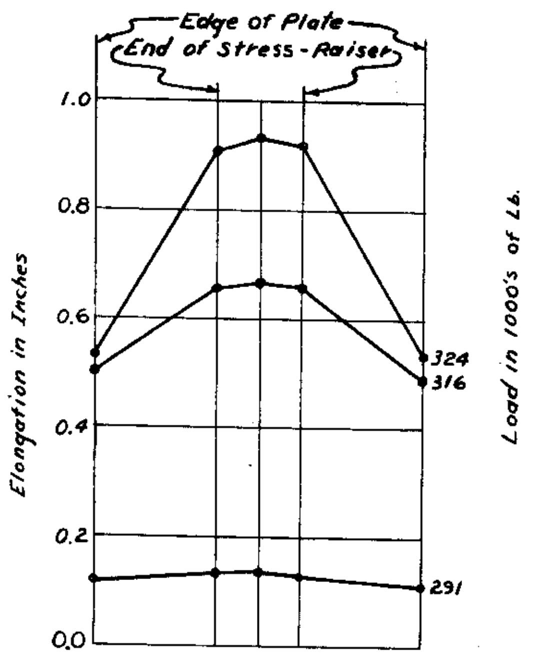
Strain Distribution Across 12-In Plate
8⅝ In. Gage Length Specimen B-10
Steel G As Rolled



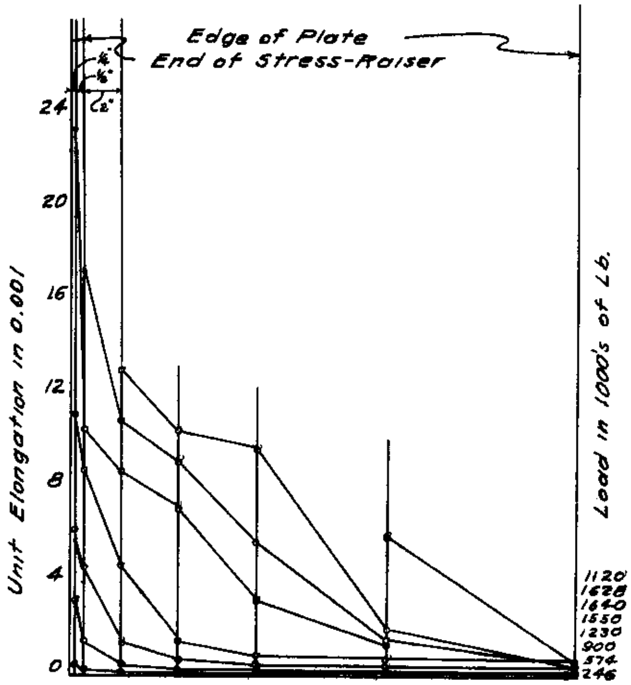
Strain Distribution Across 12-In. Plate
8⅝-In Gage Length Specimen B-5
Steel G As Rolled



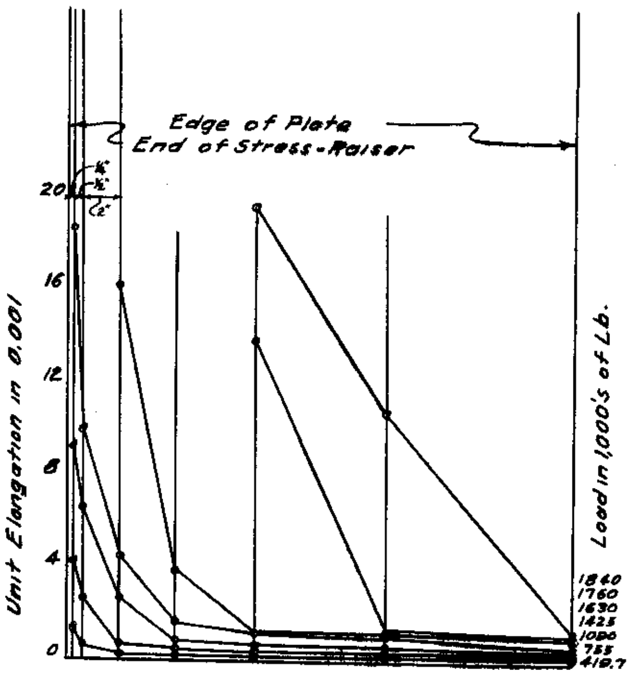
Strain Distribution Across 12-In Plate
8⅝ In Gage Length Specimen B-9
Steel G As Rolled



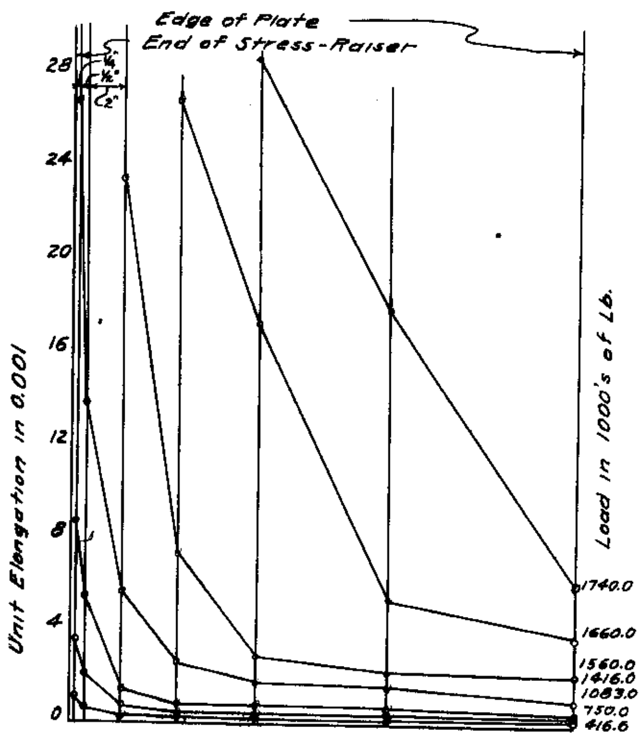
Strain Distribution Across 12-In. Plate
8⅝-In Gage Length Specimen B-6
Steel G As Rolled



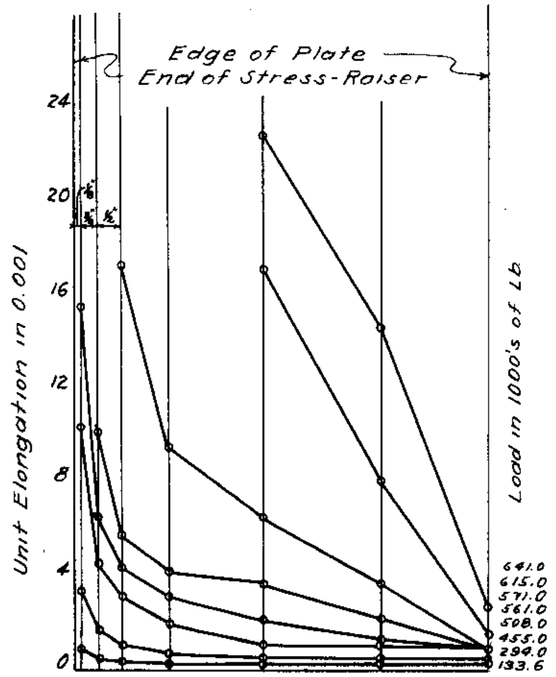
Strain Distribution Across Half of 72-In. Plate
from Electric Strain Gages
Specimen 18A-1
Steel D As-Rolled



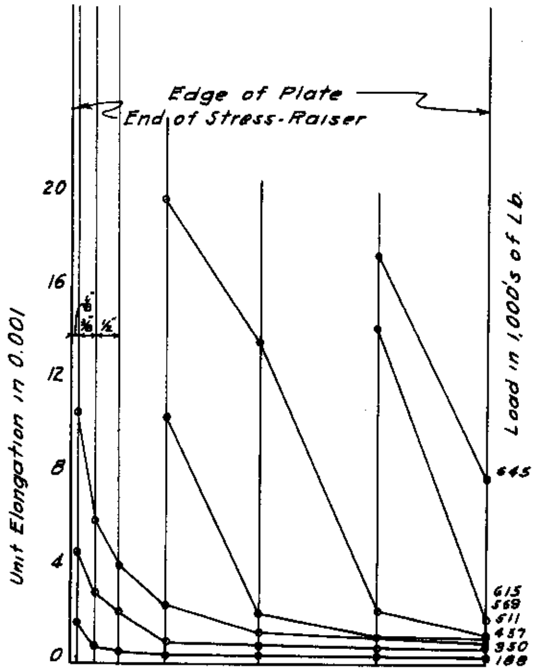
Strain Distribution Across Half of 72-In. Plate
from Electric Strain Gages Specimen 22-1
Steel D As-Rolled



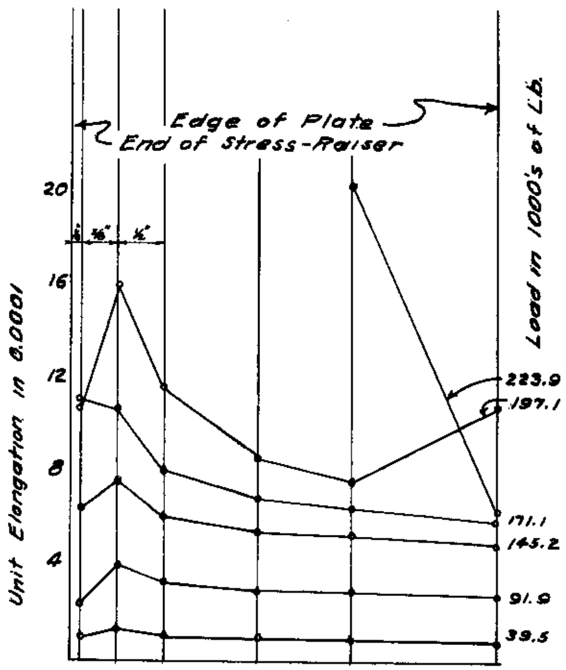
Strain Distribution Across Half of 72-In. Plate
from Electric Strain Gages
Specimen 12A-1
Steel D Normalized



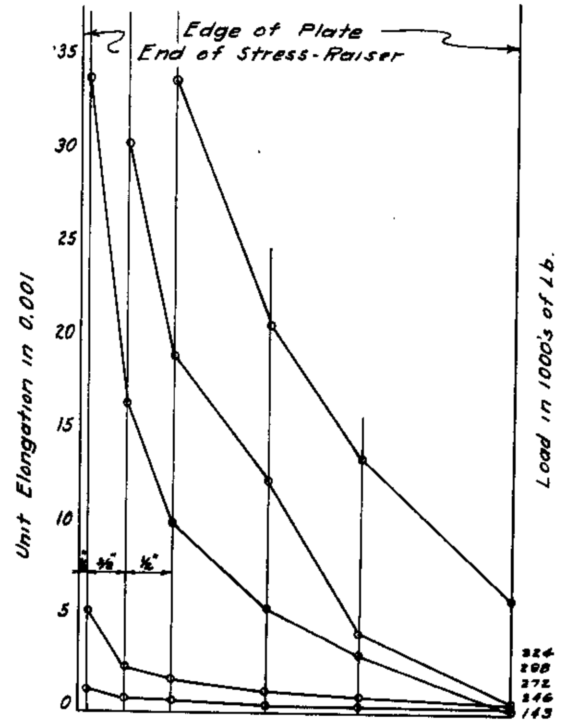
Strain Distribution Across Half of 24-In. Plate
Electric Strain Gages Specimen 18B-3
Steel D As-Rolled



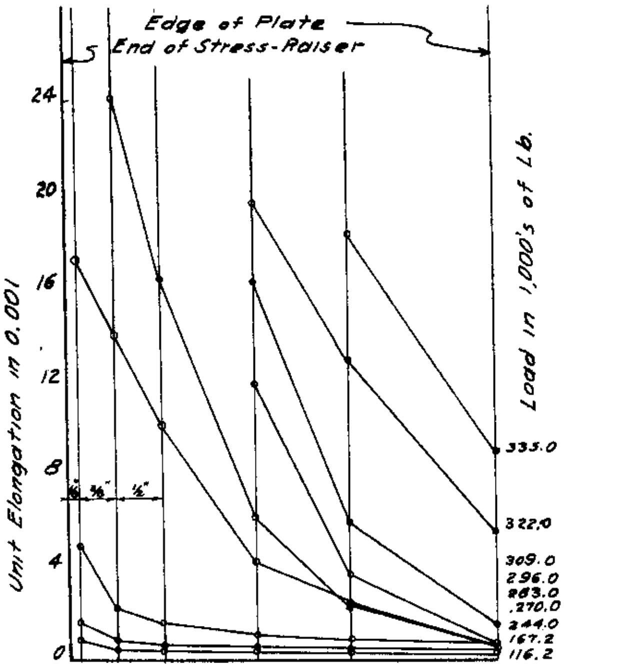
Strain Distribution Across Half of 24-In. Plate
Electric Strain Gages Specimen A-4
Steel F As-Rolled



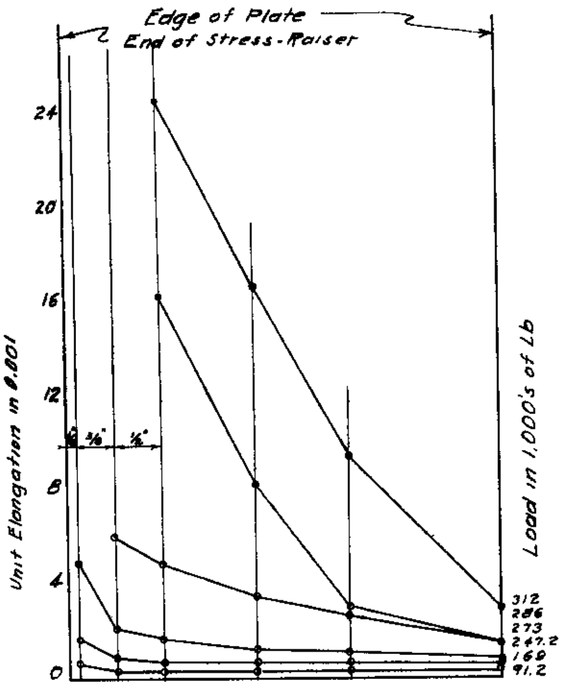
Strain Distribution Across Half of 12-In.
Plate from Electric Strain Gages
Specimen 18-9A
Steel E As-Rolled



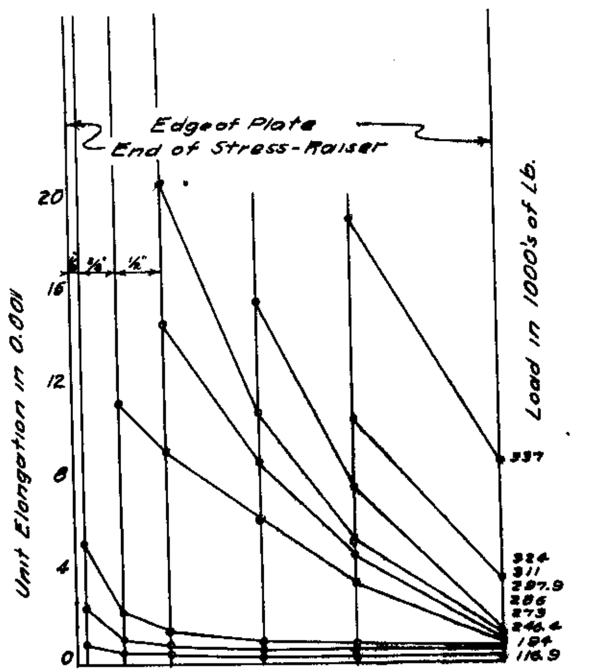
Strain Distribution Across Half of 12-In. Plate
from Electric Strain Gages Specimen 18A-5
Steel D As-Rolled



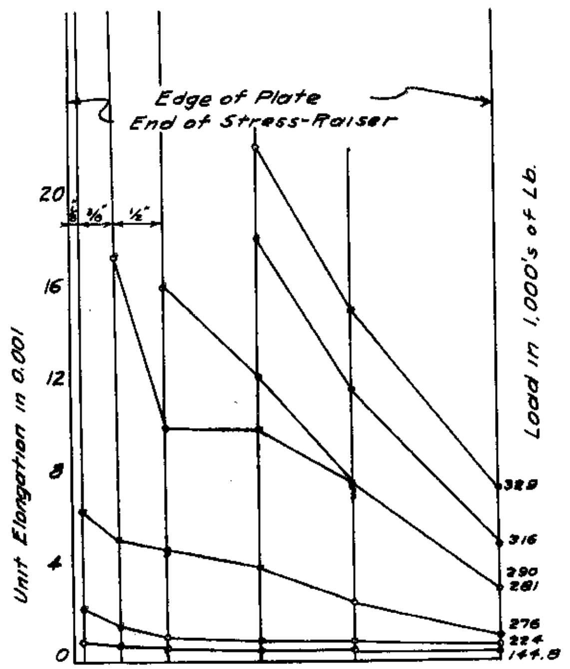
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 18A-3 Steel D As-Rolled



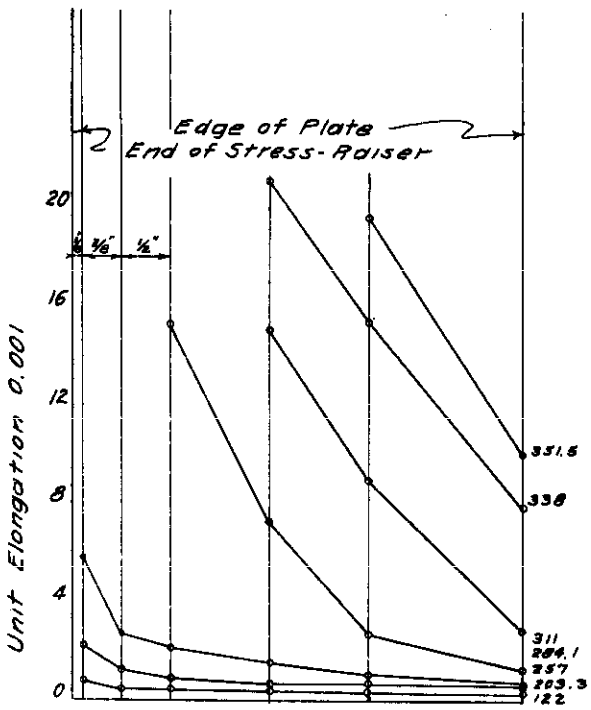
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 18B-2 Steel D As-Rolled



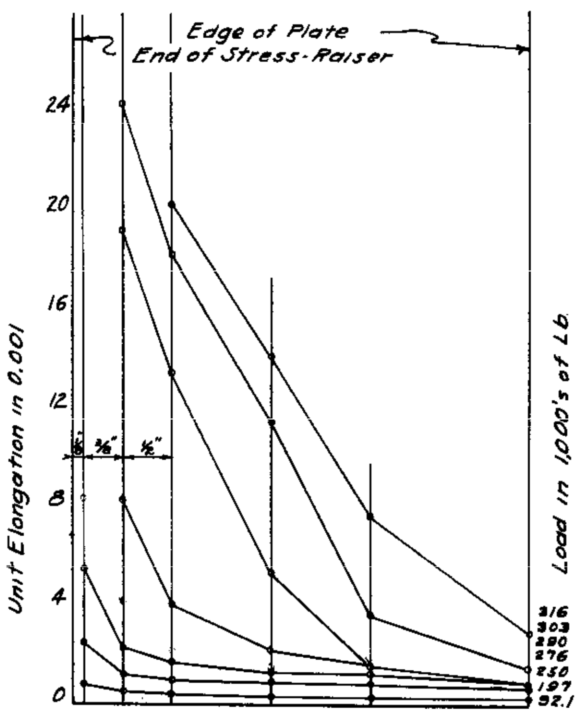
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 17-6B Steel D As-Rolled



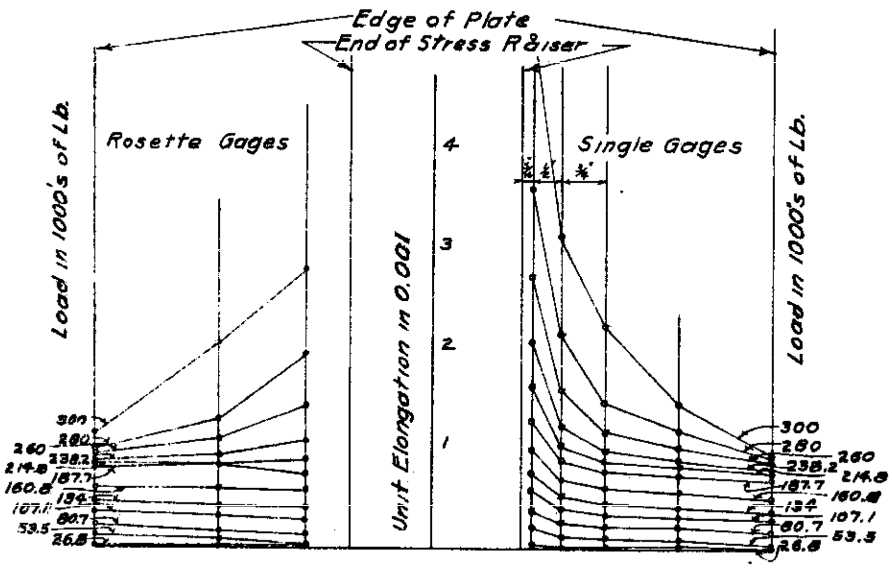
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 17-6A Steel D As-Rolled



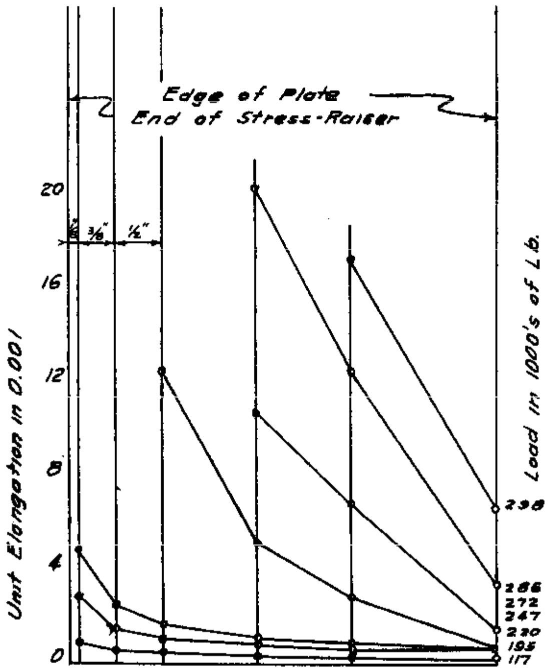
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 22A-2 Steel D As-Rolled



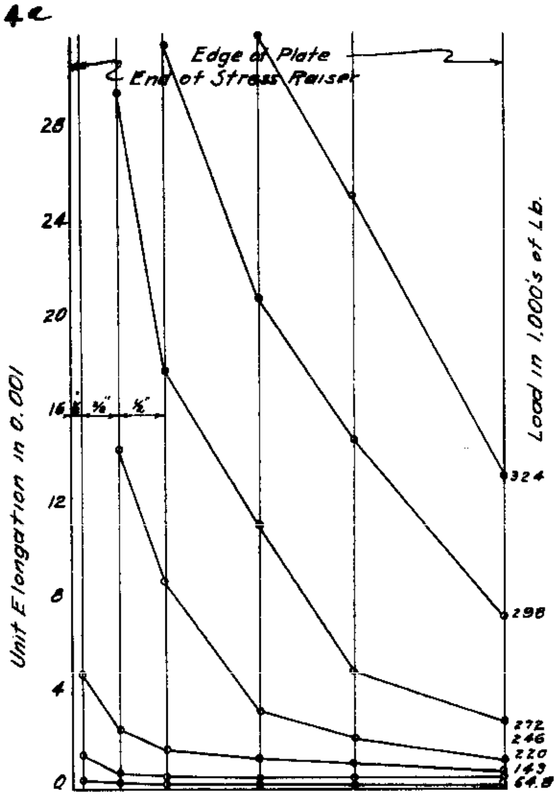
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 22B-2 Steel D As-Rolled



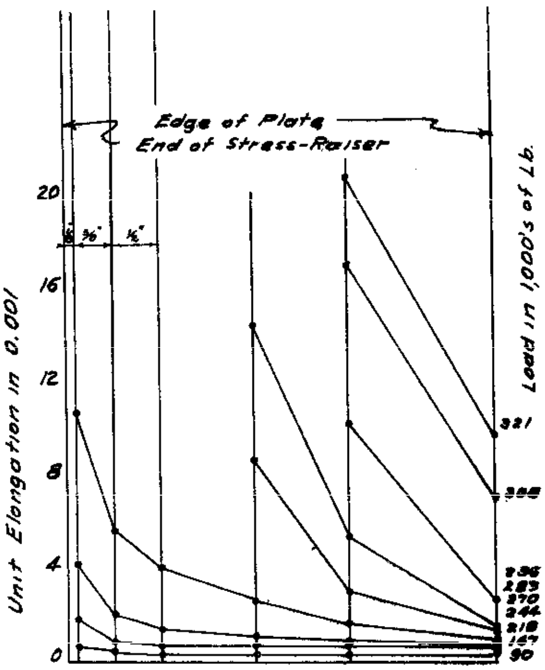
Strain Distribution Across Plate From Electric Gages Specimen 17A-5A



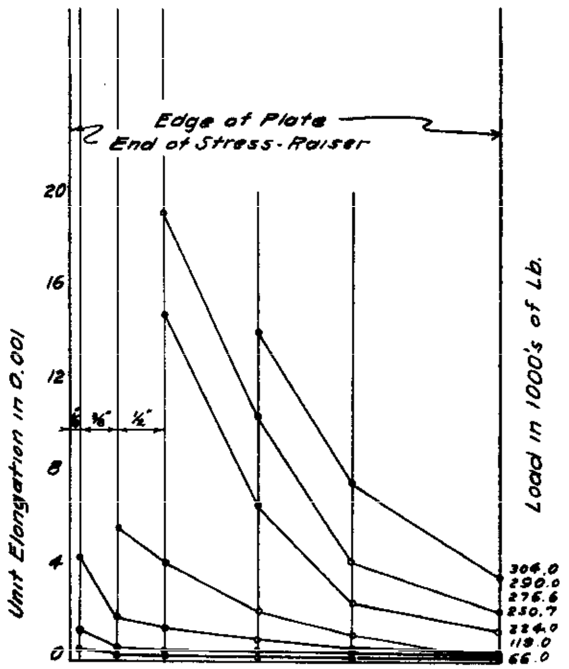
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 15-5A Steel D Normalized



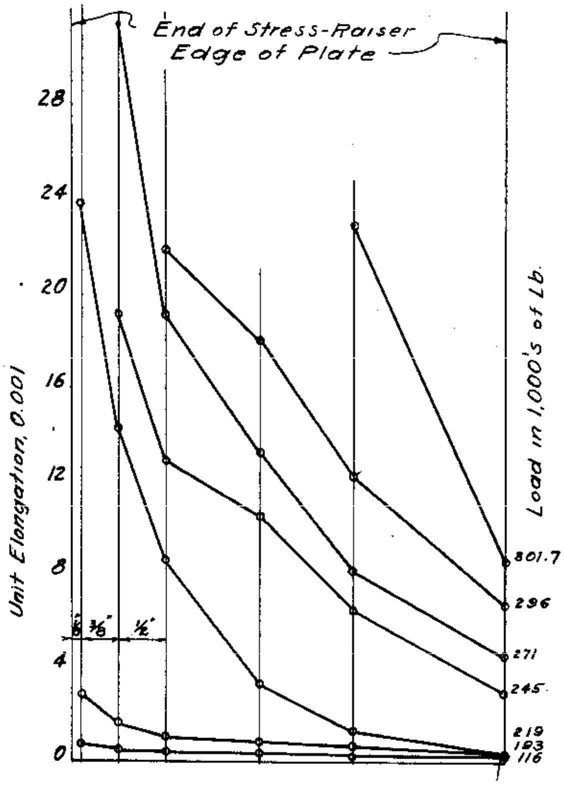
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 9-2 Steel D Normalized



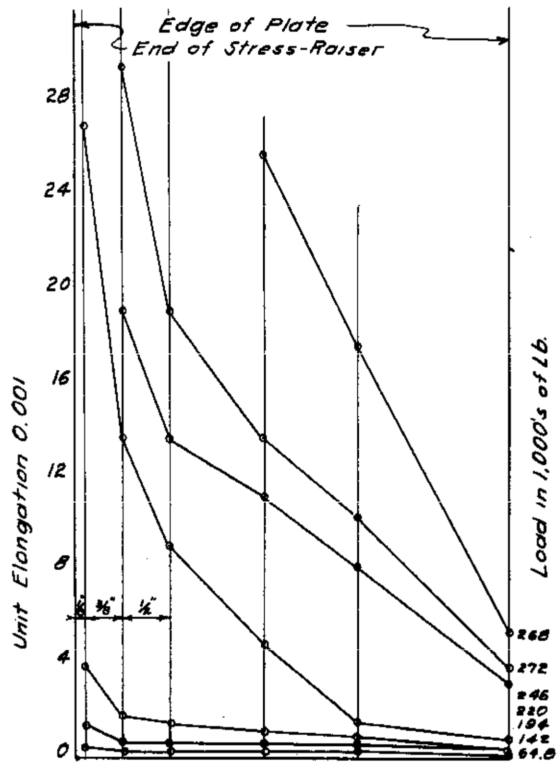
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 13-6B Steel D Normalized



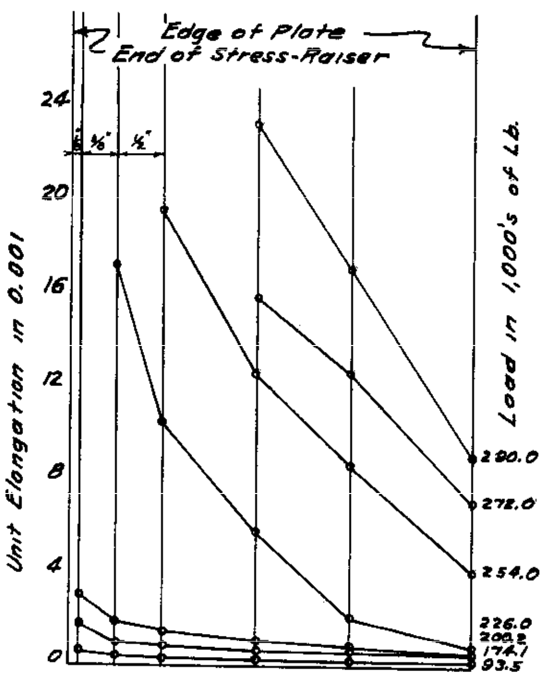
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages. Specimen 10A-4 Steel D Normalized



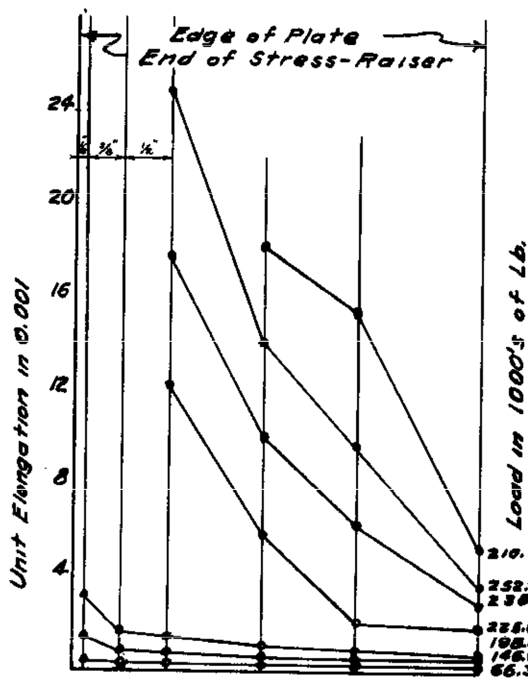
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 13A-10 Steel E As-Rolled Trans. to Direc. of Rolling



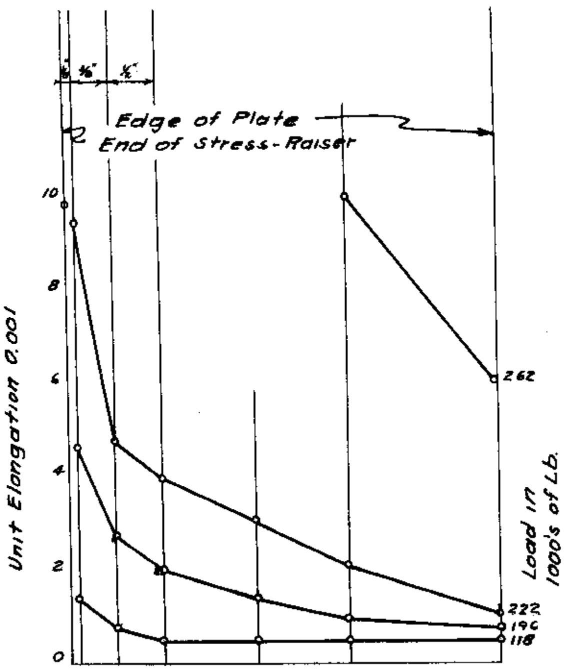
Strain Distribution Across Half of 12-In Plate from Electric Strain Gages Specimen 13A-9 Steel E As-Rolled Trans. to Direc. of Rolling



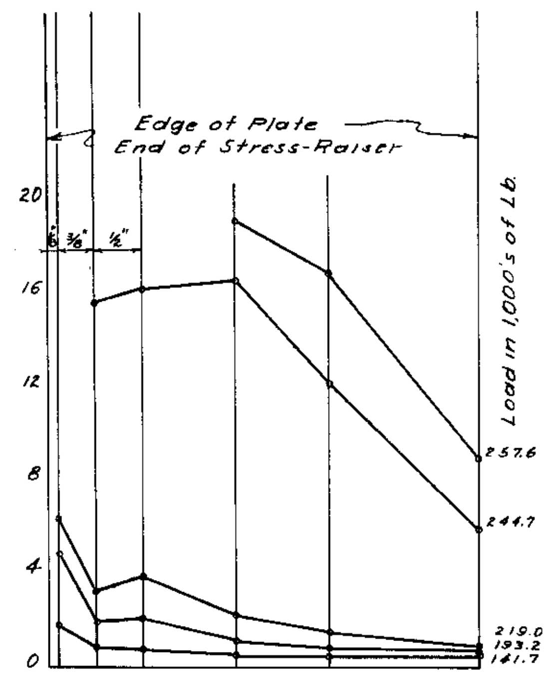
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 18-7B Steel E As-Rolled



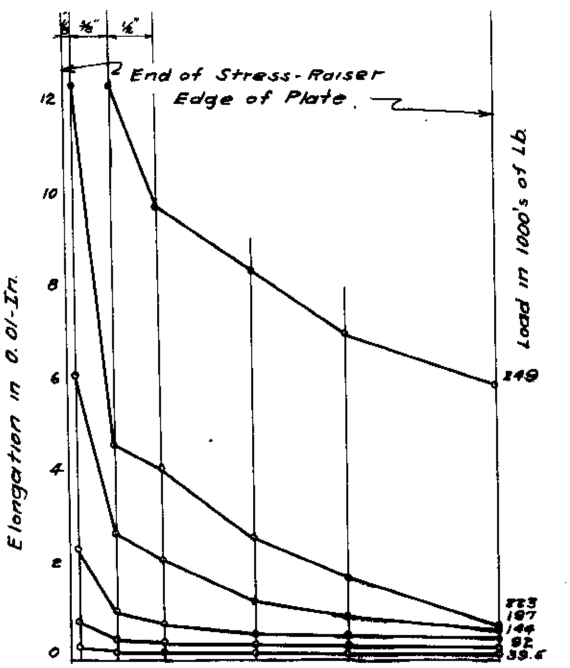
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 18-7A Steel E As-Rolled



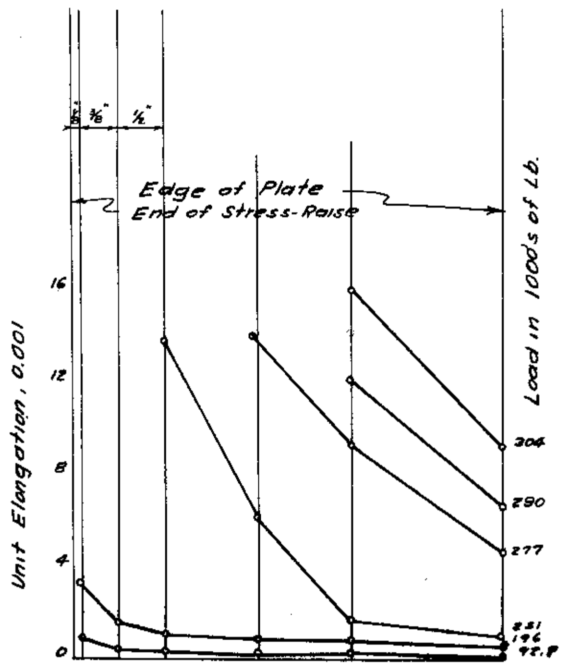
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 17-13 Steel E Normalized



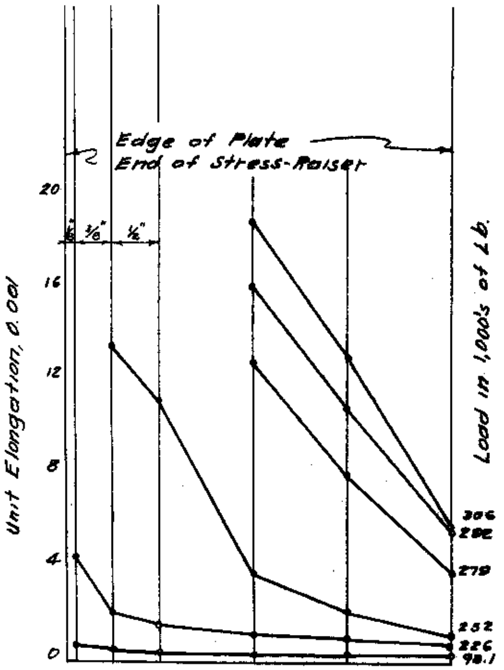
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen 16-5 Steel E Normalized



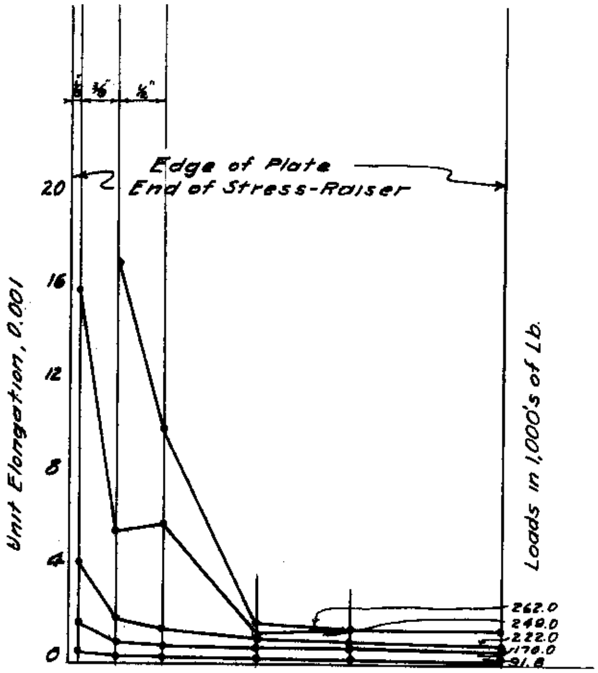
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages. Specimen 18A-3 Steel E Normalized



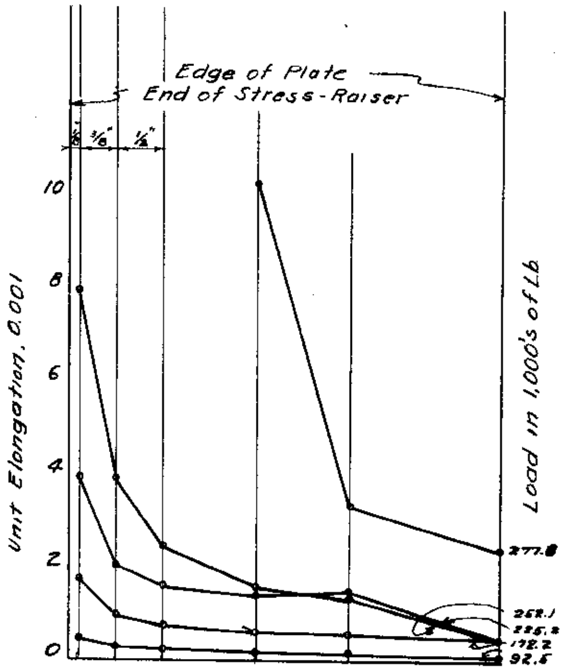
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen A-13 Steel F As-Rolled



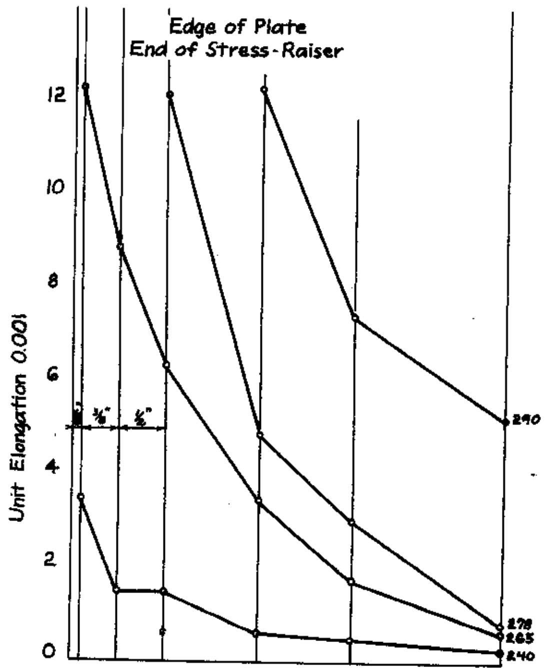
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages. Specimen A-12 Steel F As-Rolled



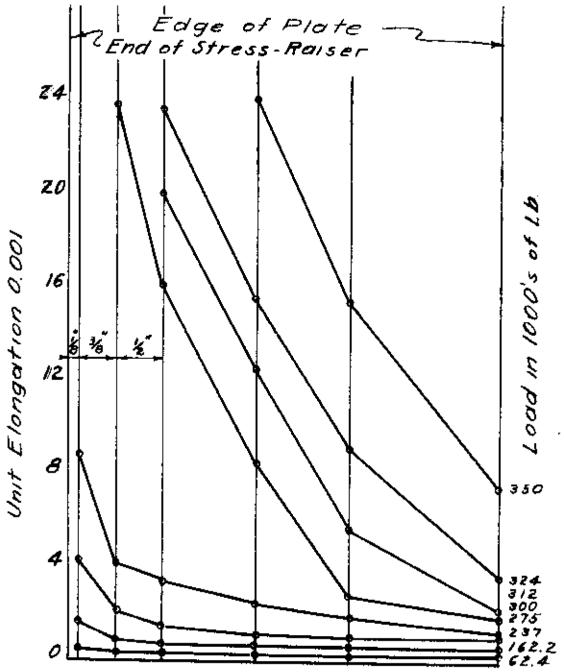
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen A-6 Steel F As-Rolled



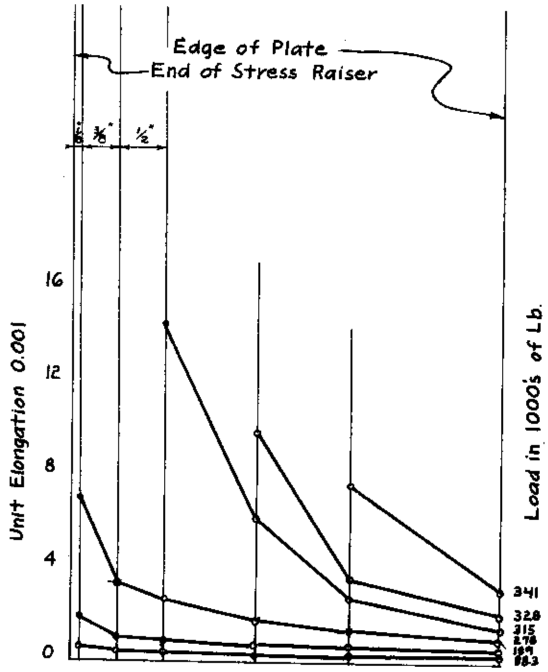
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages Specimen A-10 Steel F As-Rolled



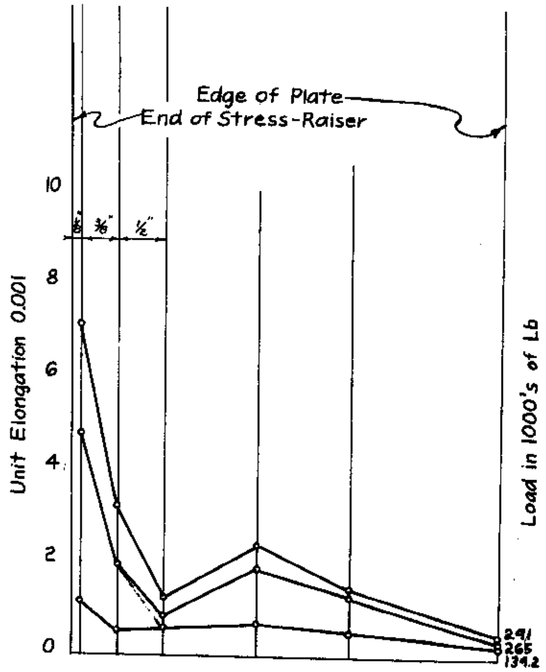
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages. Specimen B-10 Steel G As Rolled



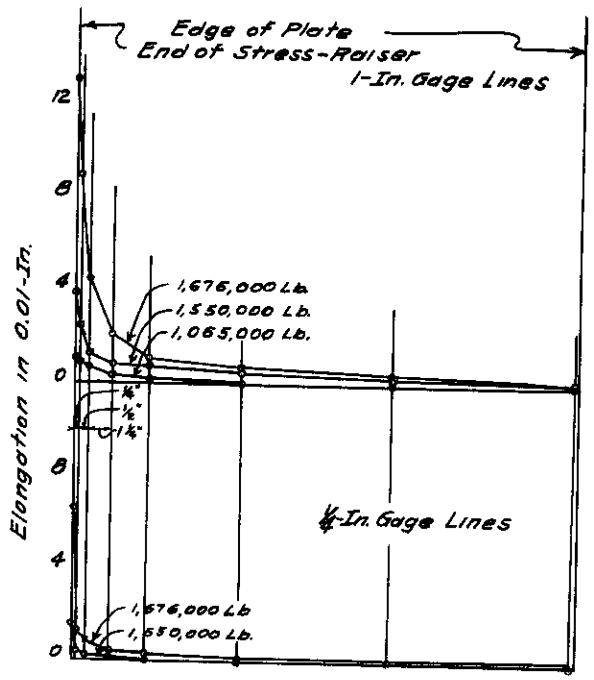
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages. Specimen B-5 Steel G. As-Rolled



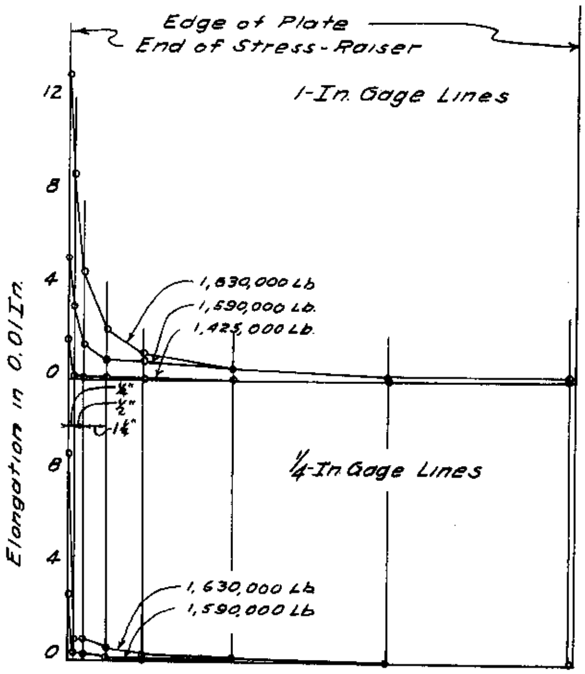
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages. Specimen B-9 Steel G As-Rolled



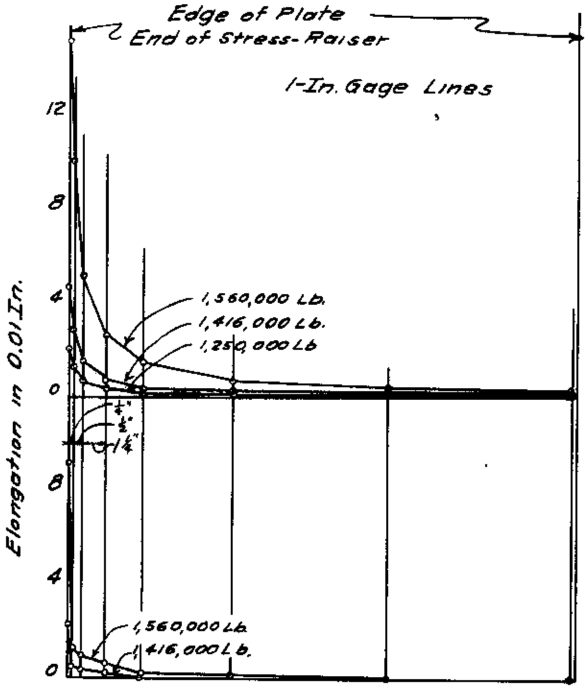
Strain Distribution Across Half of 12-In. Plate from Electric Strain Gages. Specimen B-6 Steel G As-Rolled



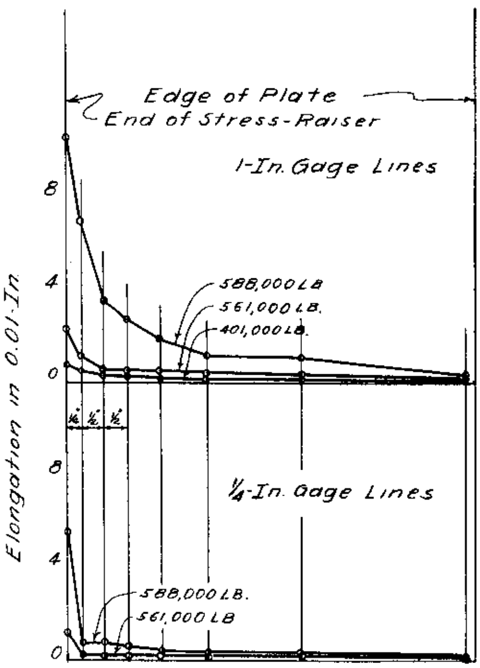
Strain Distribution Across Half of 72-In. Plate from 1/4-In. and 1-In. Gage Lines
Specimen 18A-1
Steel D As-Rolled



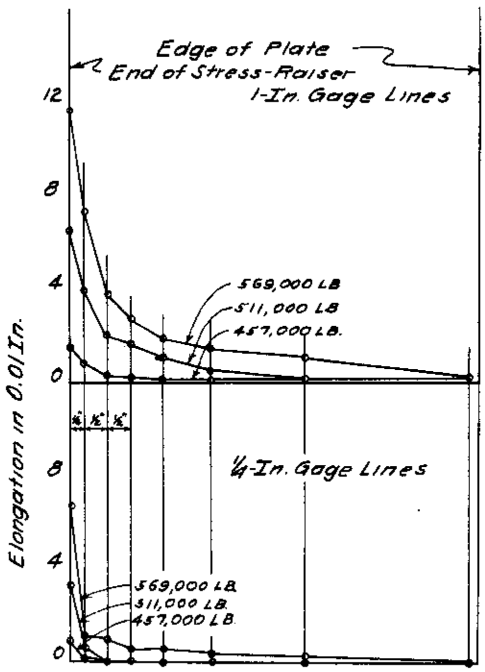
Strain Distribution Across Half of 72-In. Plate
from 1/4-In. and 1-In. Gage Lines
Specimen 22-1
Steel D As-Rolled



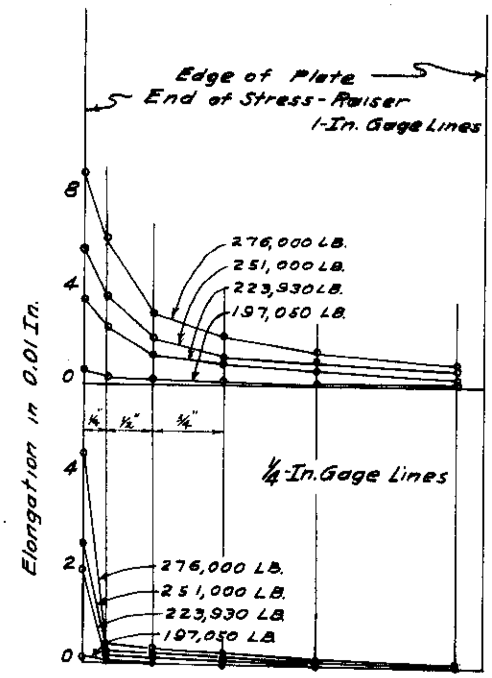
Strain Distribution Across Half of 72-In. Plate
from 1/4-In. and 1-In. Gage Lines
Specimen 12A-1
Steel D Normalized



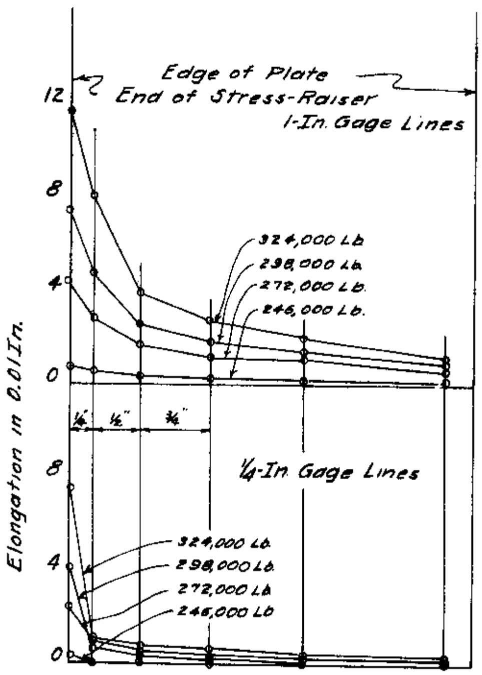
Strain Distribution Across Half of 24-In. Plate
1/4-In. and 1-In. Gage Lines Specimen 18B-3
Steel D As-Rolled



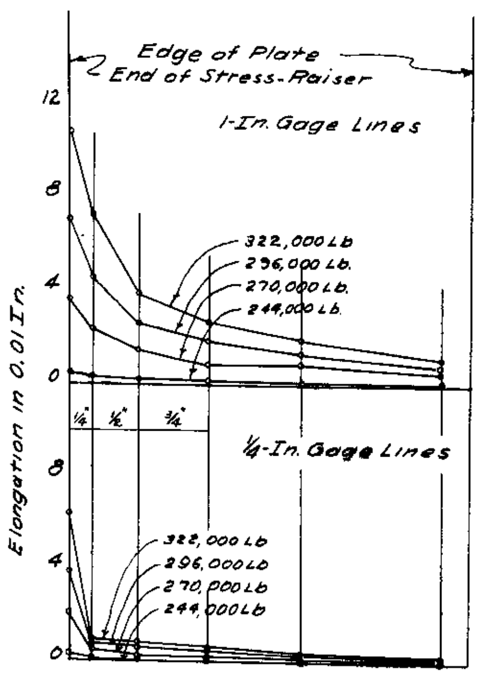
Strain Distribution Across Half of 24-In. Plate
1/4-In. and 1-In. Gage Lines Specimen A-4
Steel F As-Rolled



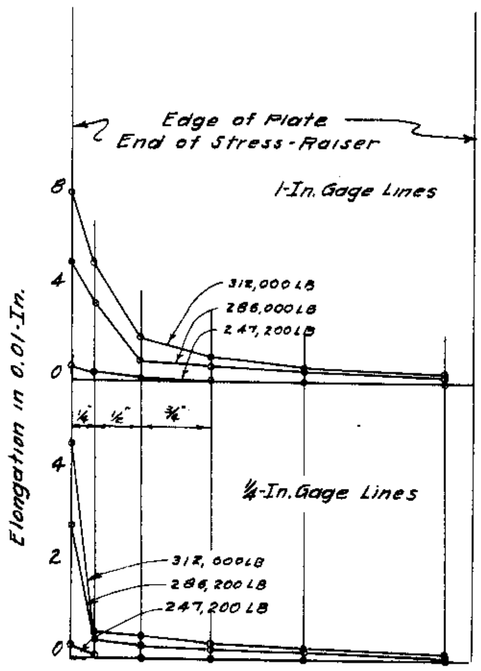
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 18-9A Steel E As-Rolled



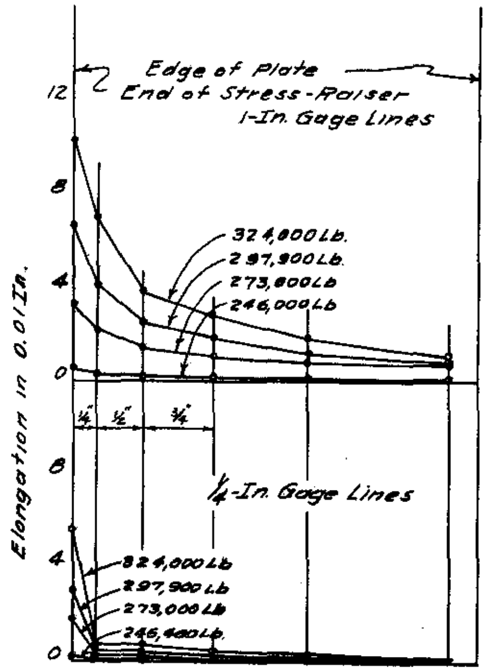
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 18A-5 Steel D As-Rolled.



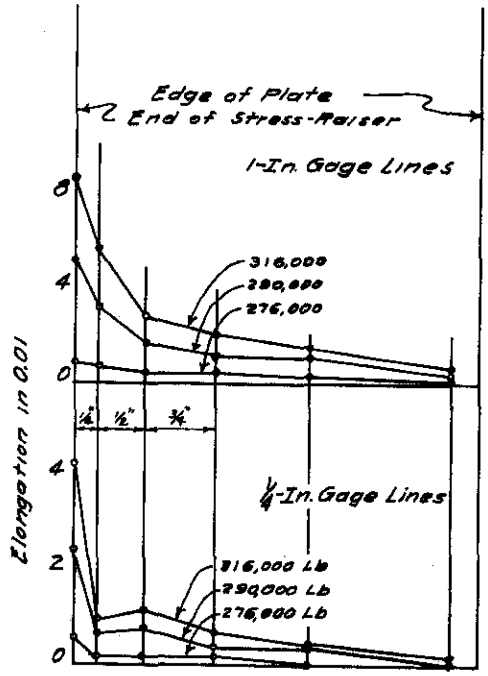
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 18A-3 Steel D As-Rolled



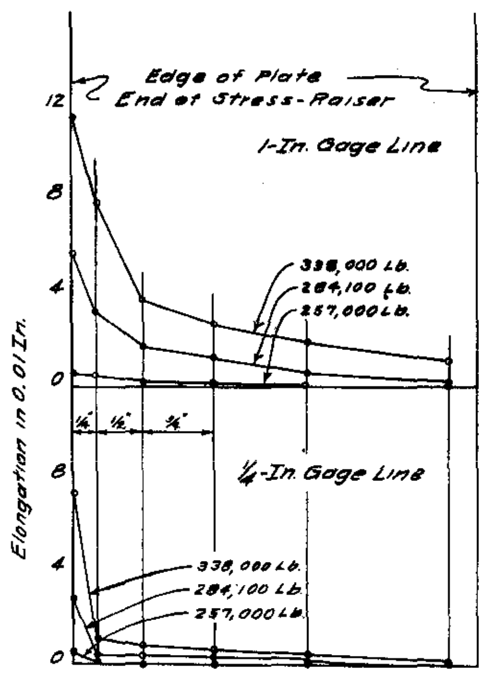
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 18B-2 Steel D As-Rolled



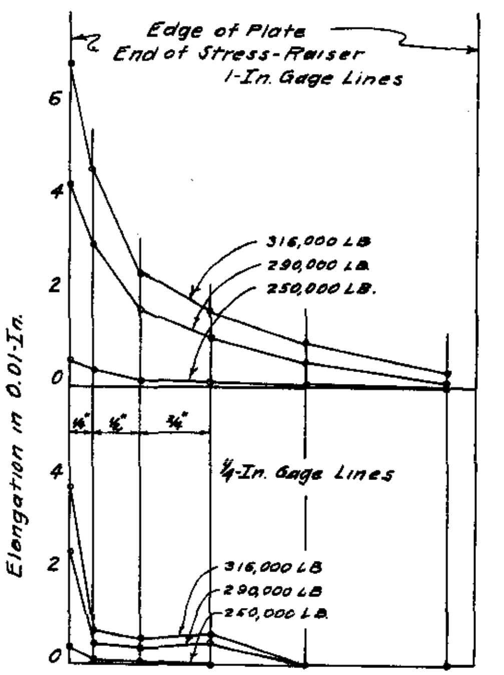
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 17-6B Steel D As-Rolled



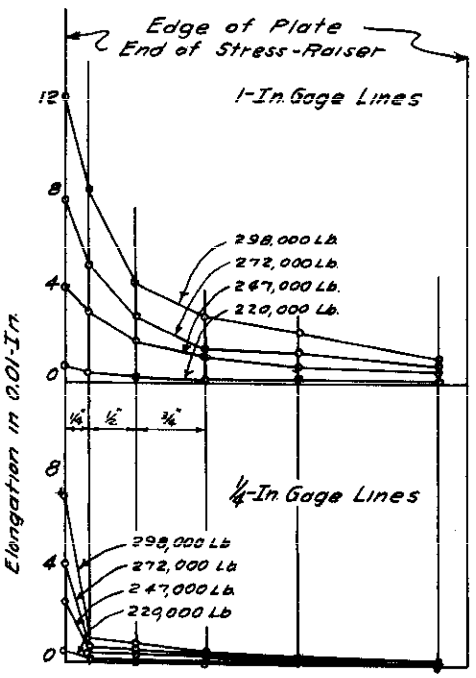
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 17-6A Steel D As-Rolled



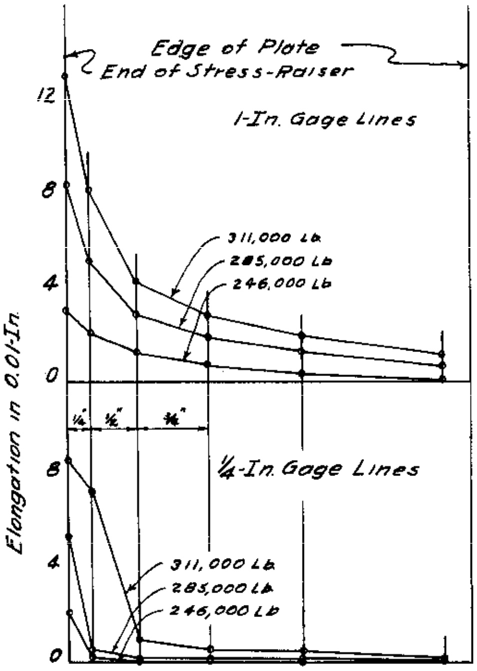
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 22A-2 Steel D As-Rolled



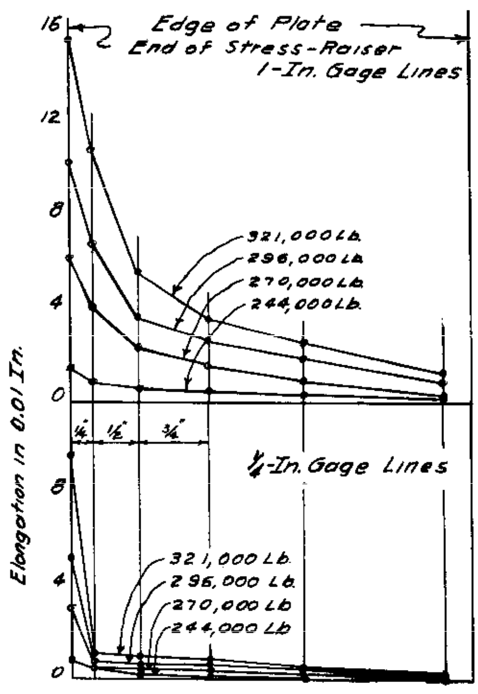
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 22B-2 Steel D As-Rolled



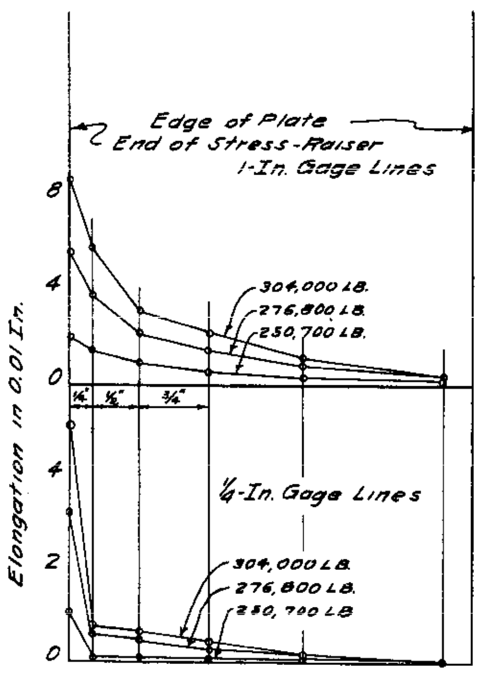
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 15-5A
Steel D Normalized



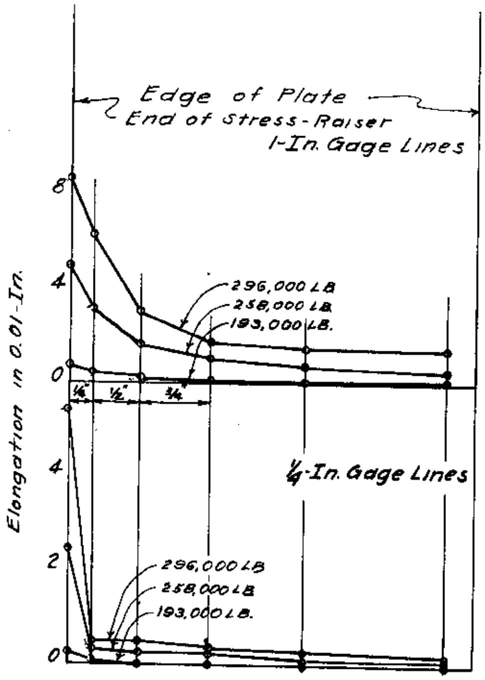
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 9-2
Steel D Normalized



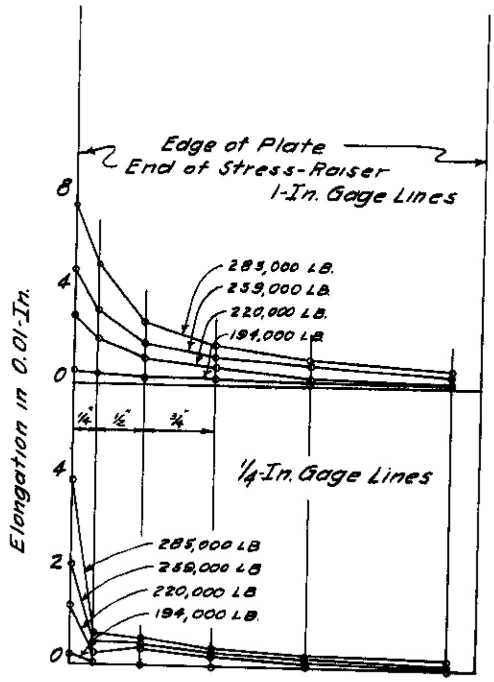
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines
Specimen 15-6B
Steel D Normalized



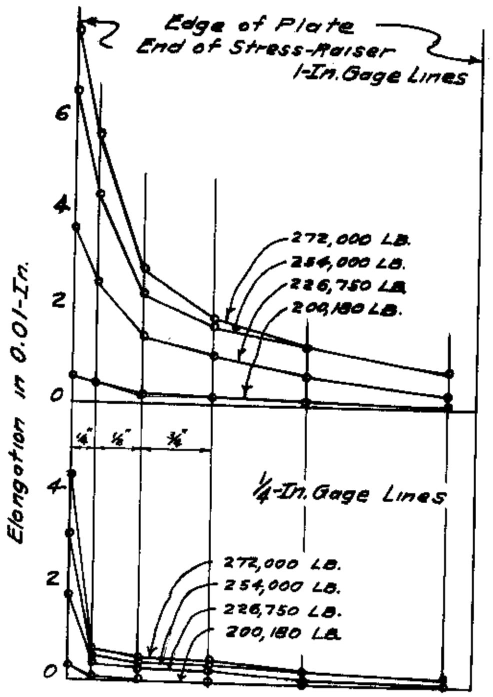
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 10A-4
Steel D Normalized



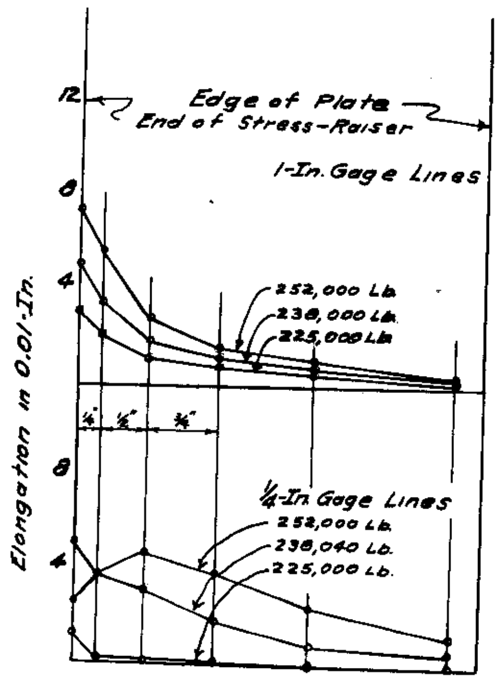
Strain Distribution Across Half of 12-In. Plate from 1/4 In. and 1-In. Gage Lines Specimen 13A-10 Steel E As-Rolled Trans. to Direc. of Rolling



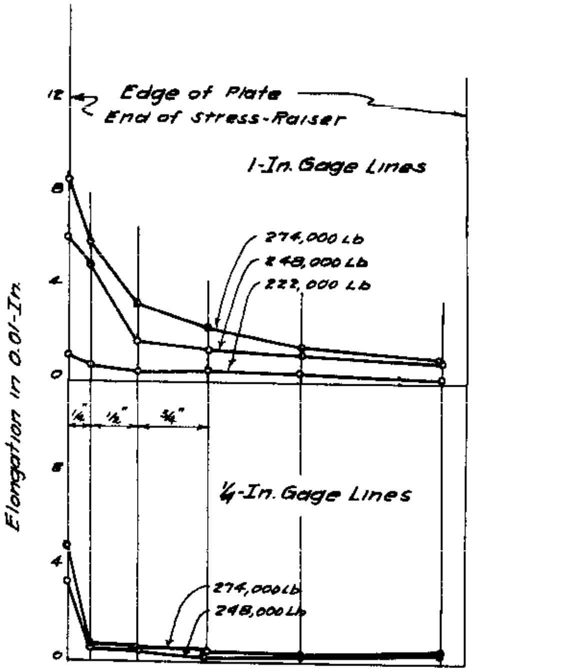
Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen 13A-9 Steel E As-Rolled Trans. Direc. Rolling



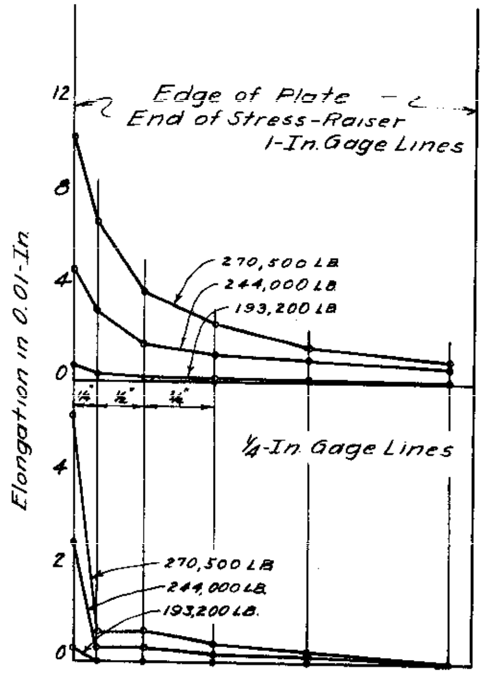
Strain Distribution Across Half of 12-In. Plate from 1-In. and 1/4-In. Gage Lines Specimen 18-7B Steel E As-Rolled



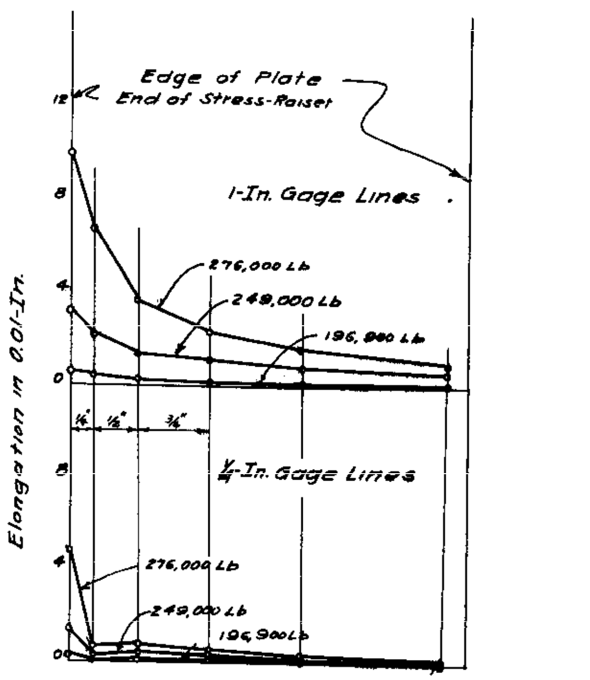
Strain Distribution Across Half of 12-In. Plate from 1-In. and 1/4-In. Gage Lines Specimen 18-7A Steel E As-Rolled



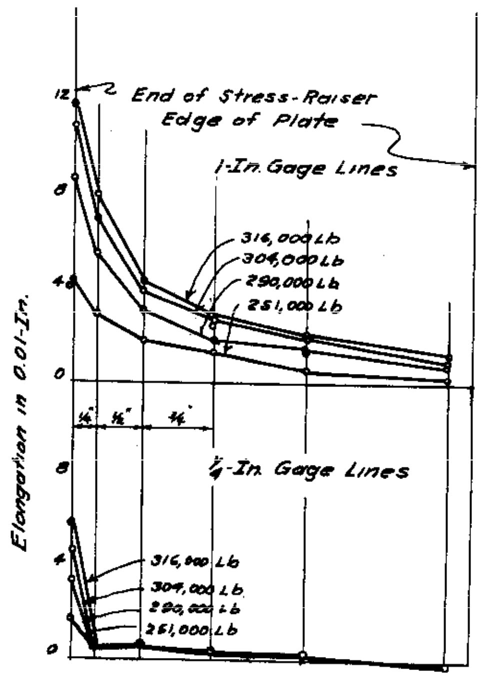
Strain Distribution Across Half of 12-In. Plate from ¼-In. and 1-In. Gage Lines. Specimen 17-13 Steel E Normalized



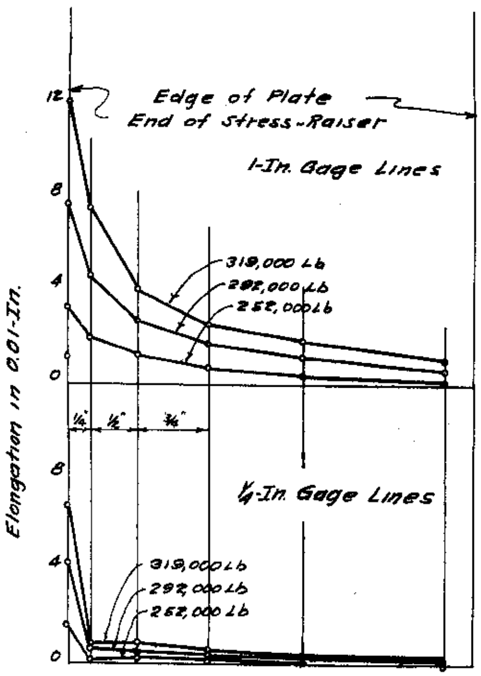
Strain Distribution Across Half of 12-In. Plate from ¼-In. and 1-In. Gage Lines Specimen 16-5 Steel E Normalized



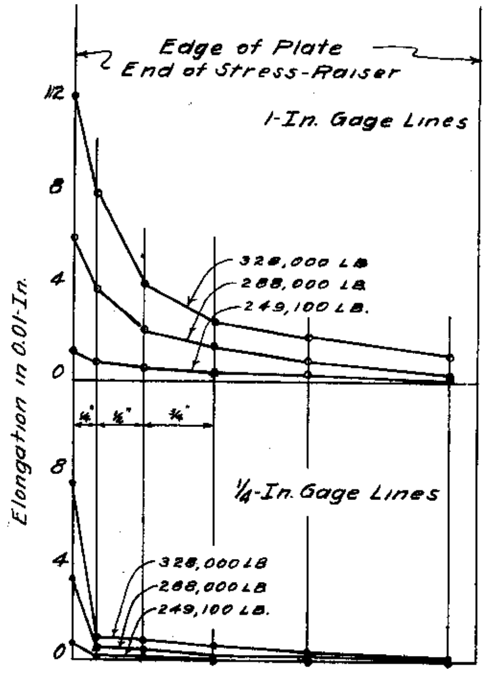
Strain Distribution Across Half of 12-In. Plate ~~from ¼-In. and~~ 1-In. Gage Lines Specimen 18A-3 Steel E Normalized



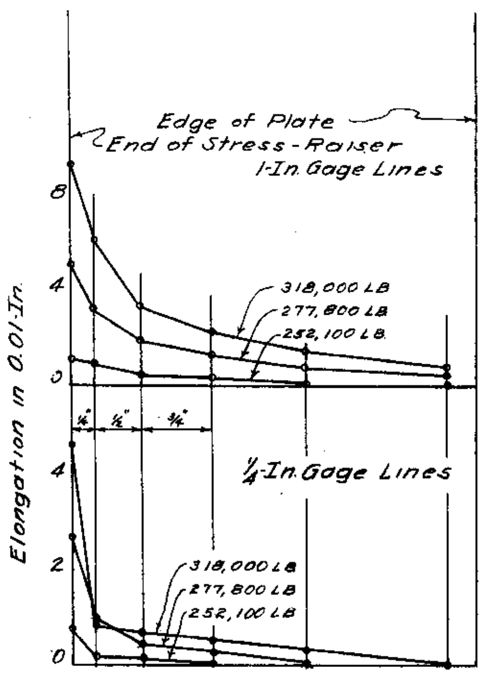
Strain Distribution Across Half of 12-In. Plate from ¼-In. and 1-In. Gage Lines Specimen A-13 Steel F As-Rolled



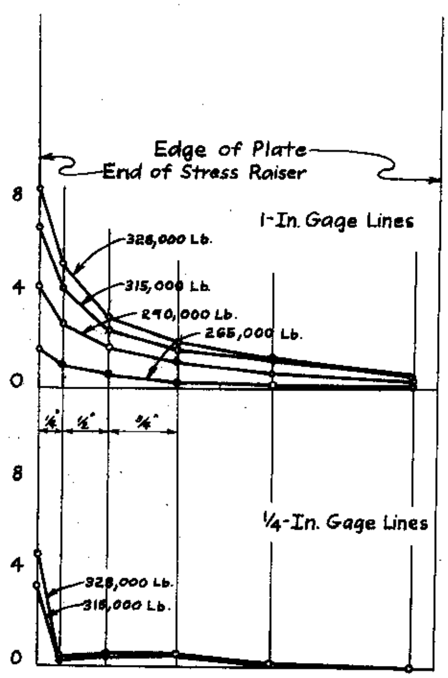
Strain Distribution Across Half of 12-In. Plate from ¼-In. and 1-In. Gage Lines Specimen A-12 Steel F As-Rolled



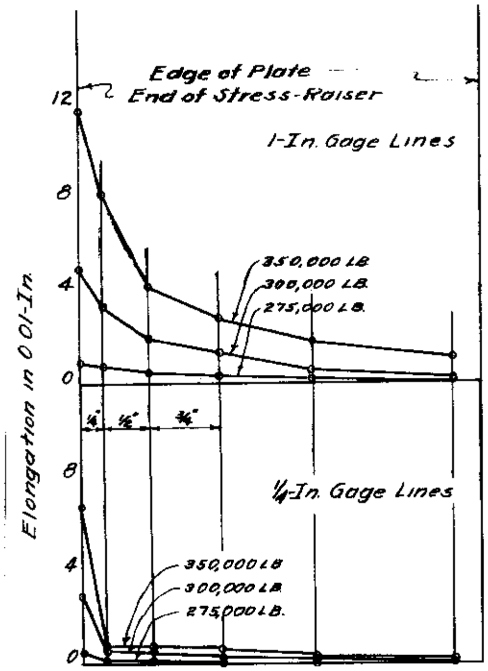
Strain Distribution Across Half of 12-In. Plate from ¼-In. and 1-In. Gage Lines Specimen A-6 Steel F As-Rolled



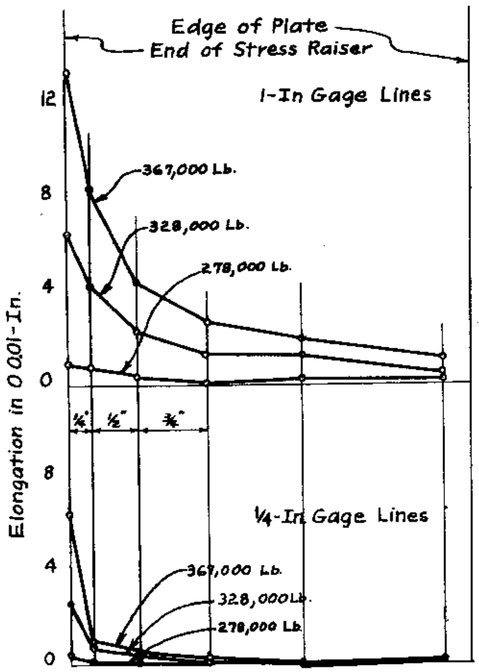
Strain Distribution Across Half of 12-In. Plate from ¼-In. and 1-In. Gage Lines Specimen A-10 Steel F As-Rolled



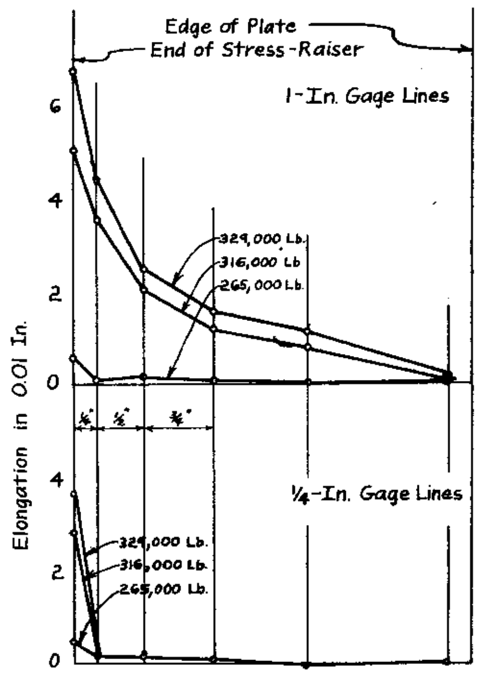
Strain Distribution Across Half of 12-In. Plate from ¼-In and 1 In. Gage Lines Specimen B-10 Steel G As-Rolled



Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In. Gage Lines Specimen B-5 Steel G As-Rolled



Strain Distribution Across Half of 12-In. Plate from 1/4-In. and 1-In Gage Lines Specimen B-9 Steel G As-Rolled

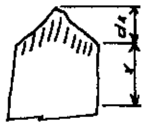


Strain Distribution Across Half of 12-In. Plate from 1/4-In and 1 In. Gage Lines Specimen B-6 Steel G As Rolled

36a

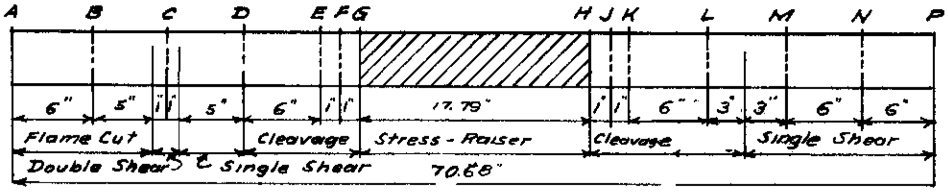
Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dX
A	← Flame Cut			→	.764	.763	.762	.761	0
B	← Flame Cut			→	.745	.745	.745	.744	0
C	.667	.671	.671	.667	.667	.672	.698	.711	0
D	.689	.704	.714	.727	.734	.739	.744	—	1/2"
E	.724	.727	.728	.730	.731	.734	.739	.741	0
F	.703	.707	.705	.712	.716	.723	.737	.746	0
G	.698	.702	.712	.731	.738	.745	.749	.751	0
H	.693	.681 +	.720	.733	.741	.746	.750	.752	0
J	.701	.707	.709	.712	.716	.723	.737	.746	0
K	.719	.730	.731	.732	.736	.735	.736	.742	0
L	.697	.735	.744	.748	.748	.749	.752	.753	0
M	.642	.657	.665	.678	.686	.698	.714	—	11/16"
N	.625	.636	.643	.653	.662	.672	.689	—	11/16"
P	.645	.652	.657	.661	.663	.668	.676	.683	9/16"

Sketch A
Profile of Sec. C



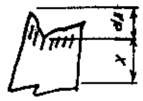
Sketch B
Profile of Secs. M, N, P, D

Sketch C
Profile of Secs. E, F, G, H, J, K, L



Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 18A-1 Steel D As-Rolled

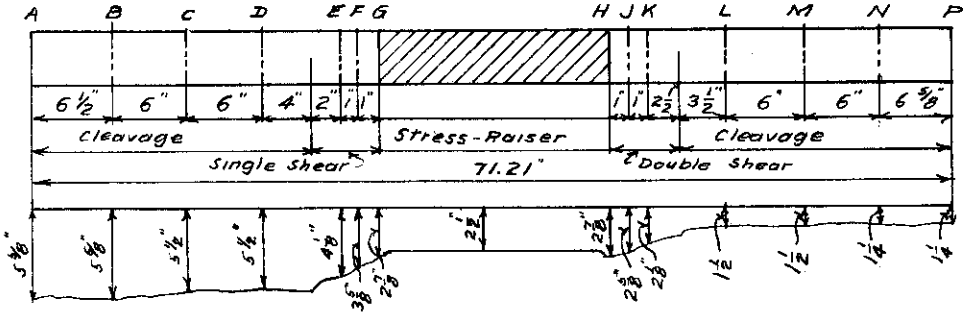
Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dX
A	.751	.753	.755	.756	.756	.756	.758	.759	0
B	.744	.750	.751	.753	.755	.756	.758	.759	0
C	.741	.744	.746	.748	.749	.751	.753	.754	0
D	.728	.728	.729	.731	.732	.724	.735	.736	0
E	.647	.650	.654	.662	.674	.694	.725	.723	11/32"
F	.660	.663	.666	.678	.691	.715	.742	.749	3/8"
G	.705	.710	.720	.744	.754	.761	.765	.767	3/32"
H	.695	.715	.731	.747	.757	.764	.766	.768	1/8"
J	.663	.666	.668	.678	.692	.717	.741	.750	11/32"
K	.642	.650	.654	.662	.680	.698	.728	.728	5/16"
L	.723	.725	.727	.728	.730	.731	.734	.737	0
M	.740	.742	.742	.746	.747	.750	.752	.753	0
N	.747	.751	.753	.755	.757	.759	.759	.760	0
P	.754	.756	.757	.758	.759	.759	.761	.761	0



Sketch A
Profile of Secs. H, J, K

Sketch B
Profile of Secs. E, F, G

Sketch C
Profile of Secs. A, B, C, D, L, M, N, P

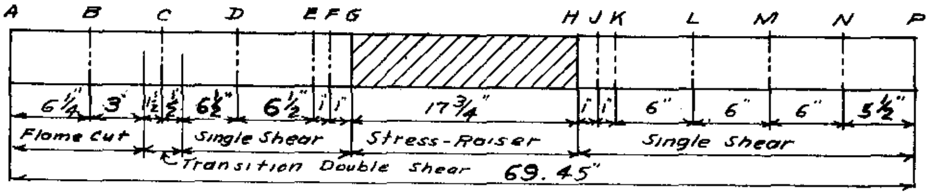


Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 22-1 Steel D As-Rolled

Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	← Flame Cut			→	.751	.750	.749	.746	0
B	← Flame Cut			→	.745	.743	.742	.740	0
C	.580	.603	.623	.647	.660	.672	.687	—	15/32"
D	.620	.641	.649	.663	.673	.683	.703	—	11/16"
E	.650	.675	.684	.700	.710	.724	.741	—	23/32"
F	.669	.694	.702	.716	.726	.739	.754	—	23/32"
G	.716	.741	.746	.755	.760	.766	.768	.769	9/32"
H	.755	.754	.750	.761	.765	.768	.769	.769	1/4"
J	.673	.698	.707	.720	.731	.743	.756	—	5/8"
K	.649	.673	.682	.703	.713	.724	.742	—	11/16"
L	.614	.641	.649	.663	.673	.686	.705	—	5/8"
M	.660	.635	.649	.655	.665	.675	.693	—	11/16"
N	.603	.633	.642	.654	.663	.673	.690	—	11/16"
P	.614	.634	.640	.649	.653	.657	.668	.675	13/32"

Sketch A
Profile of Sec. C

Sketch B
Profile of Secs. D, E, F, G, H, J, K, L, M, N, P

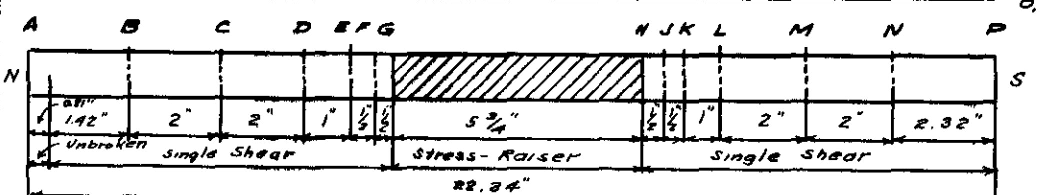


Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 12 A-1 Steel D Normalized

Sec	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.664	0.672	0.681	0.692	0.698	0.699	0.700	0.707	1/4"
B	0.644	0.696	0.662	0.672	0.680	0.691	0.707	—	3/4"
C	0.648	0.658	0.665	0.676	0.685	0.697	0.715	—	25/32"
D	0.656	0.671	0.680	0.693	0.703	0.715	0.731	—	3/4"
E	0.679	0.693	0.701	0.713	0.723	0.734	0.746	—	23/32"
F	0.688	0.704	0.713	0.727	0.736	0.746	0.752	—	9/16"
G	0.725	0.737	0.742	0.749	0.752	0.755	0.755	0.756	0
H	0.724	0.745	0.752	0.749	0.753	0.755	0.756	0.756	0
J	0.694	0.709	0.716	0.730	0.738	0.747	0.753	—	9/16"
K	0.684	0.696	0.703	0.715	0.724	0.735	0.749	—	23/32"
L	0.667	0.676	0.684	0.697	0.707	0.717	0.734	—	3/4"
M	0.646	0.659	0.666	0.678	0.686	0.698	0.715	—	3/4"
N	0.646	0.658	0.664	0.674	0.683	0.693	0.709	—	13/16"
P	0.672	0.677	0.683	0.688	0.693	0.697	0.706	0.713	9/16"

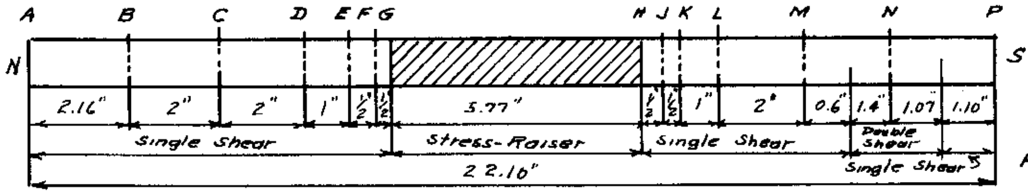
Sketch A
Profile of Secs. G, H

Sketch B
Profile of Secs. B, C, D, E, F, I, J, K, L, M, N, P



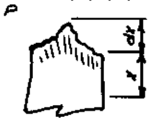
Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 18B-3 Steel D As-Rolled

Sec	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.644	0.651	0.658	0.662	0.666	0.672	0.688	0.699	19/32"
B	0.617	0.632	0.639	0.653	0.663	0.677	0.697	—	11/16"
C	0.617	0.628	0.642	0.658	0.669	0.684	0.706	—	21/32"
D	0.634	0.650	0.660	0.679	0.693	0.708	0.728	—	21/32"
E	0.663	0.680	0.690	0.707	0.719	0.733	0.747	—	21/32"
F	0.677	0.697	0.708	0.725	0.737	0.747	0.755	0.759	17/32"
G	0.739	0.745	0.748	0.752	0.756	0.758	0.760	0.760	0
H	0.716	0.736	0.741	0.753	0.757	0.760	0.762	0.763	0
J	0.652	0.676	0.692	0.717	0.733	0.748	0.759	—	3/8"
K	0.665	0.681	0.691	0.709	0.722	0.737	0.754	—	19/32"
L	0.644	0.660	0.672	0.689	0.702	0.717	0.737	—	5/8"
M	0.626	0.641	0.651	0.667	0.678	0.694	0.715	—	11/16"
N	0.614	0.616	0.618	0.624	0.636	0.659	0.691	0.712	1/4"
P	0.630	0.650	0.664	0.680	0.694	0.705	0.709	0.721	5/16"



Sketch A
Profile of Secs. G, H

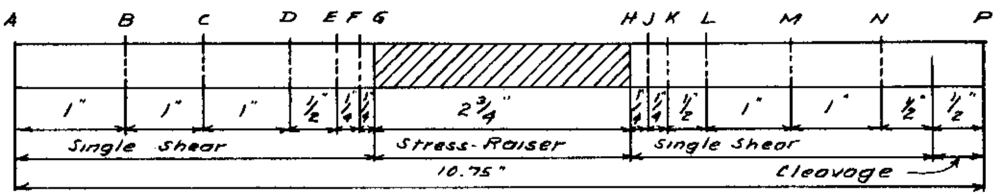
Sketch B
Profile of Secs. A, B, C, D, E, F, J, K, L, M, P

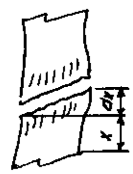


Sketch C
Profile of Secs N

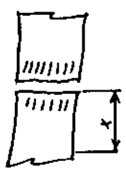
Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen A-4 Steel F As-Rolled

Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.658	.672	.682	.691	.697	.705	.721	.732	17/32"
B	.655	.672	.681	.695	.704	.717	.734	—	11/16"
C	.660	.677	.686	.699	.710	.724	.745	—	11/16"
D	.673	.693	.702	.717	.727	.741	.759	—	3/4"
E	.687	.707	.717	.735	.744	.756	.766	—	17/32"
F	.703	.721	.731	.746	.753	.761	.767	.770	3/8"
G	.742	.749	.753	.757	.761	.764	.769	.759	0
H	.731	.744	.744	.759	.762	.765	.772	.773	0
J	.721	.734	.740	.752	.759	.763	.769	.770	11/32"
K	.694	.709	.720	.737	.748	.760	.768	—	9/16"
L	.685	.699	.707	.722	.733	.746	.763	—	23/32
M	.661	.682	.690	.704	.715	.729	.749	—	23/32"
N	.661	.677	.685	.700	.709	.721	.738	—	21/32"
P	.695	.710	.714	.712	.708	.709	.720	.732	0





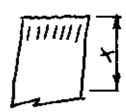
Sketch A
Profile of Secs. A, B, C, D, E, F, J, K, L, M, N



Sketch B
Profile of section P, G, H

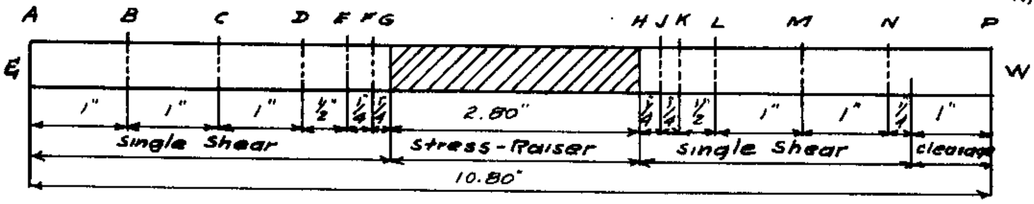
Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 18-9A Steel E As-Rolled

Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.664	0.672	0.686	0.686	0.690	0.697	0.709	0.717	9/16"
B	0.651	0.663	0.671	0.683	0.693	0.705	0.720	—	3/4"
C	0.656	0.668	0.676	0.689	0.699	0.711	0.729	—	3/4"
D	0.676	0.688	0.696	0.709	0.718	0.729	0.742	—	11/16"
E	0.686	0.705	0.712	0.724	0.728	0.740	0.747	—	5/8"
F	0.696	0.709	0.721	0.733	0.740	0.745	0.749	—	7/16"
G	0.733	0.738	0.740	0.744	0.747	0.750	0.751	0.752	0"
H	0.735	0.737	0.744	0.746	0.748	0.751	0.754	0.755	0"
J	0.693	0.711	0.720	0.734	0.742	0.747	0.752	—	5/16"
K	0.686	0.701	0.710	0.724	0.733	0.737	0.750	—	9/16"
L	0.673	0.685	0.694	0.708	0.719	0.731	0.745	—	3/4"
M	0.661	0.673	0.680	0.693	0.703	0.726	0.733	—	3/4"
N	0.659	0.671	0.677	0.689	0.698	0.710	0.725	—	3/4"
P	0.723	0.721	0.720	0.716	0.709	0.702	0.707	0.716	0



Sketch A
Profile of Secs G, H, P

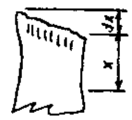
Sketch B
Profile of Secs. A, B, C, D, E, F, J, K, L, M, N



Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 18A-5 Steel D As-Rolled

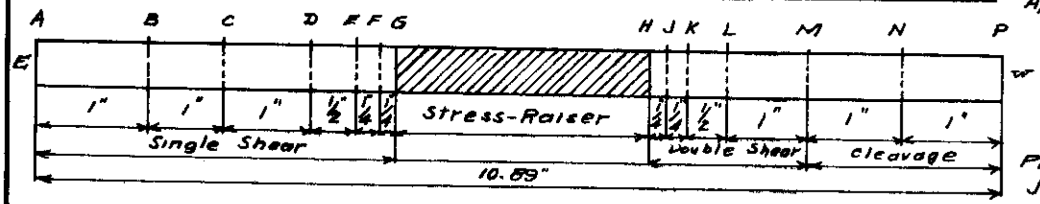
Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.658	.663	.667	.674	.679	.687	.702	.717	11/16"
B	.649	.657	.664	.676	.688	.699	.716	—	11/16"
C	.653	.665	.673	.685	.695	.708	.732	—	3/4"
D	.668	.682	.690	.703	.712	.723	.737	—	3/4"
E	.677	.693	.702	.717	.725	.736	.744	—	9/16"
F	.682	.749	.719	.724	.730	.740	.745	—	7/16"
G	.710	.721	.728	.735	.739	.744	.747	.748	0
H	.689	.696	.715	.731	.739	.744	.748	.739	0
J	.670	.668	.677	.694	.713	.732	.744	.748	1/4"
K	.651	.657	.661	.672	.688	.713	.738	.746	1/4"
L	.652	.661	.658	.663	.671	.688	.717	.733	1/4"
M	.641	.648	.647	.662	.672	.687	.707	.721	1/8"
N	.699	.701	.702	.703	.702	.700	.707	.720	0
P	.723	.730	.731	.730	.730	.725	.714	.718	0

Sketch A
Profile of Secs. G, H, M, N, P



Sketch B
Profile of Secs. A, B, C, D, E, F

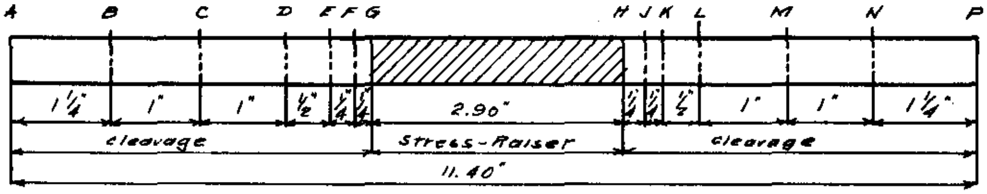
Sketch C
Profile of Secs. J, K, L



Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 18A-3 Steel D As-Rolled

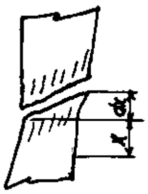
Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.745	0.749	0.750	0.751	0.752	0.752	0.752	0.748	0
B	0.740	0.747	0.750	0.751	0.750	0.750	0.750	0.751	0
C	0.734	0.744	0.746	0.747	0.747	0.748	0.749	0.752	0
D	0.727	0.737	0.738	0.740	0.741	0.742	0.747	0.752	0
E	0.727	0.730	0.731	0.733	0.736	0.740	0.749	0.753	0
F	0.720	0.722	0.724	0.730	0.737	0.743	0.750	0.756	0
G	0.713	0.729	0.735	0.742	0.746	0.749	0.751	0.756	0
H	0.704	0.717	0.723	0.736	0.743	0.747	0.754	0.760	0
J	0.717	0.721	0.724	0.727	0.735	0.744	0.752	0.759	0
K	0.726	0.728	0.730	0.733	0.735	0.742	0.751	0.755	0
L	0.733	0.735	0.736	0.738	0.740	0.742	0.749	0.753	0
M	0.739	0.742	0.742	0.745	0.746	0.749	0.751	0.752	0
N	0.742	0.745	0.746	0.748	0.750	0.752	0.753	0.755	0
P	0.748	0.750	0.751	0.753	0.753	0.755	0.755	0.756	0

Sketch A
Profile of All Sections

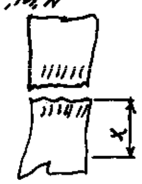


Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 18B-2 Steel D As-Rolled

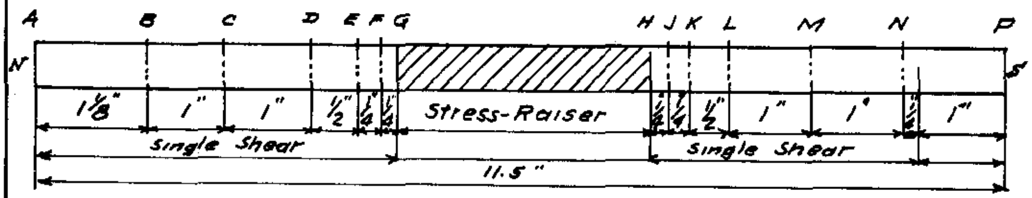
Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.664	.677	.684	.690	.695	.700	.713	.721	5/8"
B	.658	.669	.676	.689	.697	.707	.723	—	23/32"
C	.661	.675	.682	.690	.704	.714	.732	—	13/16"
D	.685	.696	.703	.714	.721	.732	.745	—	3/4"
E	.693	.705	.713	.726	.733	.742	.750	—	5/16"
F	.705	.718	.725	.736	.742	.746	.753	—	3/8"
G	.732	.737	.740	.745	.748	.750	.753	.754	1/8"
H	.709	.726	.734	.743	.748	.751	.754	.755	1/8"
J	.700	.712	.721	.735	.745	.748	.753	—	1/4"
K	.689	.707	.714	.727	.736	.745	.752	—	5/8"
L	.682	.694	.703	.715	.724	.735	.747	—	3/4"
M	.664	.677	.684	.697	.706	.719	.735	—	23/32"
N	.660	.671	.679	.690	.699	.711	.731	—	3/4"
P	.721	.721	.720	.717	.712	.707	.717	.721	0



Sketch A
Profile of Secs. A, B, C, D, E, F, G, H, J, K, L, M, N

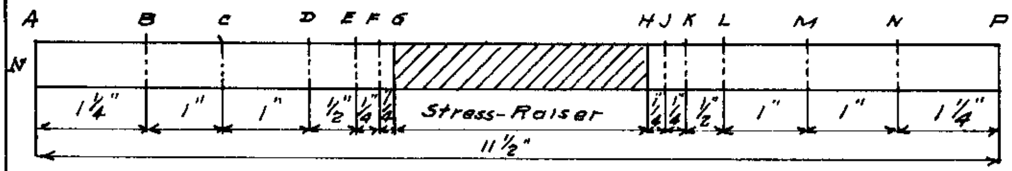


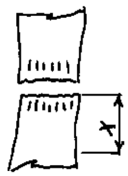
Sketch B
Profile of Section P



Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 17-6B Steel D As-Rolled

Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dX
A	.743	.745	.747	.748	.748	.747	.746	.746	0
B	.748	.744	.744	.745	.745	.744	.742	.742	0
C	.724	.741	.743	.743	.743	.741	.739	.743	0
D	.733	.738	.739	.739	.739	.740	.743	.750	0
E	.723	.725	.726	.728	.732	.739	.749	.755	0
F	.707	.710	.714	.723	.715	.743	.753	.756	0
G	.726	.734	.737	.744	.747	.751	.753	.757	0
H	.702	.719	.729	.742	.748	.755	.756	.757	0
J	.708	.711	.714	.725	.736	.746	.754	.761	0
K	.718	.723	.724	.727	.732	.741	.750	.755	0
L	.719	.736	.737	.738	.740	.741	.749	.753	0
M	.736	.744	.745	.746	.748	.748	.750	.753	0
N	.743	.746	.748	.749	.750	.751	.753	.754	0
P	.746	.749	.749	.750	.751	.752	.753	.753	0

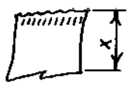




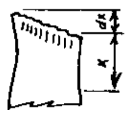
Sketch A
Profile of
All Sections

Thickness of Plate at Specified Distances from Fracture
on Various Sections Normal to the Fracture Specimen 17-6A
Steel D As-Rolled

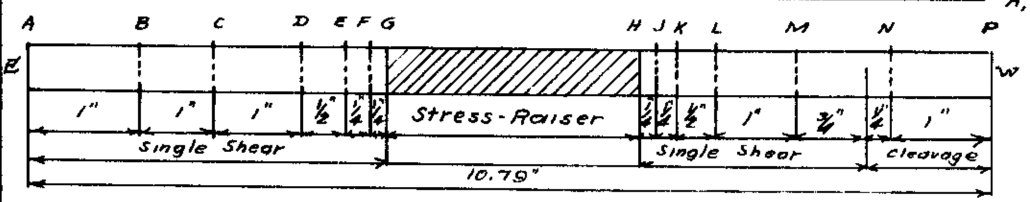
Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dX
A	.676	.690	.698	.708	.712	.737	.735	–	5/8"
B	.673	.686	.694	.708	.717	.729	.747	–	3/4"
C	.701	.693	.701	.715	.725	.739	.768	–	3/4"
D	.696	.710	.718	.733	.744	.752	.774	–	11/16"
E	.702	.720	.731	.749	.760	.771	.780	–	5/8"
F	.708	.730	.743	.761	.770	.777	.782	–	1/2"
G	.727	.754	.761	.771	.776	.780	.783	.783	0
H	.744	.758	.762	.772	.777	.781	.784	.783	0
J	.728	.740	.749	.763	.774	.778	.783	–	5/16"
K	.709	.725	.735	.752	.762	.772	.781	–	9/16"
L	.697	.711	.720	.735	.747	.759	.774	–	11/16"
M	.682	.696	.704	.718	.729	.742	.761	–	3/4"
N	.646	.655	.665	.689	.706	.723	.745	.758	1/4"
P	.753	.754	.754	.751	.745	.735	.736	.745	0



Sketch A
Profile of Secs.
G, H, N, P

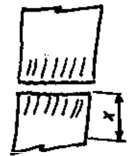


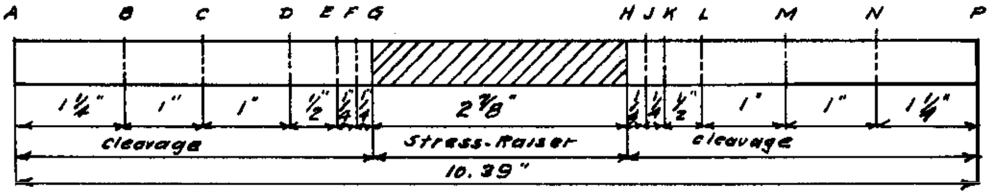
Sketch B
Profile of Secs
A, B, C, D, E, F, J,
K, L, M



Thickness of Plate at Specified Distances from Fracture
on Various Sections Normal to the Fracture Specimen 22A-2
Steel D As-Rolled

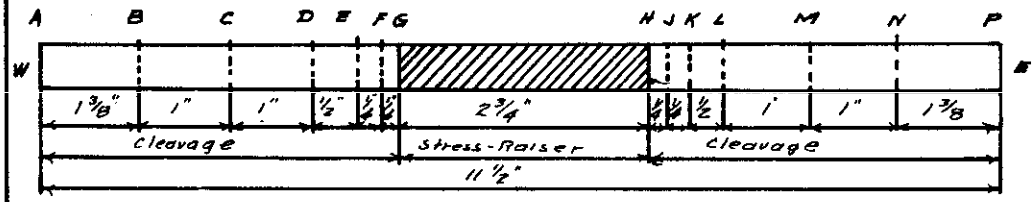
Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.758	.759	.760	.761	.762	.762	.763	.766	0
B	.760	.761	.761	.763	.763	.763	.763	.764	0
C	.756	.757	.758	.760	.761	.761	.763	.764	0
D	.751	.752	.752	.754	.755	.756	.761	.765	0
E	.742	.744	.745	.747	.750	.755	.761	.767	0
F	.735	.737	.739	.744	.752	.757	.764	.768	0
G	.733	.744	.749	.755	.758	.761	.765	.771	0
H	.731	.742	.744	.755	.761	.763	.766	.772	0
J	.737	.739	.741	.747	.754	.759	.765	.767	0
K	.745	.746	.747	.749	.753	.757	.764	.767	0
L	.753	.755	.755	.756	.756	.758	.762	.767	0
M	.760	.760	.761	.762	.762	.762	.764	.765	0
N	.762	.764	.764	.765	.766	.767	.767	.766	0
P	.766	.763	.765	.766	.768	.767	.768	.769	0





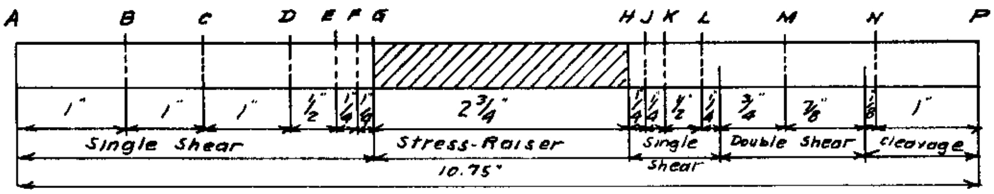
Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 22B-2 Steel D As-Rolled

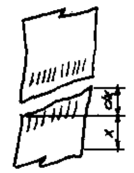
Sec	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.755	.759	.760	.761	.761	.763	.763	.763	0
B	.761	.762	.762	.763	.764	.763	.761	.760	0
C	.758	.759	.759	.759	.760	.758	.759	.758	0
D	.754	.756	.756	.756	.755	.755	.757	.764	0
E	.749	.750	.751	.751	.753	.756	.762	.767	0
F	.744	.745	.746	.750	.753	.758	.762	.765	0
G	.744	.747	.750	.756	.759	.761	.762	.766	0
H	.751	.753	.754	.756	.759	.763	.762	.766	0
J	.741	.743	.744	.750	.754	.758	.764	.767	0
K	.748	.749	.749	.751	.758	.755	.761	.763	0
L	.752	.753	.753	.753	.753	.755	.757	.763	0
M	.756	.758	.759	.758	.758	.757	.756	.760	0
N	.755	.758	.760	.761	.762	.762	.759	.761	0
P	.756	.761	.762	.763	.764	.763	.762	.763	0



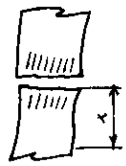
Thickness of Top Half of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 17A-5A Steel D As-Rolled

Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dX
A	.639	.657	.664	.675	.683	.689	.703	.713	9/16"
B	.632	.647	.655	.670	.681	.694	.713	—	11/16"
C	.641	.654	.663	.677	.690	.704	.723	—	23/32"
D	.656	.674	.683	.699	.710	.723	.738	—	23/32"
E	.665	.685	.698	.713	.725	.736	.744	—	19/32"
F	.674	.696	.708	.723	.733	.741	.746	—	5/16"
G	.709	.724	.732	.738	.742	.746	.748	.750	0
H	.716	.726	.735	.740	.745	.747	.750	.751	0
J	.682	.700	.709	.725	.733	.742	.747	.751	1/2"
K	.672	.687	.697	.710	.725	.737	.745	—	5/8"
L	.670	.672	.682	.699	.708	.722	.738	—	23/32"
M	.603	.610	.616	.631	.650	.679	.661	—	3/8"
N	.595	.598	.622	.643	.658	.677	.700	.716	1/8"
P	.704	.708	.708	.725	.703	.695	.702	.711	0

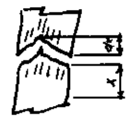




Sketch A
Profile of Secs.
A, B, C, D, E, F, J, K, L



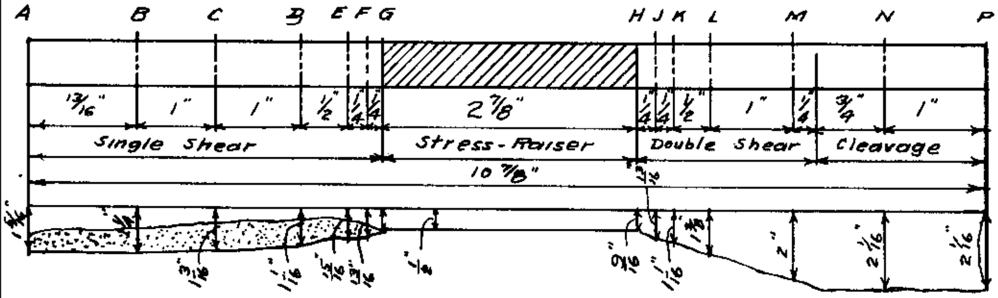
Sketch B
Profile of Secs.
G, H, N, P

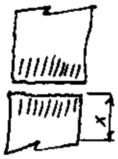


Sketch C
Profile of Secs.
M.

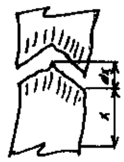
Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 15-5A
Steel D-Normalized

Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dX
A	.661	.669	.674	.681	.684	.691	.705	.718	9/16"
B	.640	.653	.661	.676	.680	.699	.719	—	23/32"
C	.648	.661	.670	.684	.696	.710	.730	—	23/32"
D	.664	.680	.689	.654	.714	.727	.743	—	5/8"
E	.675	.693	.703	.704	.730	.740	.750	—	9/16"
F	.674	.697	.711	.734	.737	.745	.751	.757	3/8"
G	.727	.736	.739	.745	.748	.750	.754	.757	0
H	.744	.746	.750	.751	.752	.754	.757	.758	0
J	.657	.665	.679	.697	.725	.741	.752	.756	9/64"
K	.643	.650	.656	.672	.690	.719	.747	.754	1/4"
L	.628	.638	.643	.656	.671	.675	.726	.694	1/4"
M	.625	.636	.640	.647	.658	.679	.708	.677	13/64"
N	.681	.685	.685	.687	.686	.692	.708	.722	0
P	.732	.733	.734	.734	.731	.719	.712	.716	0

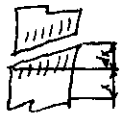




Sketch A
Profile of Sec.
G, H, N, P



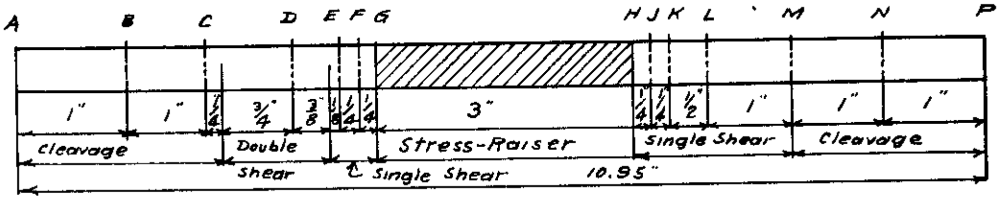
Sketch B
Profile of Sec.
J, K, L, M

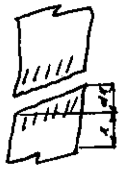


Sketch C
Profile of Sec.
A, B, C, D, E, F

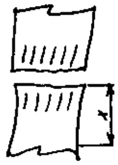
Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 9-2
Steel D Normalized

Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.695	.697	.699	.700	.700	.697	.688	.689	0
B	.679	.682	.683	.685	.685	.686	.697	.711	0
C	.615	.624	.634	.656	.672	.691	.715	.732	9/32"
D	.649	.665	.675	.691	.704	.718	.736	—	11/16"
E	.663	.681	.692	.709	.721	.733	.745	—	5/8"
F	.667	.688	.701	.719	.735	.739	.747	—	7/16"
G	.717	.726	.730	.736	.740	.745	.749	.751	0
H	.708	—	.719	.742	.756	.750	.752	.753	0
J	.685	.705	.715	.732	.740	.746	.751	—	7/16"
K	.673	.691	.704	.717	.730	.740	.749	—	5/8"
L	.573	.581	.589	.617	.657	.694	.727	—	1/2"
M	.620	.623	.622	.628	.641	.663	.695	.720	0
N	.696	.699	.699	.698	.697	.695	.702	.715	0
P	.729	.732	.736	.736	.736	.733	.722	.716	0





Sketch A
Profile of Secs. E, F, J, K, L.



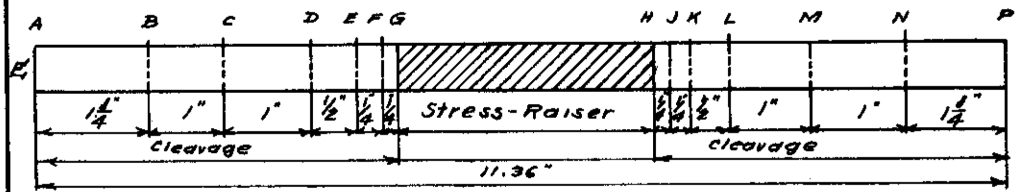
Sketch B
Profile of Secs. A, B, C, G, H, M, N

Sketch C
Profile of Sec. D

Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 15-6B Steel D-Normalized

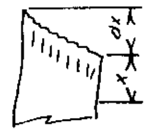
Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dX
A	.758	.766	.766	.767	.767	.766	.766	.768	0
B	.759	.761	.762	.763	.764	.764	.765	.767	0
C	.756	.758	.759	.760	.760	.761	.763	.765	0
D	.748	.750	.751	.752	.753	.755	.761	.766	0
E	.734	.737	.738	.741	.745	.753	.763	.768	0
F	.722	.724	.726	.735	.747	.752	.764	.769	0
G	.723	.739	.745	.754	.759	.763	.767	.772	0
H	.738	.744	.751	.760	.763	.767	.771	.773	0
J	.727	.731	.734	.741	.748	.762	.768	.772	0
K	.740	.742	.743	.745	.750	.757	.768	.771	0
L	.753	.754	.755	.754	.756	.758	.763	.767	0
M	.760	.762	.763	.765	.764	.764	.765	.766	0
N	.765	.767	.767	.768	.769	.768	.768	.767	0
P	.771	.771	.771	.773	.773	.743	.742	.739	0

Sketch A
Profile of All Sections

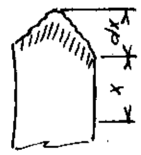


Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 10A-4 Steel D Normalized

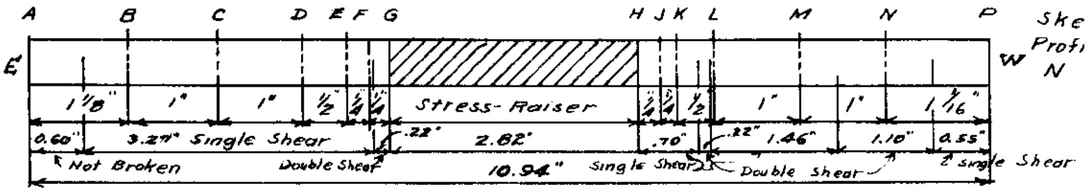
Sec.	Distance from Fracture, x								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.683	.700	.710	.712	.709	.700	.694	.708	1/8"
B	.656	.660	.676	.688	.697	.707	.721	—	9/16"
C	.658	.672	.680	.693	.703	.715	.732	—	5/8"
D	.672	.688	.699	.711	.718	.728	.740	—	9/16"
E	.651	.660	.674	.703	.720	.733	.741	.745	5/16"
F	.641	.671	.690	.718	.730	.738	.743	.747	3/16"
G	.720	.730	.734	.739	.742	.743	.745	.749	0
H	.734	.734	.744	.742	.747	.744	.747	.749	0
J	.715	.723	.728	.738	.740	.742	.747	.750	11/32"
K	.688	.703	.712	.726	.733	.740	.746	—	7/16"
L	.682	.693	.702	.713	.721	.731	.742	-	9/16"
M	.665	.676	.684	.696	.706	.718	.735	—	9/16"
N	.598	.627	.634	.663	.682	.698	.717	.724	1/4"
P	.663	.673	.681	.686	.691	.698	.710	.718	7/16"



Sketch A
Profile of Secs
B, C, D, E, F, J, K
L, M, P

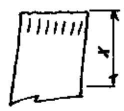


Sketch B
Profile of Secs
N

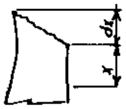


Thickness of Plate at Specified Distances from Fracture
on Various Sections Normal to the Fracture Specimen 13A-10
Steel E As-Rolled Transverse to Direction of Rolling

Sec.	Distance from Fracture, x								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.695	.709	.716	.718	.716	.711	.716	.724	5/16"
B	.621	.624	.641	.673	.689	.704	.722	.735	5/16"
C	.603	.631	.648	.676	.694	.712	.731	.742	3/16"
D	.591	.618	.648	.684	.710	.730	.743	.749	0
E	.666	.697	.716	.730	.735	.741	.748	.752	0
F	.684	.706	.720	.740	.740	.748	.753	.754	0
G	.697	.725	.735	.744	.748	.750	.752	.754	0
H	.689	.713	.722	.741	.745	.749	.751	.756	0
J	.673	.705	.715	.739	.735	.744	.751	.755	0
K	.638	.672	.695	.721	.731	.738	.749	.754	0
L	.622	.646	.662	.690	.709	.700	.746	.752	3/16"
M	.649	.669	.680	.696	.707	.719	.735	—	15/32"
N	.657	.672	.679	.694	.703	.712	.728	—	9/16"
P	.664	.676	.682	.692	.698	.705	.716	.724	7/16"

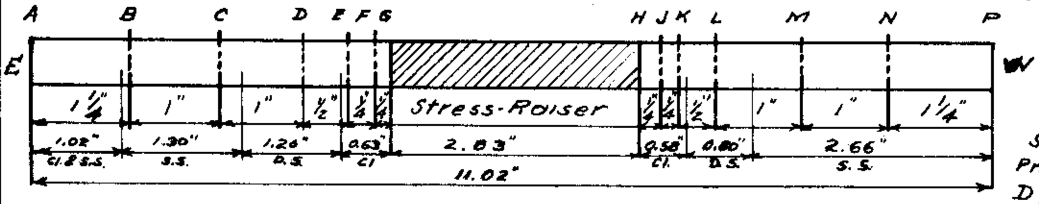


Sketch A
Profile of Secs.
E, F, G, H, J, K



Sketch B
Profile of Secs.
B, C, M, N, P

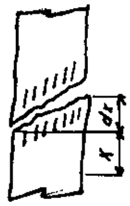
Sketch C
Profile of Secs.
D, L

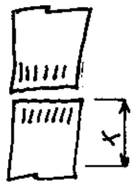


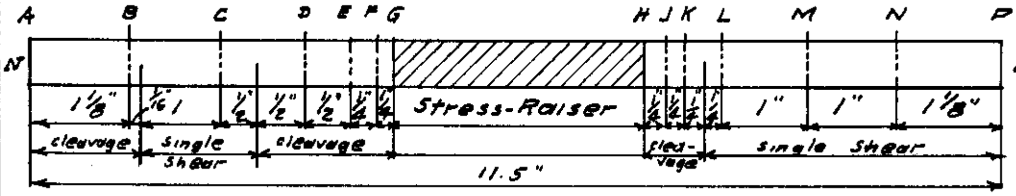
Note: In above diagram; Cl = Cleavage, S.S. = Single Shear,
D.S. = Double Shear type of fractures

Thickness of Plate at Specified Distances from Fracture
on Various Sections Normal to the Fracture Specimen 13A-9
Steel E As-Rolled Transverse to Direction of Rolling

Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.712	.733	.768	.745	.740	.732	.730	.738	0
B	.623	.643	.657	.682	.700	.716	.736	.748	0
C	.605	.634	.656	.684	.704	.722	.745	.757	1/8"
D	.591	.612	.646	.680	.708	.735	.758	.766	0
E	.603	.640	.673	.712	.733	.756	.767	.771	0
F	.643	.686	.713	.739	.755	.764	.741	.772	0
G	.684	.732	.752	.760	.765	.769	.773	.773	0
H	.711	.735	.750	.762	.767	.770	.775	.774	0
J	.642	.674	.703	.739	.751	.767	.771	.778	0
K	.610	.646	.703	.710	.737	.756	.768	.772	0
L	.633	.661	.686	.709	.729	.747	.763	.768	7/32"
M	.632	.664	.685	.705	.718	.732	.751	–	3/8"
N	.668	.684	.693	.707	.715	.727	.743	–	1/2"
P	.687	.700	.703	.711	.715	.724	.735	.744	5/8"

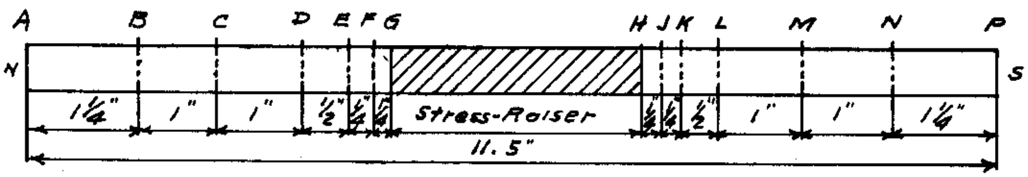






Thickness of Plate at Specified Distances from Fracture
on Various Sections Normal to the Fracture Specimen 18-7B
Steel E As-Rolled

Sec.	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.760	.758	.757	.757	.758	.759	.761	.760	0
B	.751	.757	.758	.759	.759	.760	.762	.761	0
C	.746	.750	.751	.751	.752	.754	.758	.763	0
D	.709	.718	.726	.737	.747	.756	.763	.767	0
E	.703	.737	.745	.749	.754	.759	.766	.768	0
F	.706	.729	.740	.749	.757	.762	.769	.769	0
G	.734	.751	.756	.760	.763	.765	.770	.772	0
H	.735	.751	.757	.759	.763	.766	.767	.768	0
J	.710	.730	.749	.754	.757	.762	.767	.767	0
K	.723	.738	.742	.749	.754	.761	.764	.767	0
L	.708	.741	.753	.754	.755	.757	.763	.766	0
M	.726	.730	.737	.736	.743	.752	.759	.762	0
N	.750	.752	.753	.754	.754	.755	.755	.758	0
P	.780	.777	.772	.764	.763	.760	.761	.758	0



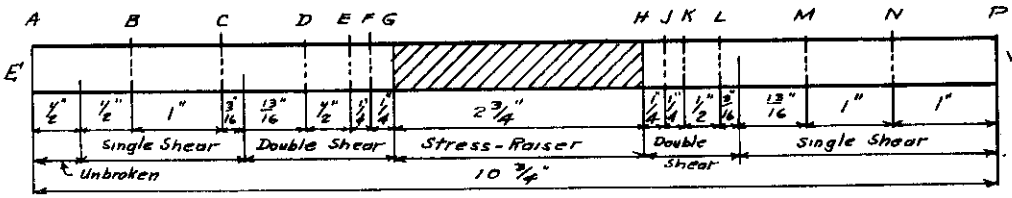
Thickness of Plate at Specified Distances from Fracture
on Various Sections Normal to the Fracture Specimen 18-7A
Steel E As-Rolled

Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.662	0.687	0.702	0.715	0.712	0.701	0.725	0.713	0
B	0.647	0.661	0.669	0.681	0.690	0.701	0.720	—	11/16"
C	0.650	0.661	0.669	0.682	0.693	0.707	0.728	—	33/64"
D	0.645	0.648	0.651	0.661	0.675	0.698	0.731	0.744	1/4"
E	0.651	0.658	0.664	0.677	0.695	0.722	0.749	0.756	1/4"
F	0.661	0.668	0.675	0.699	0.718	0.742	0.755	0.758	5/32"
G	0.739	0.745	0.747	0.751	0.753	0.755	0.756	0.759	0
H	0.737	0.737	0.749	0.753	0.758	0.758	0.761	0.762	0
J	0.647	0.669	0.681	0.705	0.730	0.748	0.757	0.760	5/32"
K	0.639	0.652	0.662	0.680	0.699	0.726	0.751	0.757	3/16"
L	0.623	0.639	0.650	0.668	0.684	0.707	0.736	0.758	3/16"
M	0.648	0.666	0.673	0.688	0.693	0.713	0.733	—	11/16"
N	0.649	0.663	0.671	0.683	0.693	0.705	0.723	—	11/16"
P	0.644	0.659	0.668	0.684	0.694	0.703	0.714	0.723	3/8"


Sketch A
Profile of Secs. G, H


Sketch B
Profile of Secs. B, C, M, N, P

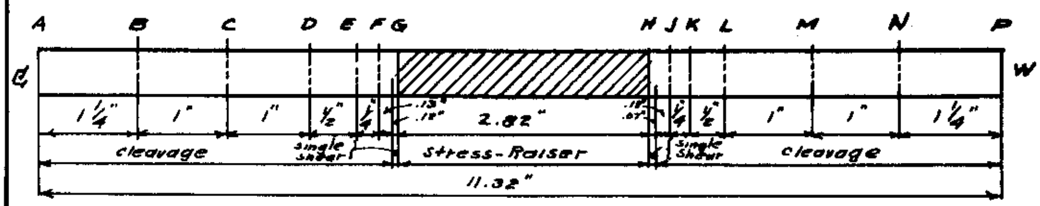

Sketch C
Profile of Secs B, E, F, J, K, L



Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 17-13 Steel E Normalized

Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.730	0.732	0.733	0.735	0.735	0.736	0.741	0.746	0
B	0.730	0.733	0.733	0.734	0.735	0.736	0.739	0.742	0
C	0.728	0.729	0.730	0.731	0.731	0.732	0.736	0.741	0
D	0.715	0.715	0.716	0.717	0.718	0.722	0.737	0.746	0
E	0.695	0.696	0.698	0.703	0.712	0.725	0.740	0.748	0
F	0.672	0.676	0.682	0.701	0.718	0.732	0.743	0.748	0
G	0.716	0.724	0.730	0.736	0.740	0.743	0.747	0.754	0
H	0.734	0.736	0.739	0.740	0.742	0.744	0.748	0.750	0
J	0.673	0.666	0.694	0.710	0.724	0.736	0.745	0.748	0
K	0.698	0.701	0.703	0.709	0.716	0.730	0.743	0.748	0
L	0.719	0.721	0.722	0.722	0.724	0.728	0.738	0.745	0
M	0.730	0.732	0.733	0.735	0.736	0.737	0.739	0.743	0
N	0.735	0.738	0.739	0.740	0.741	0.743	0.743	0.743	0
P	0.736	0.739	0.741	0.742	0.744	0.746	0.750	0.750	0

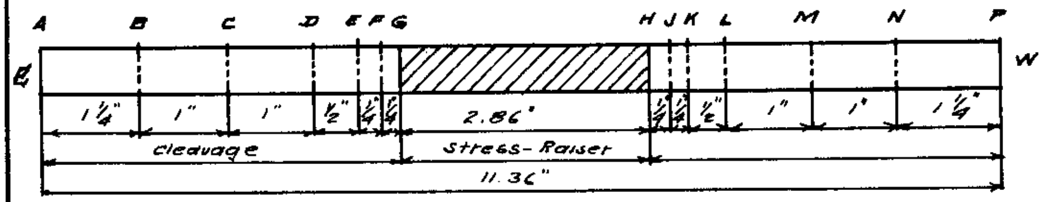

Sketch A
Profile of All Sections



Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 16-5 Steel E Normalized

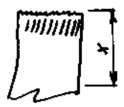
Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.746	0.747	0.748	0.750	0.751	0.755	0.759	0.759	0
B	0.744	0.747	0.747	0.749	0.749	0.751	0.759	0.761	0
C	0.744	0.746	0.747	0.748	0.748	0.750	0.755	0.760	0
D	0.736	0.739	0.739	0.740	0.741	0.745	0.756	0.761	0
E	0.721	0.723	0.724	0.728	0.735	0.747	0.760	0.764	0
F	0.708	0.710	0.713	0.725	0.739	0.750	0.762	0.767	0
G	0.731	0.741	0.745	0.753	0.756	0.760	0.765	0.766	0
H	0.721	0.740	0.745	0.752	0.756	0.760	0.765	0.767	0
J	0.709	0.717	0.715	0.726	0.740	0.752	0.762	0.756	0
K	0.723	0.726	0.727	0.729	0.735	0.745	0.759	0.764	0
L	0.735	0.737	0.738	0.739	0.739	0.742	0.751	0.759	0
M	0.744	0.746	0.746	0.749	0.749	0.750	0.753	0.757	0
N	0.749	0.751	0.751	0.751	0.753	0.754	0.757	0.757	0
P	0.742	0.743	0.743	0.746	0.748	0.751	0.755	0.749	0

Sketch A
Profile of All Sections



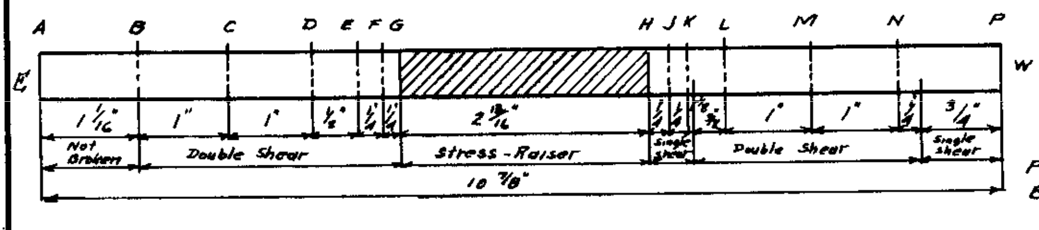
Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 18A-3
Steel E Normalized

Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.640	0.659	0.671	0.688	0.697	0.699	0.702	0.716	5/16"
B	0.641	0.647	0.652	0.659	0.666	0.675	0.691	0.712	1/4"
C	0.631	0.633	0.636	0.642	0.652	0.672	0.707	0.729	1/4"
D	0.611	0.621	0.629	0.646	0.664	0.693	0.730	0.749	3/16"
E	0.630	0.638	0.649	0.670	0.691	0.722	0.753	0.761	5/32"
F	0.637	0.652	0.662	0.687	0.711	0.743	0.759	0.763	3/16"
G	0.741	0.746	0.750	0.755	0.758	0.761	0.763	0.764	0
H	0.745	0.749	0.757	0.755	0.758	0.761	0.762	0.764	0
J	0.699	0.733	0.722	0.743	0.753	0.755	0.761	0.763	3/8"
K	0.669	0.690	0.704	0.720	0.733	0.747	0.758	—	5/8"
L	0.613	0.621	0.632	0.655	0.682	0.711	0.741	0.751	3/8"
M	0.636	0.635	0.636	0.636	0.641	0.663	0.703	0.703	1/4"
N	0.617	0.629	0.635	0.647	0.657	0.673	0.697	0.688	5/16"
P	0.622	0.638	0.650	0.661	0.669	0.678	0.694	0.709	1/4"



Sketch A
Profile of Secs. G, H

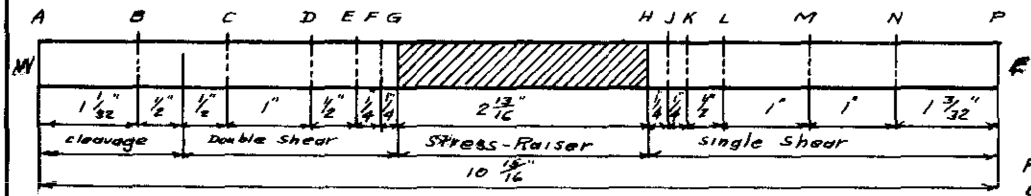
Sketch B
Profile of Secs J, K, P



Sketch C
Profile of Secs. B, C, D, E, F, L, M, N

Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen A-13
Steel F As-Rolled

Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.655	0.668	0.676	0.684	0.691	0.708	0.725	0.732	5/8"
B	0.627	0.646	0.659	0.677	0.690	0.705	0.731	—	11/16"
C	0.643	0.680	0.670	0.688	0.701	0.718	0.742	—	11/16"
D	0.662	0.680	0.692	0.710	0.724	0.741	0.760	—	5/8"
E	0.682	0.701	0.712	0.732	0.745	0.756	0.767	—	9/16"
F	0.696	0.715	0.727	0.709	0.755	0.763	0.768	0.772	3/8"
G	0.755	0.758	0.760	0.763	0.765	0.768	0.771	0.772	0"
H	0.745	0.751	0.765	0.763	0.766	0.769	0.771	0773	0"
J	0.702	0.724	0.740	0.739	0.729	0.761	0.767	0.770	3/16"
K	0.674	0.653	0.660	0.678	0.699	0.730	0.760	0.766	3/16"
L	0.627	0.636	0.644	0.653	0.670	0.701	0.739	0.760	3/16"
M	0.632	0.635	0.638	0.646	0.658	0.681	0.714	0.736	1/4"
N	0.673	0.679	0.679	0.681	0.683	0.689	0.701	0.708	0"
P	0.738	0.738	0.738	0.737	0.733	0.725	0.714	0.722	0"



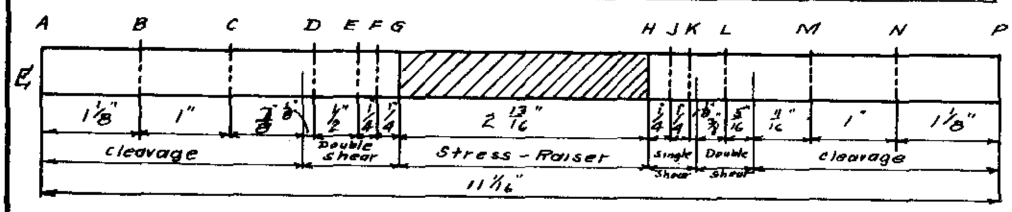
Sketch A
Profile of Secs.
G, H, N, P

Sketch B
Profile of Secs.
J, K, L, M, N, P

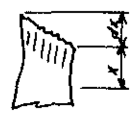
Sketch C
Profile of Secs.
C, D, E, F

Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen A-12 Steel F As-Rolled

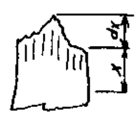
Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.721	0.722	0.724	0.724	0.725	0.724	0.725	0.720	0
B	0.717	0.718	0.719	0.719	0.720	0.720	0.721	0.728	0
C	0.683	0.684	0.686	0.688	0.690	0.697	0.717	0.735	0
D	0.621	0.631	0.634	0.645	0.660	0.687	0.724	0.744	1/4"
E	0.637	0.642	0.647	0.662	0.680	0.712	0.745	0.756	1/4"
F	0.654	0.660	0.665	0.682	0.704	0.733	0.753	0.760	1/4"
G	0.731	0.740	0.744	0.750	0.754	0.756	0.760	0.761	0
H	0.744	0.750	0.756	0.757	0.761	0.762	0.763	0.764	0
J	0.696	0.716	0.728	0.742	0.754	0.757	0.760	0.767	3/8"
K	0.678	0.696	0.708	0.726	0.737	0.750	0.761	—	9/16"
L	0.620	0.629	0.639	0.661	0.683	0.715	0.743	0.754	3/8"
M	0.670	0.682	0.684	0.687	0.691	0.701	0.724	0.742	0
N	0.725	0.727	0.727	0.728	0.726	0.727	0.727	0.736	0
P	0.746	0.749	0.750	0.751	0.751	0.750	0.744	0.737	0



Sketch A
Profile of Secs.
A, B, C, G, H, M, N, P



Sketch B
Profile of Secs.
J, K

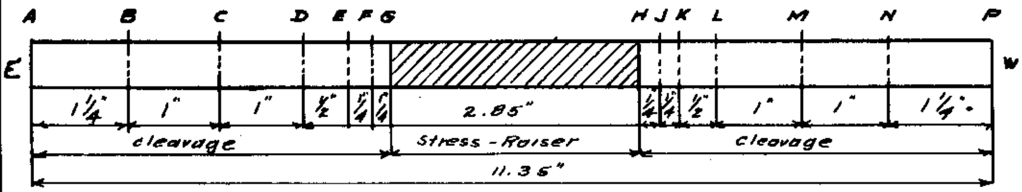


Sketch C
Profile of Secs.
D, E, F, L

Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen A-6 Steel F As-Rolled

Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.756	0.757	0.759	0.759	0.759	0.762	0.764	0.766	0
B	0.757	0.757	0.758	0.760	0.761	0.762	0.762	0.764	0
C	0.749	0.754	0.755	0.756	0.757	0.758	0.760	0.762	0
D	0.746	0.746	0.747	0.749	0.749	0.751	0.759	0.765	0
E	0.728	0.731	0.732	0.736	0.742	0.751	0.763	0.768	0
F	0.711	0.714	0.719	0.732	0.745	0.756	0.765	0.770	0
G	0.750	0.752	0.752	0.756	0.760	0.764	0.769	0.771	0
H	0.720	0.736	0.745	0.756	0.759	0.765	0.769	0.770	0
J	0.717	0.721	0.722	0.733	0.744	0.757	0.766	0.768	0
K	0.733	0.733	0.735	0.738	0.744	0.752	0.763	0.768	0
L	0.747	0.747	0.748	0.750	0.750	0.753	0.761	0.765	0
M	0.755	0.757	0.758	0.760	0.761	0.762	0.764	0.764	0
N	0.760	0.762	0.763	0.764	0.765	0.766	0.766	0.766	0
P	0.762	0.765	0.766	0.768	0.769	0.769	0.770	0.770	0

Sketch A
Profile of All Sections



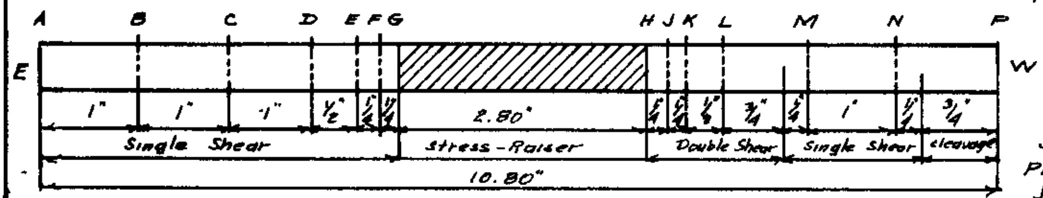
Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen A-10 Steel F As-Rolled

Sec.	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.644	0.654	0.660	0.668	0.673	0.679	0.691	0.701	19/32"
B	0.629	0.632	0.650	0.662	0.672	0.684	0.703	—	11/16"
C	0.635	0.647	0.656	0.669	0.679	0.693	0.711	—	11/16"
D	0.651	0.664	0.673	0.687	0.698	0.711	0.724	—	21/32"
E	0.664	0.679	0.688	0.703	0.712	0.723	0.730	—	9/16"
F	0.670	0.686	0.697	0.711	0.718	0.725	0.731	—	3/8"
G	0.698	0.711	0.715	0.722	0.725	0.729	0.731	0.733*	0
H	0.716	0.723	*0.730	0.728	0.729	0.729	0.729	0.735	0
J	0.664	0.668	0.676	0.689	0.712	0.727	0.730	0.734	3/16"
K	0.633	0.639	0.648	0.661	0.680	0.706	0.725	0.731	9/32"
L	0.621	0.627	0.630	0.641	0.659	0.683	0.711	0.725	1/4"
M	0.632	0.646	0.654	0.666	0.676	0.689	0.708	—	9/16"
N	0.639	0.650	0.659	0.667	0.675	0.686	0.700	—	21/32"
P	0.700	0.699	0.697	0.690	0.684	0.680	0.670	0.698	0

Sketch A
Profile of Secs G, H, P.

Sketch B
Profile of Secs A, B, C, D, E, F, M, N

Sketch C
Profile of Secs J, K, L

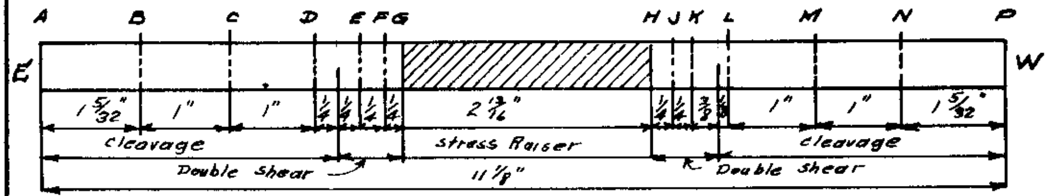


Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen B-10 Steel G As-Rolled

Sec.	Distance from Fracture X							
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.709	0.711	0.706	0.706	0.706	0.707	0.703	0.702	0
B	0.696	0.698	0.698	0.701	0.702	0.698	0.705	0.707	0
C	0.679	0.680	0.682	0.683	0.685	0.688	0.698	0.710	0
D	0.618	0.623	0.628	0.640	0.659	0.680	0.705	0.717	0
E	0.608	0.623	0.631	0.648	0.664	0.690	0.715	0.723	3/16"
F	0.625	0.638	0.648	0.669	0.689	0.709	0.720	0.726	3/16"
G	0.699	0.707	0.711	0.715	0.718	0.721	0.723	0.727	0
H	0.714	0.718	0.717	0.721	0.723	0.723	0.727	0.730	0
J	0.656	0.658	0.668	0.693	0.707	0.719	0.725	0.726	3/16"
K	0.627	0.632	0.638	0.654	0.674	0.700	0.720	0.727	1/4"
L	0.601	0.611	0.624	0.646	0.663	0.685	0.709	0.722	0
M	0.681	0.682	0.684	0.686	0.687	0.691	0.701	0.713	0
N	0.702	0.704	0.705	0.706	0.706	0.706	0.706	0.710	0
P	0.714	0.717	0.718	0.719	0.719	0.715	0.717	0.713	0

Sketch A
Profile of Secs
A, B, C, D, G, H, L, M, N, P.

Sketch B
Profile of Secs
E, F, J, K

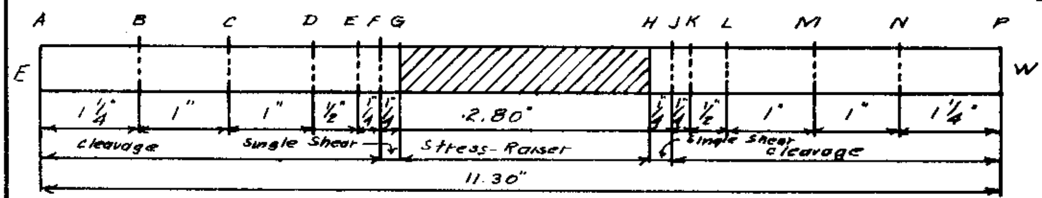


Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen B-5 Steel G As-Rolled

Sec.	Distance from Fracture X							
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.718	0.720	0.722	0.723	0.724	0.725	0.725	0.725	0
B	0.714	0.716	0.716	0.718	0.719	0.720	0.722	0.718	0
C	0.705	0.707	0.708	0.710	0.711	0.712	0.715	0.720	0
D	0.690	0.692	0.693	0.695	0.697	0.703	0.717	0.725	0
E	0.654	0.658	0.664	0.681	0.697	0.712	0.723	0.728	1/8"
F	0.651	0.668	0.691	0.702	0.713	0.720	0.727	0.730	1/4"
G	0.697	0.709	0.713	0.719	0.722	0.725	0.727	0.731	0
H	0.714	0.718	0.725	0.725	0.728	0.730	0.731	0.734	0
J	0.683	0.693	0.700	0.714	0.722	0.726	0.730	0.732	5/16"
K	0.651	0.660	0.671	0.687	0.706	0.718	0.728	0.731	5/32"
L	0.688	0.690	0.692	0.697	0.700	0.708	0.720	0.728	0
M	0.709	0.711	0.712	0.713	0.714	0.716	0.718	0.722	0
N	0.715	0.717	0.718	0.720	0.721	0.723	0.724	0.723	0
P	0.720	0.72[illegible]	0.726	0.727	0.727	0.728	0.728	0.728	0

Sketch A
Profile of Secs
A, B, C, D, G, H, L, M, N, P

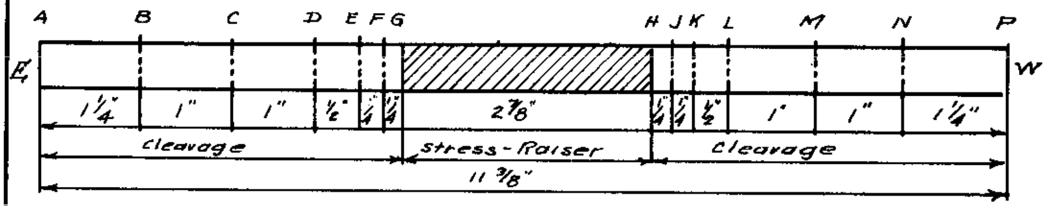
Sketch B
Profile of Secs
E, F, J, K.



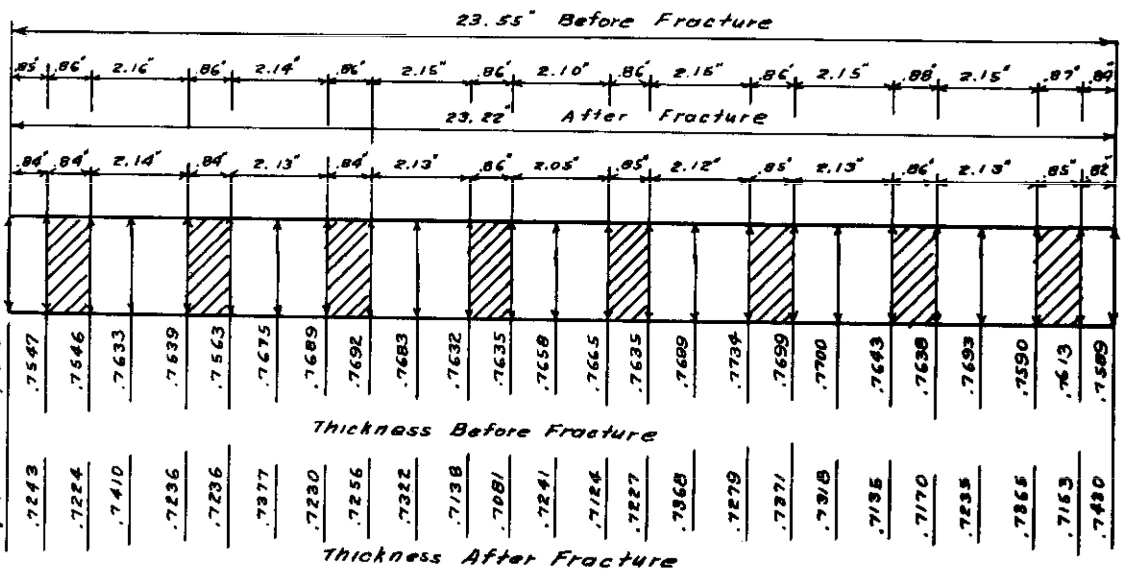
Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen B-9 Steel G As-Rolled

Sec	Distance from Fracture X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	0.722	0.726	0.729	0.731	0.732	0.734	0.734	0.734	0
B	0.724	0.726	0.727	0.729	0.731	0.731	0.731	0.733	0
C	0.722	0.723	0.724	0.725	0.726	0.728	0.730	0.732	0
D	0.719	0.720	0.720	0.721	0.722	0.724	0.730	0.733	0
E	0.714	0.715	0.716	0.718	0.721	0.724	0.732	0.735	0
F	0.707	0.709	0.701	0.714	0.717	0.726	0.733	0.736	0
G	0.711	0.717	0.721	0.726	0.729	0.732	0.735	0.738	0
H	0.715	0.723	—	0.728	0.731	0.733	0.738	0.739	0
J	0.706	0.711	0.714	0.715	0.717	0.729	0.735	0.740	0
K	0.714	0.715	0.716	0.717	0.721	0.726	0.734	0.738	0
L	0.716	0.722	0.722	0.724	0.724	0.726	0.733	0.736	0
M	0.726	0.727	0.728	0.729	0.730	0.732	0.732	0.733	0
N	0.727	0.729	0.731	0.732	0.733	0.742	0.734	0.734	0
P	0.729	0.732	0.735	0.735	0.736	0.738	0.736	0.736	0

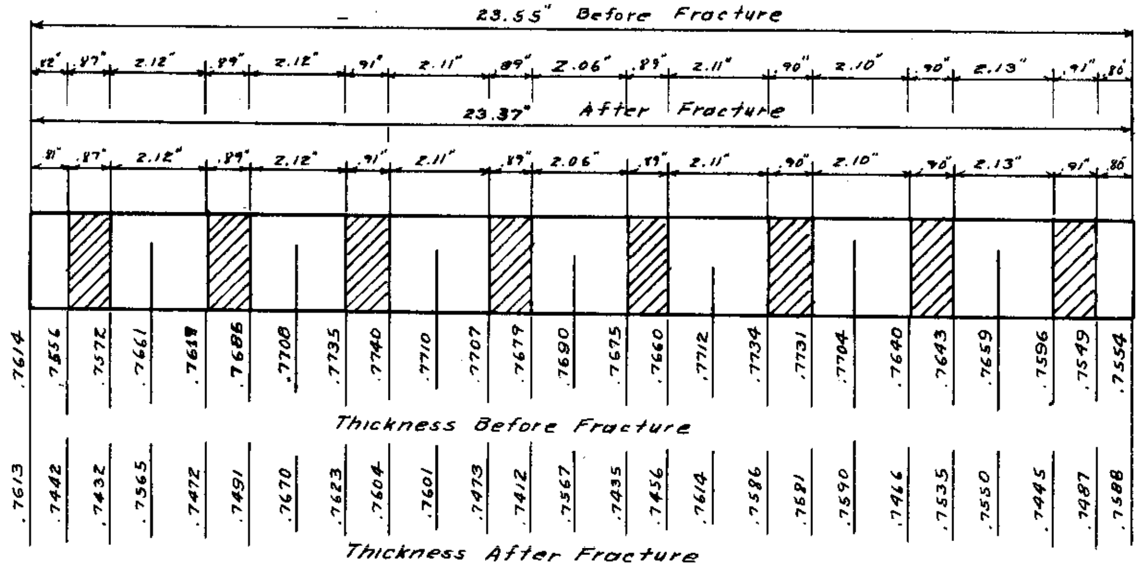
Sketch A
Profile of All Sections



Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen B-6 Steel G As-Rolled



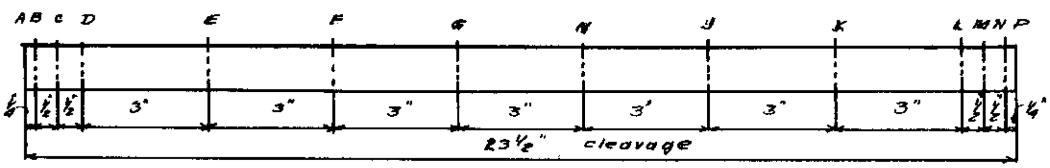
Thickness of Plate Before and After Fracture Taken at Edge of Fracture Specimen 17-9 Steel E As-Rolled 13/16-In Punched Holes as Stress-Raiser



Thickness of Plate Before and After Fracture Taken at Edge of Fracture. Specimen 17-8. Steel E As-Rolled 13/16-In. Punched Holes as Stress-Raiser

Sec	Distance from Fracture, X								
	0	1/16"	1/8"	1/4"	3/8"	5/8"	1 1/8"	1 5/8"	dx
A	.712	.713	.713	.711	.709	.709	.716	.716	0
B	.737	.738	.739	.738	.738	.737	.744	.750	0
C	.747	.750	.751	.751	.754	.757	.760	.757	0
D	.745	.748	.749	.750	.753	.755	.759	.756	0
E	.756	.753	.755	.756	.758	.758	.755	.755	0
F	.747	.754	.755	.757	.759	.760	.756	.756	0
G	.755	.757	.757	.758	.761	.762	.759	.759	0
H	.759	.760	.761	.762	.762	.763	.760	.759	0
J	.759	.761	.762	.763	.764	.765	.763	.762	0
K	.758	.761	.762	.763	.763	.764	.765	.762	0
L	.760	.760	.761	.762	.762	.762	.764	.759	0
M	.761	.762	.761	.763	.763	.763	.764	.762	0
N	.754	.754	.754	.753	.754	.753	.751	.759	0
P	.729	.729	.729	.730	.728	.728	.729	.737	0

Profile of All Sections



Thickness of Plate at Specified Distances from Fracture on Various Sections Normal to the Fracture Specimen 17-12 Steel E As-Rolled Sheared Edge Plate

APPENDIX B

MECHANICAL PROPERTIES AND

CHEMICAL ANALYSES OF MATERIALS.

From:

University of Illinois
College of Engineering

Report Prepared by:

Wilbur M. Wilson
Robert A. Hechtman
Walter H. Bruckner

LIST OF TABLES.

APPENDIX B.

MECHANICAL PROPERTIES AND CHEMICAL ANALYSES OF MATERIALS.

TENSILE COUPON TESTS.

Tensile coupons were taken from each plate used in this investigation for the purpose of determining the mechanical properties of the material. Duplicate tests were made of $1\frac{1}{2}$-in. x 3/4-in. A.S.T.M. standard flat tensile coupons in the direction of rolling and 0.505-in. diameter A.S.T.M. standard round tensile coupons both parallel and normal to the direction of rolling. The results of these tests are shown in Tables Ib and IIb. The chemical composition of these various steels are given in Table IIIb.

The mechanical properties for plates not given in this appendix have appeared previously in previous reports[1,2].

TABLE Ib.

MECHANICAL PROPERTIES OF MATERIALS.*

Standard A.S.T.M. 1½-in. x 3/4-in. Flat Tensile Coupons
Tested in Direction of Rolling.

PLATE NO.	STRENGTH, lb. per sq.in. ULTIMATE	YIELD POINT	ELONGATION IN 8 In., Percent	REDUCTION OF AREA, Percent
		RIMMED-STEEL E AS-ROLLED		
16	55 800	30 000	33.5	59.6
	56 400	30 200	29.2	56.3
Av.	56 100	30 100	31.4	58.0
18A	58 000	29 900	33.4	54.7
	57 700	29 800	30.9	54.7
Av.	57 900	29 900	32.2	54.7
		RIMMED-STEEL E NORMALIZED		
16	57 300	34 800	30.9	55.8
	58 100	35 400	30.8	55.8
Av.	57 700	35 100	30.9	55.8
		KILLED-STEEL D AS-ROLLED		
18A	67 100	39 200	29.7	52.0
	66 700	40 800	29.5	55.1
Av.	66 900	40 000	29.6	53.6
18B	65 400	38 600	29.7	52.9
	64 400	36 500	30.6	52.7
Av.	64 900	37 600	30.2	52.8
22	65 500	37 700	30.7	54.6
	64 700	36 800	29.2	55.6
Av.	65 100	37 300	30.0	55.1
22A	64 100	37 100	32.7	53.4
	63 800	36 100	31.0	54.8
Av.	64 000	36 600	31.9	54.1
22B	65 300	36 700	30.0	51.8
	63 500	36 200	29.3	56.4
Av.	64 400	36 500	29.7	54.1

* Mechanical properties of plates not appearing in this report are given in the previous reports[(1),(2)]. The normalizing treatments are described on page 7b of this appendix.

TABLE Ib. (Concl'd)

MECHANICAL PROPERTIES OF MATERIALS.

PLATE NO.	STRENGTH, lb. per sq.in. ULTIMATE	YIELD POINT	ELONGATION IN 8 In., Percent	REDUCTION OF AREA, Percent
		KILLED-STEEL D NORMALIZED		
3	58 700	34 300	32.5	59.0
	59 200	33 400	32.4	59.8
Av.	59 000	33 900	32.5	59.4
9	60 100	35 100	30.7	58.4
	59 900	34 800	31.7	60.2
Av.	60 000	35 000	31.2	59.3
10A	59 400	34 600	29.9	60.1
	59 400	35 300	31.3	59.4
Av.	59 400	35 000	30.6	59.8
12A	59 900	35 400	31.8	58.5
	59 600	34 200	30.9	56.3
Av.	59 800	34 800	31.4	57.4
		KILLED-STEEL F AS-ROLLED		
A	61 000	33 650	30.8	62.4
	60 500	34 450	30.3	62.4
Av.	60 750	34 050	30.6	62.4
		KILLED-STEEL G AS-ROLLED		
B	69 800	41 500	27.7	55.0
	70 300	41 100	28.0	56.6
Av.	70 100	41 300	27.9	55.8

TABLE IIb.

MECHANICAL PROPERTIES OF MATERIALS.*

Standard A.S.T.M. 0.505-In. Diameter Round Tensile Coupons.

PLATE NO.	ROLLING* DIRECTION	STRENGTH, lb. per sq.in. ULTIMATE	YIELD POINT	ELONGATION IN 2 In., Percent	REDUCTION OF AREA, Percent
		RIMMED-STEEL E AS-ROLLED			
16	P	59 800	31 900	36.0	59.0
	P	60 000	33 300	37.0	59.6
Av.		59 900	32 600	36.5	59.3
16	N	59 800	31 200	33.5	56.6
	N	59 900	31 100	33.0	56.7
Av.		59 900	31 200	33.3	56.7
18A	P	60 400	31 400	35.5	59.4
	P	60 100	31 800	34.5	59.5
Av.		60 300	31 600	35.0	59.5
18A	N	59 800	33 100	35.0	57.4
	N	59 600	31 900	35.0	57.4
Av.		59 700	32 600	35.0	57.4
		RIMMED-STEEL E NORMALIZED			
16	P	62 600	41 800	34.5	59.5
	P	62 200	40 700	35.0	60.1
Av.		62 400	41 300	34.8	59.8
16	N	62 200	42 300	37.0	57.4
	N	62 200	38 700	35.0	56.2
Av.		62 200	40 500	36.0	56.8

* Mechanical properties of plates not appearing in this report are given in the previous reports (1),(2). The normalizing treatments are described on page 7b of this appendix.

TABLE IIb. (Cont'd)

MECHANICAL PROPERTIES OF MATERIALS.

PLATE NO.	ROLLING DIRECTION*	STRENGTH, lb. per sq.in. ULTIMATE	YIELD POINT	ELONGATION IN 2 In., Percent	REDUCTION OF AREA, Percent
		KILLED-STEEL D AS-ROLLED			
18A	P	68 200	41 700	33.5	55.6
	P	68 200	41 400	35.5	59.6
Av.		68 200	41 600	34.5	57.6
18A	N	67 200	41 800	31.5	53.9
	N	67 500	44 000	33.0	54.0
Av.		67 400	42 900	32.3	54.0
18B	P	67 200	40 800	36.5	63.1
	P	67 600	41 300	35.0	61.9
Av.		67 400	41 100	35.8	62.5
18B	N	67 300	41 200	34.5	53.4
	N	67 500	41 700	33.5	55.8
Av.		67 400	41 500	34.0	54.6
22	P	67 900	40 600	34.6	61.9
	P	68 000	38 600	33.5	61.6
Av.		68 000	39 600	34.0	61.8
22	N	67 500	38 400	32.5	57.5
	N	67 500	37 800	33.0	56.0
Av.		67 500	38 100	32.8	56.8
22A	P	64 500	37 800	35.5	65.5
	P	64 200	37 900	35.0	61.4
Av.		64 400	37 900	35.3	63.5
22A	N	64 500	39 000	35.0	57.4
	N	64 700	37 500	35.0	58.5
Av.		64 600	38 300	35.0	58.0
22B	P	67 100	38 300	35.0	61.0
	P	67 100	38 100	35.0	60.0
Av.		67 100	38 200	35.0	60.5
22B	N	66 900	38 400	35.0	57.7
	N	67 100	38 200	32.0	57.8
Av.		67 000	38 300	33.5	57.8

TABLE IIb (Concl'd).

MECHANICAL PROPERTIES OF MATERIALS

PLATE NO.	ROLLING DIRECTION*	STRENGTH, lb. per sq.in. ULTIMATE	YIELD POINT	ELONGATION IN 2 In., Percent	REDUCTION OF AREA, Percent
		KILLED-STEEL D NORMALIZED			
9	P	63 400	38 400	36.5	63.3
	P	63 700	38 700	37.0	64.2
Av.		63 600	38 600	36.8	63.8
9	N	63 200	37 200	37.0	61.8
	N	63 400	37 800	34.5	61.3
Av.		63 300	37 500	35.8	61.6
10A	P	62 600	37 100	35.0	61.6
	P	62 500	37 300	35.5	60.4
Av.		62 600	37 200	35.3	61.0
10A	N	62 700	37 600	34.5	57.0
	N	62 700	37 400	35.5	58.0
Av.		62 700	37 500	35.0	57.5
12A	P	62 900	37 500	35.0	62.5
	P	63 000	37 600	35.0	63.2
Av.		63 000	37 600	35.0	62.9
12A	N	64 200	37 800	36.0	59.0
	N	63 100	37 900	34.5	56.7
Av.		63 700	37 800	35.3	57.9

TABLE IIIb.

CHEMICAL ANALYSES OF PLATE STEELS.*

KIND OF STEEL	CHEMICAL ANALYSIS - Per Cent													
	C	Mn	P	S	Si	Al	Ni	Cu	Cr	Mo	Sn	V	As	N
Rimmed-Steel E As-Rolled	.20	.33	.013	.020	.01	.009	.15	.18	.09	.018	.024	.02	.01	.005
Killed-Steel D As-Rolled	.22	.55	.013	.024	.21	.020	.16	.22	.12	.022	.023	.02	.01	.005
Killed-Steel D Normalized	.19	.54	.011	.024	.19	.019	.15	.22	.12	.021	.025	.02	.01	.006
Killed-Steel F As-Rolled	.18	.82	.012	.031	.15	.054	.04	.05	.03	.008	.021	.02	.01	.006
Killed-Steel G As-Rolled	.20	.86	.020	.020	.19	.045	.08	.15	.04	.018	.012	.02	.01	.006

HEAT TREATMENT OF NORMALIZED STEELS.

Killed-steel D normalized was normalized at the rolling mill at a temperature of 1650 degrees F. The length of time at the normalizing temperature is not known.

Rimmed-steel E normalized was normalized at the University of Illinois. It was held at a temperature of 1650 degrees F. for one hour and then cooled in still air.

* Data furnished by Dr. S. Epstein, Bethlehem Steel Corporation.

APPENDIX C.

TENSILE PROPERTIES OF MATERIALS AT DIFFERENT TEMPERATURES.

From:
University of Illinois
College of Engineering

Report Prepared by:
Wilbur M. Wilson
Robert A. Hechtman
Walter H. Bruckner

LIST OF FIGURES.

APPENDIX C

TENSILE PROPERTIES OF MATERIALS AT DIFFERENT TEMPERATURES

In Appendix B are described tensile coupon tests at room temperature made with 0.505-in. diameter A.S.T.M. standard round tensile specimens. Tests of the same type of specimens at different temperatures ranging from approximately 150°F. to -100°F. are described in this appendix. The tensile coupons for these tests were taken from one plate for each kind of steel and were made for all the kinds of steel covered in this Final Report.

1. Procedure: Specimens tested below room temperature were immersed directly in the refrigerating liquid, while specimens tested above room temperature were heated with infra-red lamps. The specimens were brought to the testing temperature, mounted in the testing machine, and then kept at the testing temperature for about twenty minutes to insure uniform distribution of temperature. A thermocouple in intimate contact with the specimen was used to measure the specimen temperature. An attached extensometer with an initial gage length of 2-in. measured the elongation.

2. Data: The mechanical properties of the different kinds of steels are tabulated in Table 1c and plotted in the diagrams of Figs. 1c to 5c, inclusive. The fractured specimens are shown in Figs. 6c, 7c and 8c.

TABLE Ic

TESTS OF 0.505-IN. DIAMETER TENSILE COUPONS AT DIFFERENT TEMPERATURES FOR THE VARIOUS KINDS OF STEEL.

PLATE NO.	TEMP. °F.	STRENGTH, lb. per sq.in. ULTIMATE	STRENGTH, lb. per sq.in. YIELD POINT	YIELD POINT / ULT. STRENGTH Percent	ELONGATION IN 2 In., Percent	REDUCTION OF AREA, Percent
			RIMMED-STEEL E AS-ROLLED			
20A	151	61 600	34 000	55.2	34.0	56.7
	151	61 600	33 800	54.9	33.0	59.3
Av.	151	61 600	33 900	55.1	33.5	58.1
20A	74	65 000	34 900	53.7	35.5	60.6
	75	64 500	36 900	57.2	34.5	56.5
Av.	74.5	64 800	35 900	55.4	35.0	58.6
20A	0	67 800	36 000	53.1	36.0	59.4
	+1	68 400	35 800	52.4	34.0	55.8
Av.	+0.5	68 100	35 900	52.8	35.0	57.6
20A	-49	70 800	40 200	56.8	39.0	55.1
	-50	70 600	43 100	61.0	36.0	53.0
Av.	-49.5	70 700	41 700	58.9	37.5	54.1
20A	-98	75 500	48 600	64.4	36.5	52.4
	-102	75 900	50 400	66.4	36.5	56.5
Av.	-100	75 700	49 500	65.4	36.5	54.5
			KILLED-STEEL D AS-ROLLED			
18	146	63 500	39 000	61.4	34.0	62.9
	147	63 500	40 100	63.2	36.0	64.0
Av.	146.5	63 500	39 600	62.4	35.0	63.5
18	70	66 200	39 600	59.8	36.5	60.8
	75	66 500	40 500	60.9	35.0	62.4
Av.	72.5	66 400	40 100	60.4	35.8	61.6
18	-1	70 200	41 200	58.7	37.0	61.5
	+5	69 900	42 400	60.7	36.0	60.8
Av.	+2	70 100	41 800	59.7	36.5	61.2
18	-47	72 900	44 400	61.0	39.5	62.9
	-50	71 900	48 100	66.9	34.0	61.1
Av.	-48.5	72 400	46 100	64.0	39.0	60.9
18	-101	77 600	51 800	66.7	39.5	62.4
	-103	77 300	50 500	65.3	38.5	59.3
Av.	-102	77 500	51 200	66.1	39.0	60.9

TABLE Ic (Cont'd)

TESTS OF 0.505-IN. DIAMETER TENSILE COUPONS AT DIFFERENT TEMPERATURES FOR THE VARIOUS KINDS OF STEEL.

PLATE NO.	TEMP. °F.	STRENGTH, lb. per sq. in. ULTIMATE	STRENGTH, lb. per sq. in. YIELD POINT	YIELD POINT / ULT. STRENGTH Percent	ELONGATION IN 2 In., Percent	REDUCTION OF AREA, Percent
		KILLED-STEEL D NORMALIZED				
5A	148	60 100	36 800	61.2	36.0	67.3
	145	60 000	36 400	60.6	36.0	67.3
Av.	146.5	60 100	36 600	60.9	36.0	67.3
5A	74	62 000	36 900	59.5	37.0	64.5
	74	62 000	37 100	59.9	36.0	65.5
Av.	74	62 000	37 000	59.7	36.5	65.0
5A	0	66 700	41 700	62.5	37.0	64.6
	-2	66 700	42 700	64.0	40.5	65.5
Av.	-1	66 700	42 100	63.3	38.8	65.1
5A	-49	69 300	42 500	61.3	41.0	56.2
	-49	70 100	45 600	65.0	29.0	62.5
Av.	-49	69 700	44 100	63.2	35.0	59.4
5A	-100	74 400	51 700	69.6	41.0	61.9
	-99	73 900	50 600	67.4	38.5	59.9
Av.	-99.5	74 200	51 200	68.3	39.8	60.9
		KILLED-STEEL F AS-ROLLED				
A	151	58 400	34 600	59.3	38.0	69.0
	152	58 100	35 700	61.4	39.0	64.8
Av.	151.5	58 300	35 200	60.4	38.5	66.9
A	76	61 300	34 800	56.8	36.5	62.9
	75	60 800	36 500	60.1	37.5	67.5
Av.	75.5	61 100	35 700	58.4	37.0	65.7
A	-4	64 400	35 700	55.4	37.5	63.7
	+2	64 200	36 800	57.3	39.0	67.6
Av.	-1	64 300	36 300	56.5	38.3	65.7
A	-49	67 000	39 900	59.6	34.0	61.9
	-48	67 200	39 000	58.0	40.0	66.0
Av.	-48.5	67 100	39 500	58.9	37.0	64.0
A	-100	70 700	45 400	64.2	30.0	64.4
	-99	71 500	44 300	61.9	43.0	65.4
Av.	-99.5	71 100	44 900	63.2	37.7	65.0

TABLE Ic (Concl'd)

TESTS OF 0.505-IN. DIAMETER TENSILE COUPONS AT DIFFERENT TEMPERATURES FOR THE VARIOUS KINDS OF STEEL.

PLATE NO.	TEMP. °F.	STRENGTH, lb. per sq. in. ULTIMATE	STRENGTH, lb. per sq. in. YEILD POINT	YIELD POINT / ULT. STRENGTH Percent	ELONGATION IN 2 In., Percent	REDUCTION OF AREA, Percent
			KILLED-STEEL G AS-ROLLED			
B	150	68 700	43 400	63.2	34.0	64.0
	152	68 900	40 500	58.8	31.5	62.2
Av.	151	68 800	42 000	61.1	32.8	63.1
B	75	75 700	42 500	56.2	34.0	59.2
	74	72 400	42 900	59.3	33.0	62.3
Av.	74.5	74 100	42 700	57.7	33.5	60.8
B	-10	76 800	45 200	59.0	34.0	60.0
	+2	75 400	45 100	59.8	33.5	61.2
Av.	-4	76 100	45 200	59.4	33.8	60.6
B	-49	78 800	49 500	62.8	38.5	61.2
	-49	79 400	50 800	63.9	35.5	59.5
Av.	-49	79 100	50 200	63.5	37.0	60.4
B	-100	84 100	56 000	66.4	36.5	57.0
	-102	83 500	51 100	61.2	35.0	60.2
Av.	-101	83 800	53 600	64.0	35.8	58.6

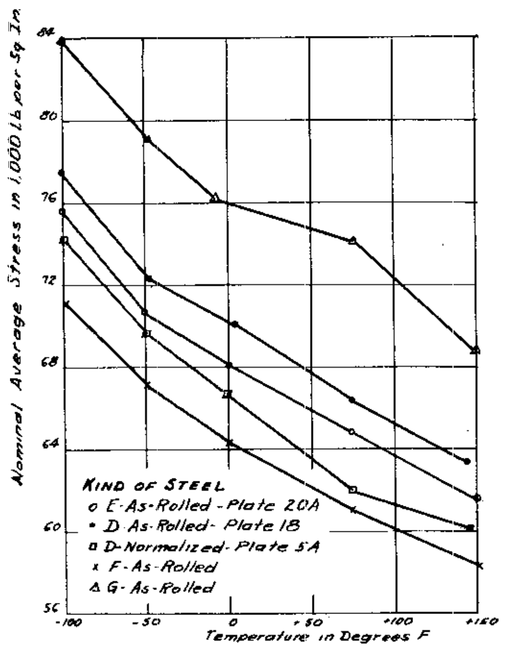


Fig. 1c.
Comparison of Temperature and Nominal Ultimate Strength for 0.505-In. Diameter Tensile Coupons, Average of Two Specimens

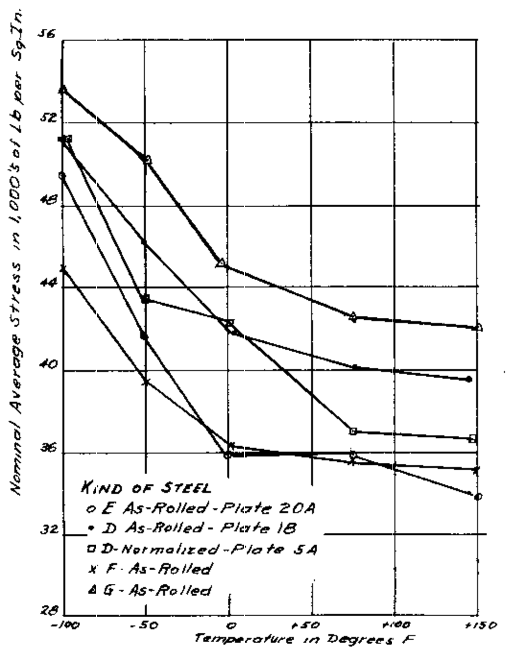


Fig. 2c
Comparison of Temperature and Yield Point for 0.505-In. Diameter Tensile Coupons, Average of Two Specimens

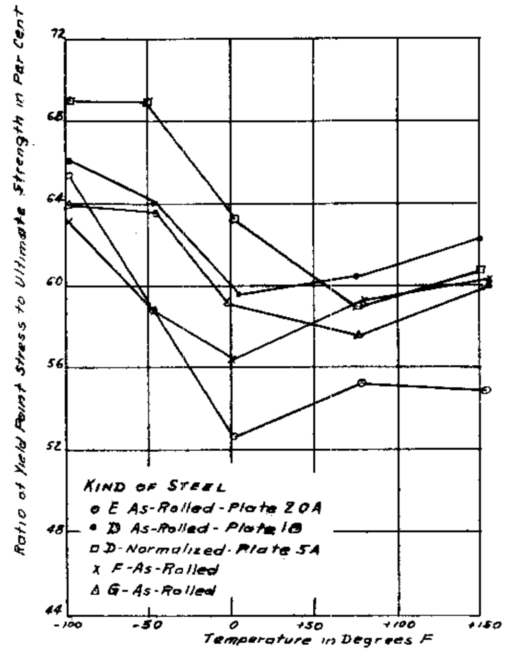


Fig. 3c
Comparison of Temperature and Ratio of Yield Point Stress to Ultimate Strength for 0.505-In. Diameter Tensile Coupons, Average of Two Specimens

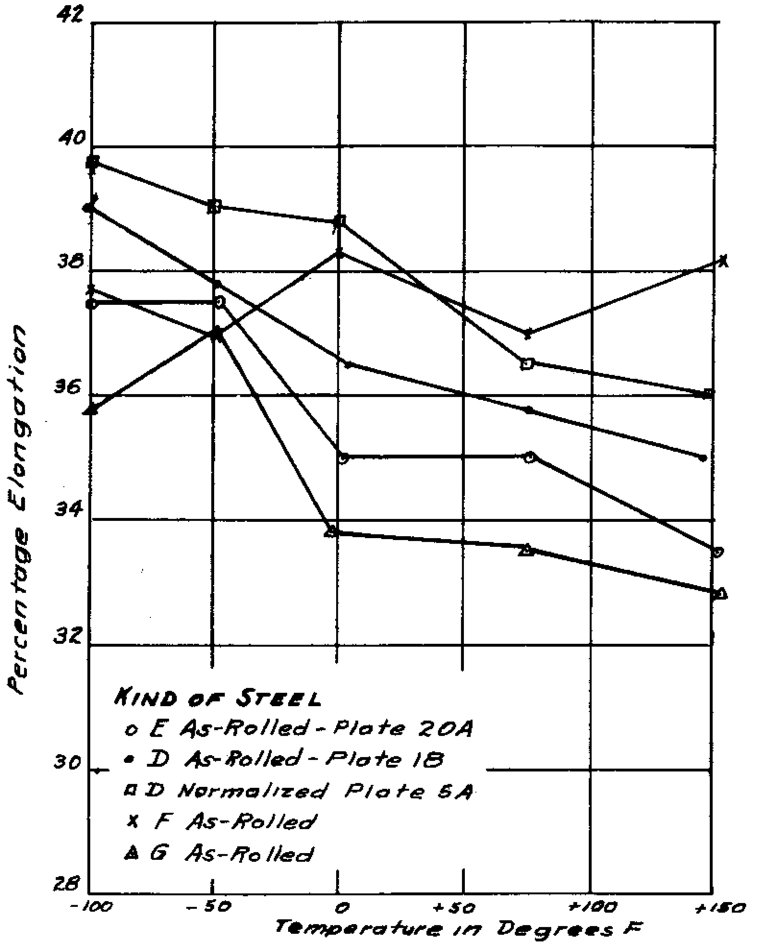


Fig. 4c
Comparison of Temperature and Percentage Elongation in 2-In. for 0.505-In. Diameter Tensile Coupons, Average of Two Specimens

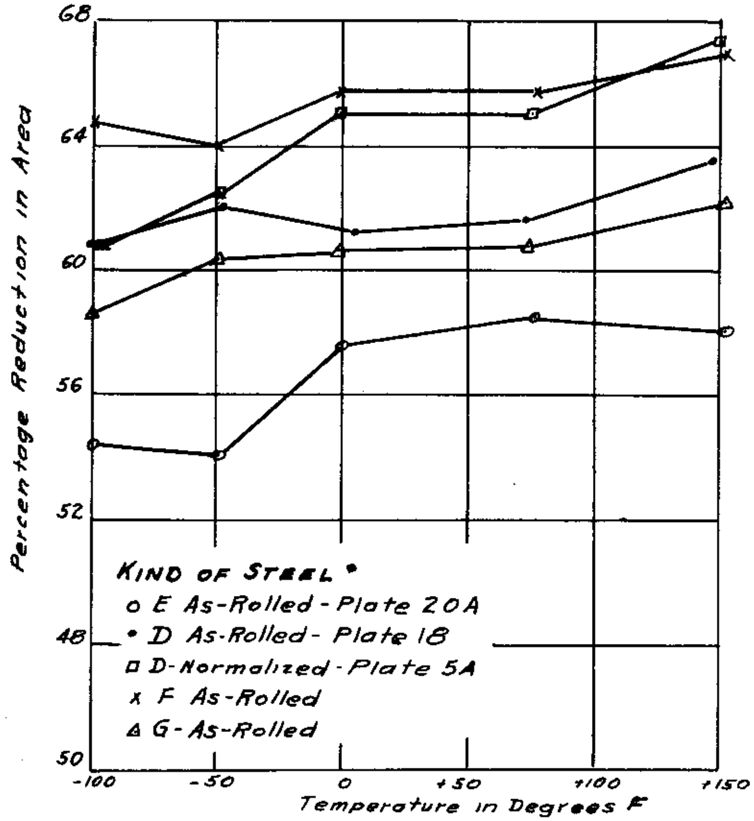
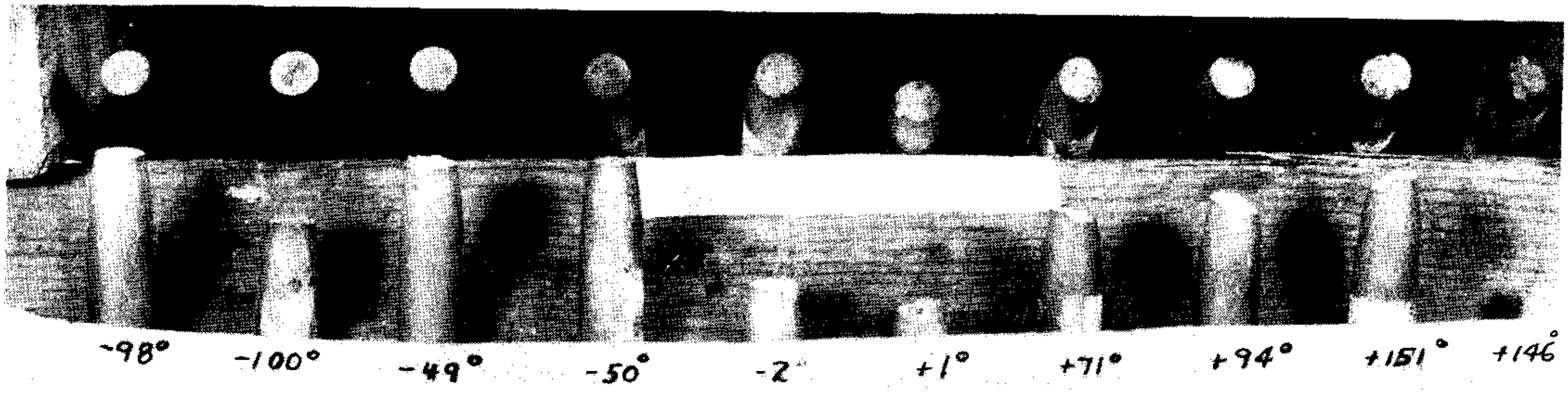


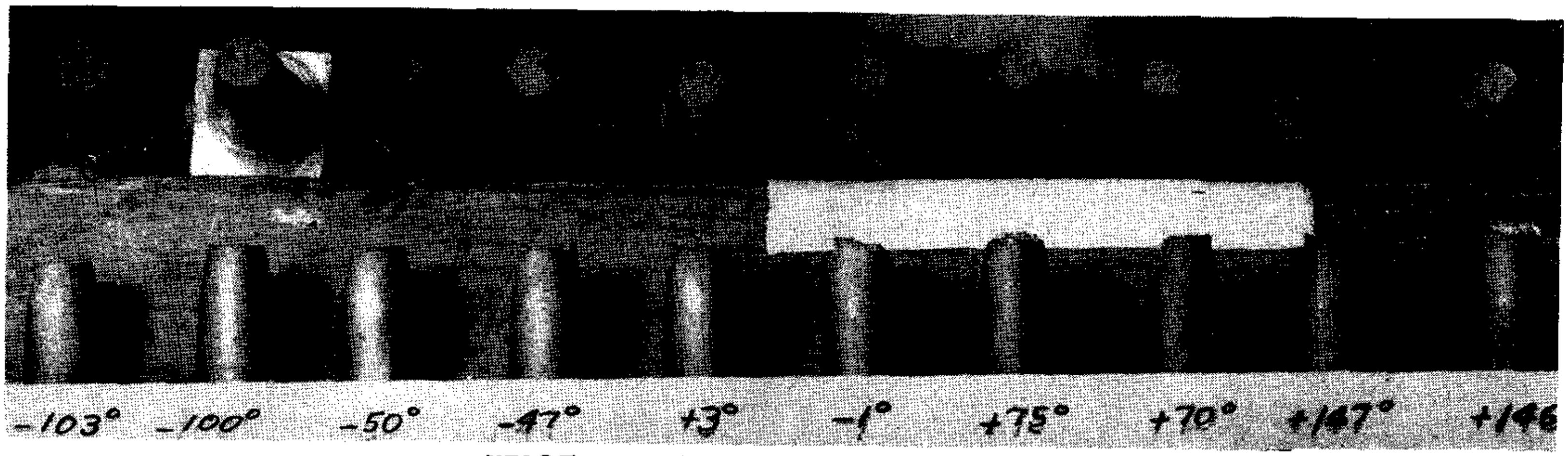
Fig. 5c
Comparison of Temperature and Reduction in Area for 0.505-In. Diameter Tensile Coupons, Average of Two Specimens

3. Discussion of Data: As shown in Figs. 1c and 2c, the nominal ultimate strengths of all five kinds of steel increased about 22 percent when the temperature was reduced from approximately 150°F. to -100°F., while the yield points increased between 27 and 40 percent for the same reduction of temperature. The ratio of the yield point to the nominal ultimate strength increased as the temperature was decreased as shown in Fig. 3c. The percentage elongation in 2-in. was about the same for all temperatures while the reduction in area decreased slightly with decrease in temperature.

The nature of the fracture changed as the temperature was reduced. The shear cone present in the specimens tested at room temperature gradually disappeared until at -100°F. no evidence of a shear cone was visible.



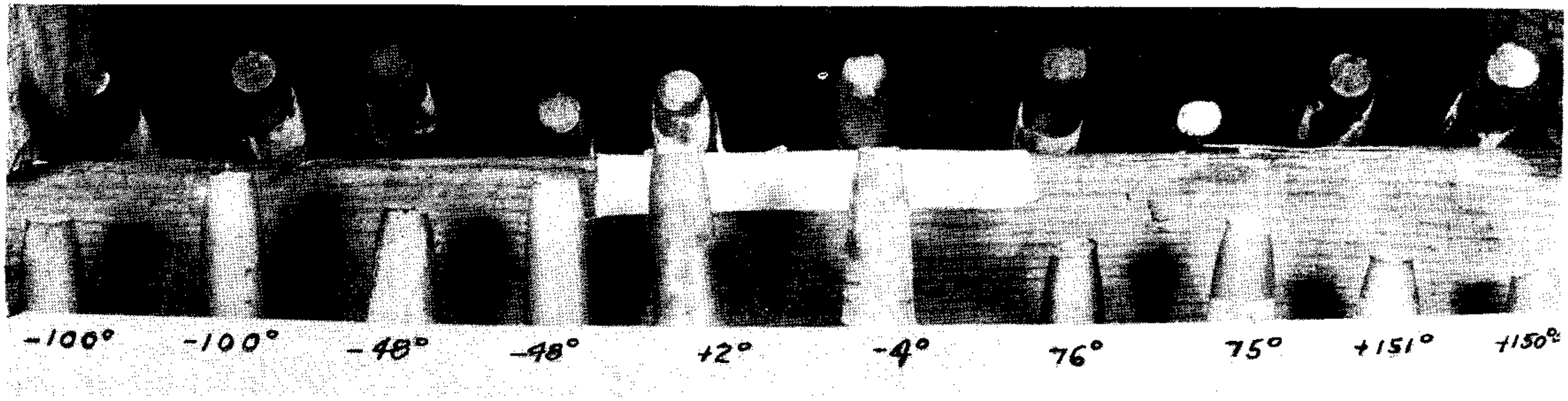
RIMMED-STEEL E AS-ROLLED



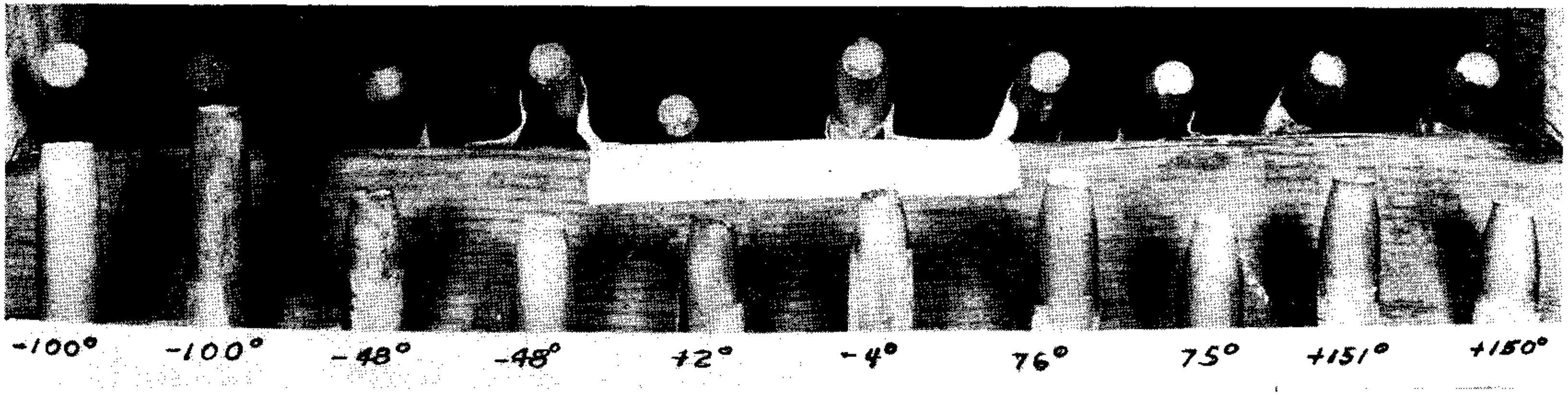
KILLED-STEEL D AS-ROLLED

FIG. 6c.

FRACTURES OF TENSILE COUPON SPECIMENS TESTED AT DIFFERENT TEMPERATURES.
STEELS E AS-ROLLED AND D AS-ROLLED.



KILLED-STEEL D NORMALIZED



KILLED-STEEL F AS-ROLLED

FIG. 7c.

FRACTURES OF TENSILE COUPON SPECIMENS TESTED AT DIFFERENT TEMPERATURES.
KILLED-STEELS D NORMALIZED AND F AS-ROLLED.

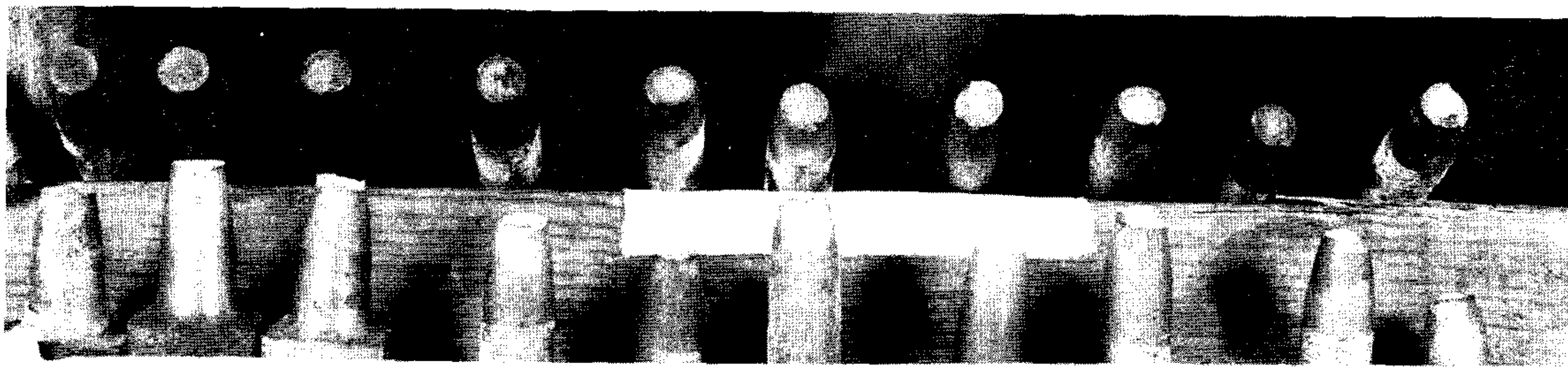


FIG. 8c.
FRACTURES OF TENSILE COUPON SPECIMENS TESTED AT DIFFERENT TEMPERATURES.
KILLED-STEEL G AS-ROLLED.

APPENDIX D

HARDNESS SURVEYS AND ENERGY-ABSORPTION ANALYSES OF FRACTURED WIDE PLATE SPECIMENS.

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APPENDIX D.

HARDNESS SURVEYS AND ENERGY-ABSORPTION ANALYSES OF FRACTURED SIDE PLATES.

SYNOPSIS

The fact that plastic elongation of a metal increases its hardness is well known. Moreover, the greater the plastic deformation, the higher the hardness. Furthermore, since energy must be expended to produce plastic deformation, and thereby an increase in hardness, it is possible to determine the relation between the amount of energy absorbed and the increase in hardness. This relation between energy absorption and increase in hardness has been used to study the distribution and total amount of energy absorbed by permanently strained plates.*

The method outlined in the previous paragraph has been used to determine the energy absorbed by three wide-plate specimens with jeweler's-saw cut stress-raisers which were tested statically to failure in tension. The three specimens were all from the same heat of killed-steel D as-rolled. The thickness was 3/4" and the length of the stress-raiser was one-fourth of the width of the plate for all specimens. The application of this method involved the following studies:

Part I - Hardness surveys of wide plates tested to failure in tension.

Part II- Hardness surveys of control specimens and energy absorption determination of wide plates.

It was of interest to compare the maximum hardness near the fracture for the wide plate specimens and for the tensile coupon specimens. This comparison is made in Part III, Vickers hardness studies of fractures in wide-plate

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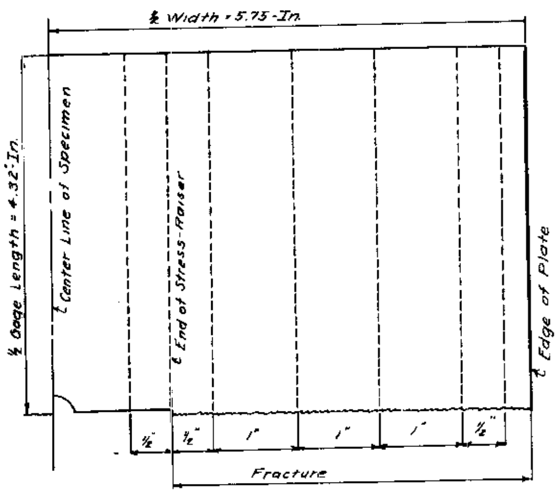
* The suggestion that the energy absorption of a wide plate could be studied in this manner was made by Dr. E. R. Parker, University of California.

specimens and standard tensile specimens.

PART I. Hardness Survey of Wide Plates Tested to Failure in Tension

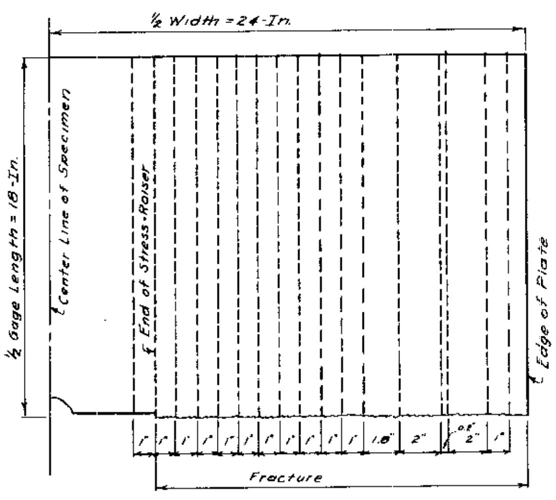
The specimens used in these tests were made of 3/4" killed-steel D as-rolled plates and all were from the same heat. They all had a jeweler's-saw cut stress-raiser with a length equal to one-fourth the width of the plate. The specimen numbers and widths were as follows: 17A-5A, 12" wide tested at $-50^{o}F.$; 18-1, 48" wide tested at $18^{o}F.$; and 17-7, 72" wide tested at $0^{o}F.$ These plates had all been tested in the series of wide-plate tests and the energy absorption to failure had been determined from the measured elongation of 8 gage lines over a length equal to 3/4 W (width of plate). The energy absorption to failure for these three wide-plate specimens, as determined from the elongation on a gage length equal to 3/4 W, had values of 23,600 in./lb., 304,000 in./lbs., and 228,000 in./lb., respectively. All three plates failed with a 100% cleavage fracture.

Values of the energy absorption of the same plates, based on a hardness survey of one-quarter of each specimen, were determined in the following manner: The four quarters into which each plate is divided by longitudinal and transverse centerlines are geometrically similar and were similarly loaded. A general hardness survey was made of one-quarter of each specimen, using a Rockwell B indenter. The hardness indents were made on planes normal to both the plane of fracture and the rolled surfaces of the plate. One quarter of each wide-plate specimen was sawed into strips as shown in Figs. 1d, 2d, and 3d, for specimens 17A-5A, 18-1, and 17-7 respectively. The sawed surfaces were ground with a coolant and finished by polishing with a No. 1/2 grit metallographic polishing paper.



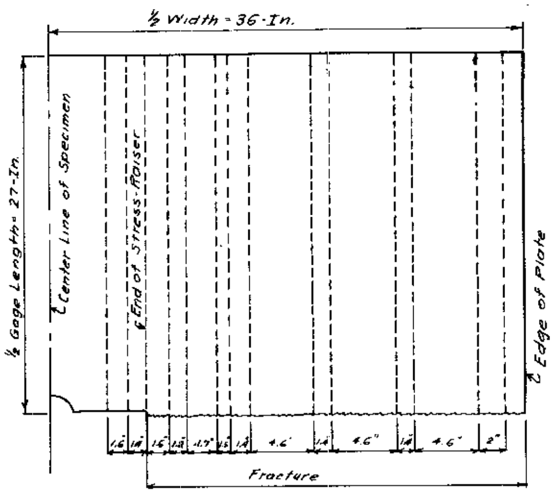
Note: Position of Planes of Hardness Tests Shown
By Dashed Lines

Fig. 1d
One-Fourth of Specimen 17A-5A Showing
Lines for Cutting of Samples for Hardness
Surveys.



Note: Position of Planes of Hardness Tests Shown
By Dashed Lines

Fig. 2d
One-Fourth of Specimen 18-1 Showing
Lines for Cutting of Samples for Hardness
Surveys.



Note: Position of Planes of Hardness Tests Shown
By Dashed Lines

Fig. 3d
One-Fourth of Specimen 17-7 Showing
Lines for Cutting of Samples for Hardness
Surveys.

Before the hardness tests were made, the strips sawed from the wide-plate specimens were heated in water to 212°F. for two hours. This procedure was followed in order to age the plastically deformed metal to a condition in which no further change in hardness would occur at room temperature.

The strips cut from the wide-plate specimens in the manner described were then tested for hardness as indicated by the indents shown in the lower part of Fig. 4d. These indents are on a plane normal to both the fracture and the rolled surfaces of the plate. The location of the indents relative to both the fracture and the rolled surfaces of the plate is shown in the upper part of Fig. 4d. The hardness indents on a line perpendicular to the rolled surfaces gave closely similar hardness values, and the average of the three was taken as representative of the region. Hardness indents similar to the ones shown on Fig. 4d gave the hardness at points at various distances from the plane of the fracture and at various distances from a longitudinal plane normal to the rolled surfaces of the plate and tangent to the outer end of the stress-raiser. The hardness variation from the fracture to the outer end of the 3/4 W gage lengths is shown, for each of the various strips of the 12-in. plate specimen 17A-5A by the diagrams of Fig. 5d. There are six of these diagrams. The numeral in the circle at the right of each is the distance in inches from a longitudinal line tangent to the outer end of the stress-raiser to a longitudinal plane on which the hardness was measured. The upper left diagram labeled "-1/2" is for a longitudinal plane 1/2" inside of the outer end of the stress-raiser. The distance of any point on a digram from its left end is the longitudinal distance from the fracture to the indent from which the hardness in question was determined.

The iso-hardness contours for specimen 17A-5A, shown in Fig. 6d, were determined from the hardness diagrams of Fig. 5d. The iso-hardness contours for specimens 18-1 and 17-7, shown in Figs. 7d and 8d were determined in a similar manner.

PART II. <u>Hardness Surveys of Control Specimens and Energy Absorption Determination of Wide Plates</u>

In order to translate hardness increments into energy absorption, it was necessary to know the relation between a hardness increment due to plastic deformation and the energy required to produce that plastic deformation. Both tension and compression tests were used in this determination, and in the following manner.

For the compression tests, the specimens were 3/4" cylinders 3/4" high with axis parallel to the direction of rolling. The flat ends of the cylinders were made parallel planes by surface grinding. Their length and diameter were carefully measured with micrometer calipers before and after loading. For the tension tests, standard 0.505" round specimens were used. A series of nine specimens were pulled to give pre-determined residual plastic strains ranging from 1% to 30%. After straining a specimen, a piece about 3/4" long was cut from its center and the Rockwell B Hardness was determined on one flat end after the ends had been prepared as previously described for the compression tests. The cylinders were then aged for two hours at 212°F. and the hardness was determined on the end opposite to the end used for the "as-strained" hardness test.

The load-strain for these small cylinders are given in Fig. 10d for the compression tests and in Fig. 11d for the tensile tests. The corresponding hardness-strain curves are shown by the dash lines in the same figures.

The hardness-energy curves for the compression and tensile calibration tests are shown in Fig. 12d and were derived as follows:

1. A strain corresponding to a particular hardness value was selected on the hardness-strain curve.

2. The area under the load-strain curve was integrated with a planimeter from zero strain to the selected strain. This area was the energy

absorbed in inch pounds in the volume of the specimen bounded by the initial gage length.

3. This energy was converted to inch pounds per cubic inch of specimen volume.

4. The hardness in step 1 was plotted against the energy per cubic inch and a point on the hardness-energy curve was thus determined.

A repitition of this procedure determined the other points on the curve.

The energy absorbed to fracture in 1/4 of each of the wide plate specimens 17A-5A, 12 inches wide; 18-1, 48 inches wide, and 17-7, 72 inches wide, was determined by integrating the area between consecutive iso-hardness contour lines, converting the area to plate volume, and multiplying the plate volume by the energy absorption corresponding to the average hardness as determined from the curves of Fig. 12d. The total energy absorbed in one-quarter of a wide plate specimen surveyed was then multiplied by 4 to give the energy absorbed in the whole specimen. This procedure was based on the assumption that the energy absorbed in one-quarter of the specimen was 1/4 of the total energy absorption.

Tables Id, IId, and IIId give the total volumes plastically deformed to each of several different hardness levels and the energy absorption corresponding to these total volumes and hardnesses. The corresponding energy absorbed, given in Tables Id, IId and IIId, is based on both compression and tensile tests. The total energy absorption is shown at the bottom of each of the two right-hand columns. These energy values are compared in Table IVd with the corresponding values obtained from the strain gage readings.

The data in Table IVd indicates that, for the limited number of tests made, the energy absorption determined by means of hardness surveys and by means of strain gage readings differed considerably. For the 12-inch specimen, the energy absorption determined by hardness surveys was less than the energy absorption determined from strain gage readings, while for the 48-in. and 72-in. specimens the reverse was true.

A review of the possible sources of errors in determining energy absorption by means of hardness surveys shows the following to be of significance.

1. For Specimen 17A-5A both the width, 12 inches, and the testing temperature, -50^{o}F., were such as to produce an extremely small region of high energy absorption. The Rockwell B hardness indentations could not be spaced sufficiently closely for the 12-inch specimen to record higher values than the maximum of 82 Rockwell B. If a Vicker's hardness tester had been used, a more accurate hardness survey could have been made in the regions of greatest energy absorption.

2. The uncertainty of extrapolations of the iso-hardness contours, as shown by the dotted lines in Figs. 6d, 7d, and 8d, may have contributed large errors to the energy absorption evaluation. For the 72-inch specimen, No. 17-7, the largest contribution to the total energy absorbed was made by the large areas of low hardness for which the hardness values were determined largely by extrapolation.

3. The assumption of symmetry of plastic behavior with respect to the vertical and horizontal central axes of the specimen may not be entirely correct. For the 12-inch specimen 17A-5A, the quarter portion taken for hardness surveys had a somewhat lower elongation as determined from strain gage readings than the portion on the other side of the vertical centerline, as shown by the diagrams on page 15a. It would, therefore, be expected that the energy evaluation from hardness surveys might be low for this 12-inch specimen. While the strain gage measurements on the wider plates, 48 and 72 inches wide,

show essentially uniform elongation on both sides of the vertical axis of the specimens, these strain readings gave no indication of the symmetry of plastic behavior above and below the horizontal axis of the specimen.

4. The reproducibility of Rockwell B hardness values in uniform material is considered by the manufacturers of the hardness testing machine to be ± 1 Rockwell B number. It was possible with careful attention to testing details to obtain a reproducibility of ± 1/2 Rockwell B hardness on the check-blocks for hardness testing supplied by the company. The average base hardness of our as-rolled plate may vary as much as 2 or $2\frac{1}{2}$ Rockwell B numbers over portions of a large plate of killed steel as-rolled. Moreover, all three wide plate specimens were from different parent plates. Inasmuch as the increment in hardness due to the plastic strain was small, a small error in the basic hardness would cause a relatively large error in the energy absorbed as determined by hardness increment.

5. The three wide plate specimens could not be sectioned and surveyed for base hardness values before being tested. The assumption, therefore, of the same base hardness, 73, Rockwell B after aging 2 hours at 212°F., for the three wide plate specimens may have been in error.

A determination of the energy absorbed by a wide plate plastically deformed would seem to be possible from a study of the hardness increment. However, so many factors appear to be involved that the procedure to be followed should be developed in tests under conditions which permit of a careful control of all the factors that affect the results.

Although the energy evaluation by means of hardness surveys did not produce a successful measure of the total energy absorbed, the iso-hardness contours nevertheless are of value in showing the manner in which the strain is localized at the stress-raiser.

PART III. Vicker Hardness Studies of Fractures In Wide-Plate Specimens and Standard Tensile Specimens.

Tests were planned to determine the hardness near the fracture of steel specimens that had been loaded to failure in tension. Two types of specimens were used. (1) Plates with severe geometrical stress raisers that had been used in the wide-plate tests. (2) Standard round 0.505" tension specimens. Specimens of both types were studied which had been tested at various temperatures ranging from -100° F. to +150°F. The hardness tests were made with a Vickers hardness tester in order that the hardness could be measured at points near the fracture. With this instrument, using a load of 10 kilograms, the hardness could be determined with confidence at a distance from the edge of the plate of 0.02 in.

The wide-plate specimens used in these studies were: all of killed steel D as-rolled, the plates for all specimens being from the same heat. These specimens were as follows: 17A-5A, a 12-in. plate tested at a temperature of -50° F.; 17-7, a 72-in. plate tested at a temperature of 0° F.; and 18-1, a 48-in. plate tested at a temperature of 18° F.

Vickers hardness studies were made on longitudinal planes normal to the rolled surfaces of the plate and 1/16 inch outside of the outer end of the jeweler's-saw cut stress-raiser. The selected planes represented a surface having for its width the full 3/4-inch plate thickness and a length of about 1-inch measured from the fracture surface. This surface was given a metallographic polish and lightly etched. The hardness tests were made with a load of 10 kilograms on lines parallel with the rolled surfaces. The first line was spaced 0.02 inch from the nearest rolled surface and the lines thereafter were spaced 1/16 inch apart. On each of these mutually parallel lines, the indents were spaced 0.02 inch from the fracture and thereafter 0.02 inch from each other up to a distance of about 1/2 inch from the fracture. Beyond the 1/2 inch distance from the fracture the indents were spaced at 1/16 inch intervals.

The 0.505-inch diameter tensile specimens* were prepared for hardness tests by cutting the cylindrical specimens in half along the diametral plane in the longitudinal direction with a thin, slitting saw. Each specimen was heated for 2 hours to 212° F., to promote rapid aging. After being mounted in a block of Wood's metal, these longitudinal sections were then ground and polished for Vickers hardness tests. The hardness indents were made along the centerline of the flat, polished surface at intervals of 0.02 inch from the fracture to a distance of about 1/4 inch from the fracture; beyond this point the indents were spaced at 1/16 inch intervals.

For the five 0.505" tensile specimens, the variation in Vickers hardness with distance from the fracture is shown in Fig. 13d. The maximum hardness on the centerline of the specimen occurred at a distance of approximately 0.08 in. from the fracture. The maximum hardness increased slightly with a decreasing temperature of the static test. The actual values were as shown below:

Temperature of Static Test	146° F.	75° F.	-1° F.	-50° F.	-100° F.
Maximum Vickers Hardness	215	215	216	222	224

The average minimum hardness of all specimens in the portion surveyed was approximately 180 Vickers.

The results of Vickers hardness tests made as previously described, are given in part in the iso-hardness contours shown in Figs. 14d, 15d, and 16d.

*See Appendix C

The maximum hardness values found were as follows:

SPECIMEN NO.	WIDTH, IN.	TEMPERATURE OF FRACTURE TEST	MAXIMUM VICKERS HARDNESS
17A-5A	12	-50°F.	211
17-7	72	0°F.	206
18-1	48	18°F.	244

For the tensile specimens shown in Fig. 13d, the maximum hardness occurred at a small distance from the fracture.

A comparison of the maximum hardness of the wide plates with that of the 0.505" tensile specimens shows that, for the 12-and 72-inch wide specimens, the maximum hardness found was about ten Vickers hardness numbers lower than for the 0.505" tensile bars at corresponding temperatures. However, the 48-inch specimen had a maximum hardness value of 244 Vickers, which is considerably above the maximum hardness of any of the 0.505" tensile bars.

The iso-hardness contours across the thickness of the plate given in Figs. 14d, 15d, and 16d, show the contour line for 170 Vickers hardness at a progressively greater distance from the fracture as the testing temperature of the wide plate specimens was increased, and thereby indicate that the volume of plastic deformation at the end of the notch increased directly as the testing temperature.

TABLE Id

RESULTS OF HARDNESS SURVEYS AND ENERGY EVALUATION

OF 12-INCH WIDE PLATE SPECIMEN NO. 17A-5A.

ROCKWELL B HARDNESS RANGE	VOLUME OF PLATE HARDENED cu. ins.	ENERGY ABSORBED, Inch Pounds	
		COMPRESSION CALIBRATION	TENSION CALIBRATION
81-82	0.55	670	776
80-81	0.73	874	1056
79-80	0.59	562	668
78-79	2.23	1650	1472
77-78	6.66	3296	3068
76-77	9.92	3470	4460
75-76	8.84	1944	3012
74-75	6.08	730	1520
73-74	29.64	741	4188
TOTAL	65.24	14 137	20 220

TABLE IId

RESULTS OF HARDNESS SURVEYS AND ENERGY EVALUATION

OF 48-INCH WIDE PLATE SPECIMEN NO. 18-1.

ROCKWELL B HARDNESS RANGE	VOLUME OF PLATE HARDENED, cu.ins.	ENERGY ABSORBED, Inch Pounds COMPRESSION CALIBRATION	TENSION CALIBRATION
90 +	0.12	1730	1360
89-90	0.12	1086	1043
88-89	0.16	1214	1160
87-88	0.16	977	976
86-87	0.39	1853	2030
85-86	1.25	4540	5130
84-85	4.71	13830	15040
83-84	4.05	8980	9800
82-83	5.34	9720	10240
81-82	4.98	9330	8480
80-81	20.55	24670	29800
79-80	31.65	30060	35750
78-79	107.40	79600	70900
77-78	201.90	105800	92800
76-77	62.22	21750	28000
75-76	40.79	9000	13860
74-75	122.22	14660	30500
73-74	149.25	3730	20900
TOTAL	757.26	340 530	377 769

TABLE IIId.

RESULTS OF HARDNESS SURVEYS AND ENERGY EVALUATION

OF 72-INCH WIDE PLATE SPECIMEN NO. 17-7.

ROCKWELL B HARDNESS RANGE	VOLUME OF PLATE HARDENED, cu.ins.	ENERGY ABSORBED, Inch Pounds COMPRESSION CALIBRATION	TENSION CALIBRATION
87-89	.08	557	541
85-87	.28	1154	1300
84-85	.35	1029	1120
83-84	.69	1532	1670
82-83	1.09	1970	2100
81-82	1.43	2110	2430
80-81	2.51	3015	3640
79-80	32.40	30800	36600
78-79	91.20	67500	60200
77-78	135.90	71400	62500
76-77	159.30	55750	71700
75-76	252.90	56800	85900
74-75	1233.00	148000	308000
73-74	696.00	17400	97400
TOTAL	2607.13	459 017	735 101

TABLE IVd.

COMPARISON OF ENERGY ABSORPTION DETERMINATIONS FOR

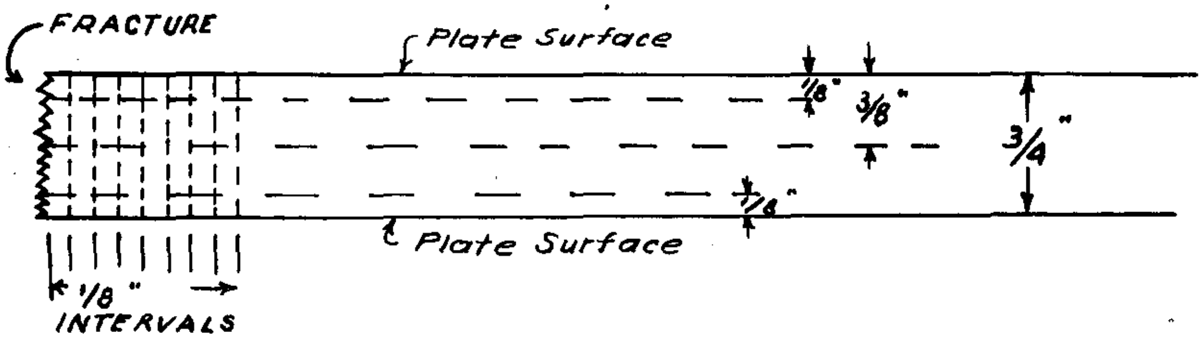
REGION BOUNDED BY GAGE LENGTH OF 3/4 W.

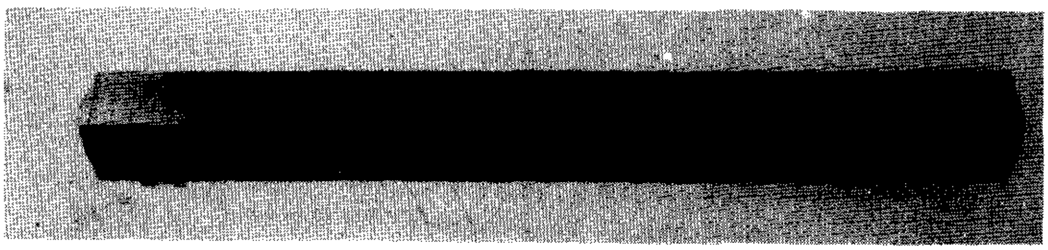
SPECIMEN NO.	WIDTH OF SPECIMEN	ENERGY ABSORBED, Inch Pounds		
		COMPRESSION TEST CALIBRATION	TENSION TEST CALIBRATION	STRAIN GAGE
17A-5A	12 In.	14 137	20 220	23 600
18-1	48 In.	340 530	377 769	304 000
17-7	72 In.	459 017	735 101	228 000

DIFFERENCE BETWEEN ENERGY ABSORPTION DETERMINED FROM

STRAIN GAGE VALUES AND HARDNESS TESTS.

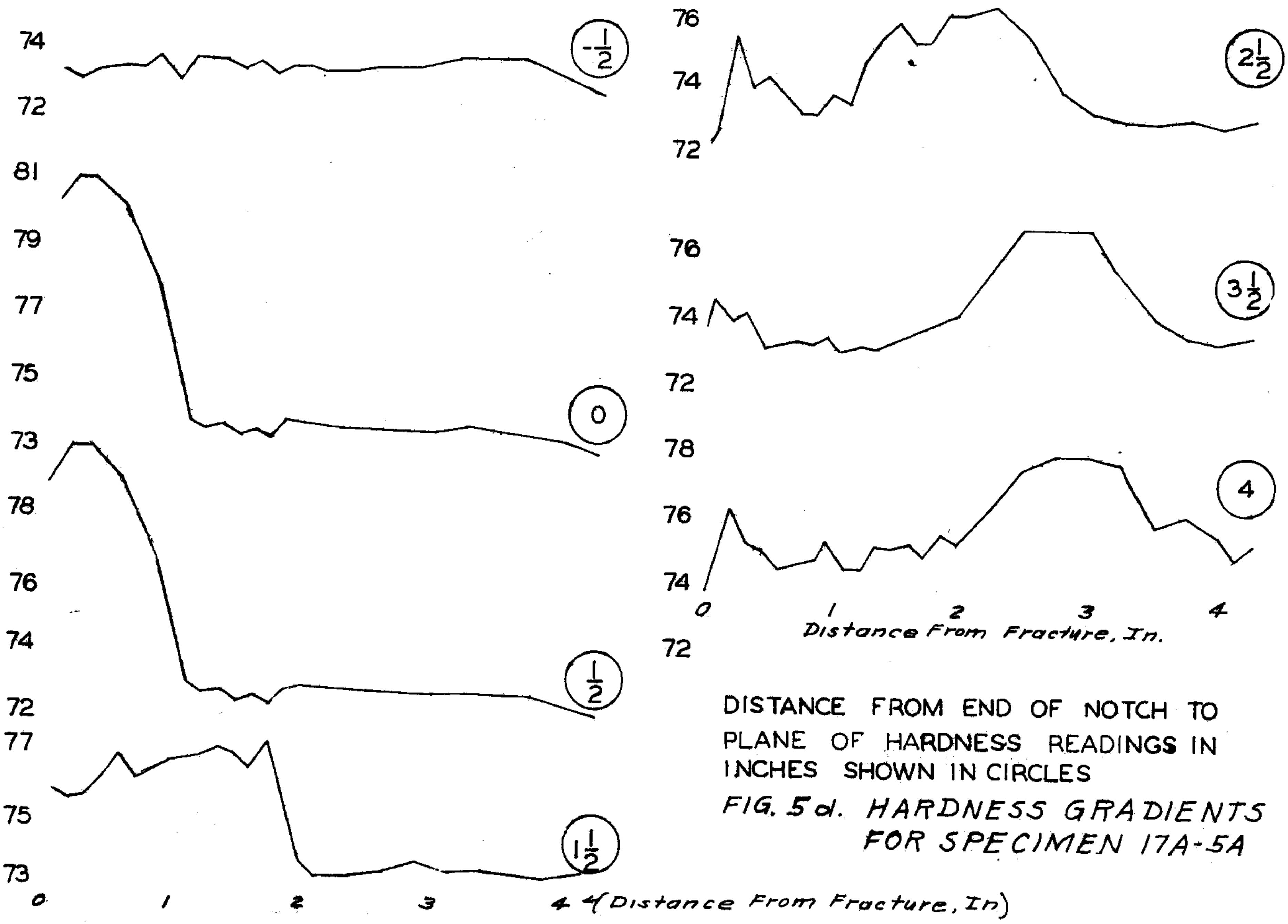
SPECIMEN NO.	WIDTH OF SPECIMEN	COMPRESSION TEST CALIBRATION	TENSION TEST CALIBRATION
17A-5A	12 In.	-40 %	- 14.3 %
18-1	48 In.	+12 %	+ 24.2 %
17-7	72 In.	+101 %	+202.2 %





Photograph of Sample with Hardness Indents

Fig. 4d.
Location of Rockwell B Hardness Indents at Intersestions of Lines on Plane of Plate Thickness.



DISTANCE FROM END OF NOTCH TO PLANE OF HARDNESS READINGS IN INCHES SHOWN IN CIRCLES

FIG. 5d. HARDNESS GRADIENTS FOR SPECIMEN 17A-5A

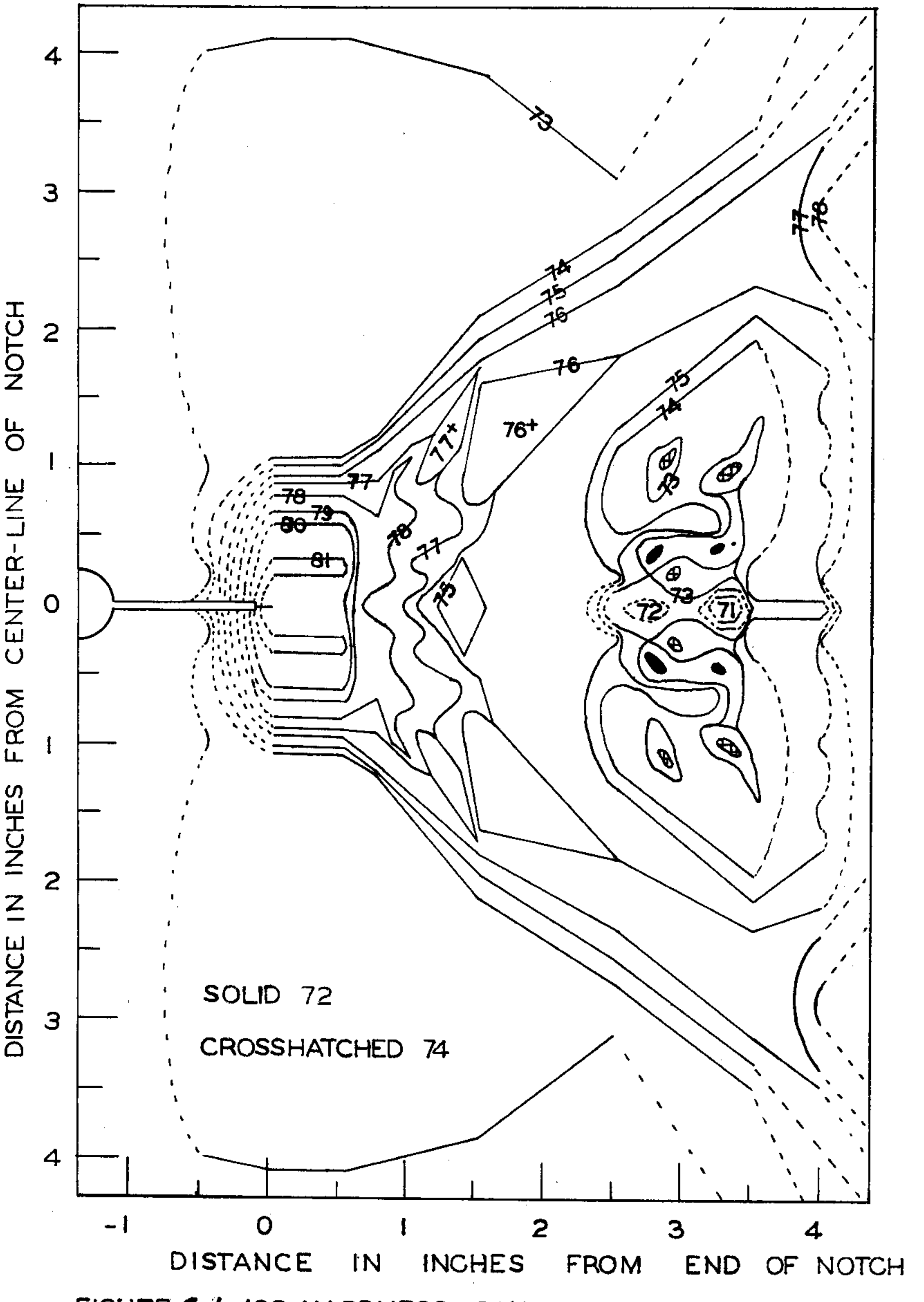


FIGURE 6d. ISO-HARDNESS CONTOURS FOR ONE HALF OF SPECIMEN 17A-5A. ROCKWELL B HARDNESS VALUES SHOWN ON CONTOURS. BASE HARDNESS 70-72.5

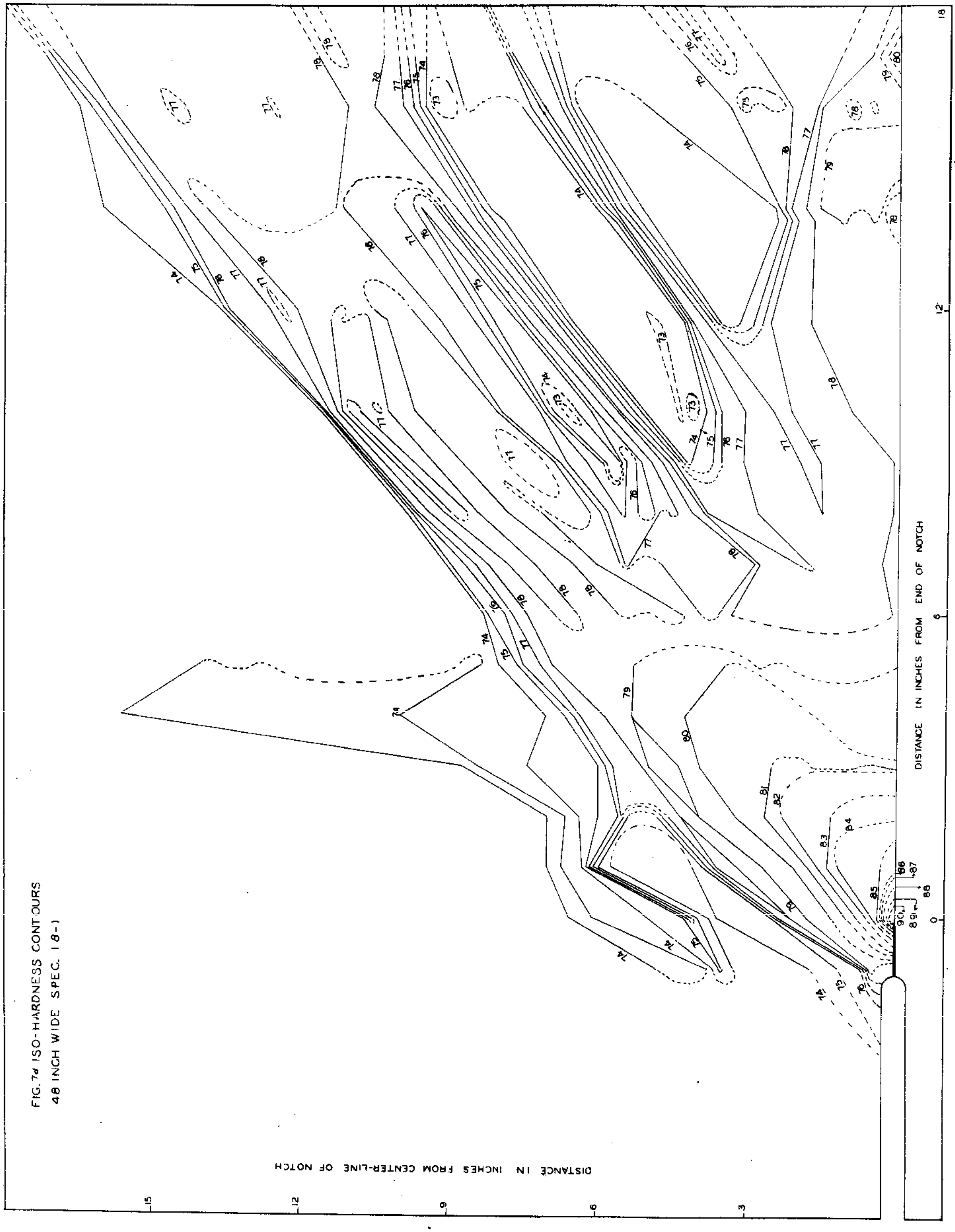


FIG. 7d ISO-HARDNESS CONTOURS
48 INCH WIDE SPEC. 18-1

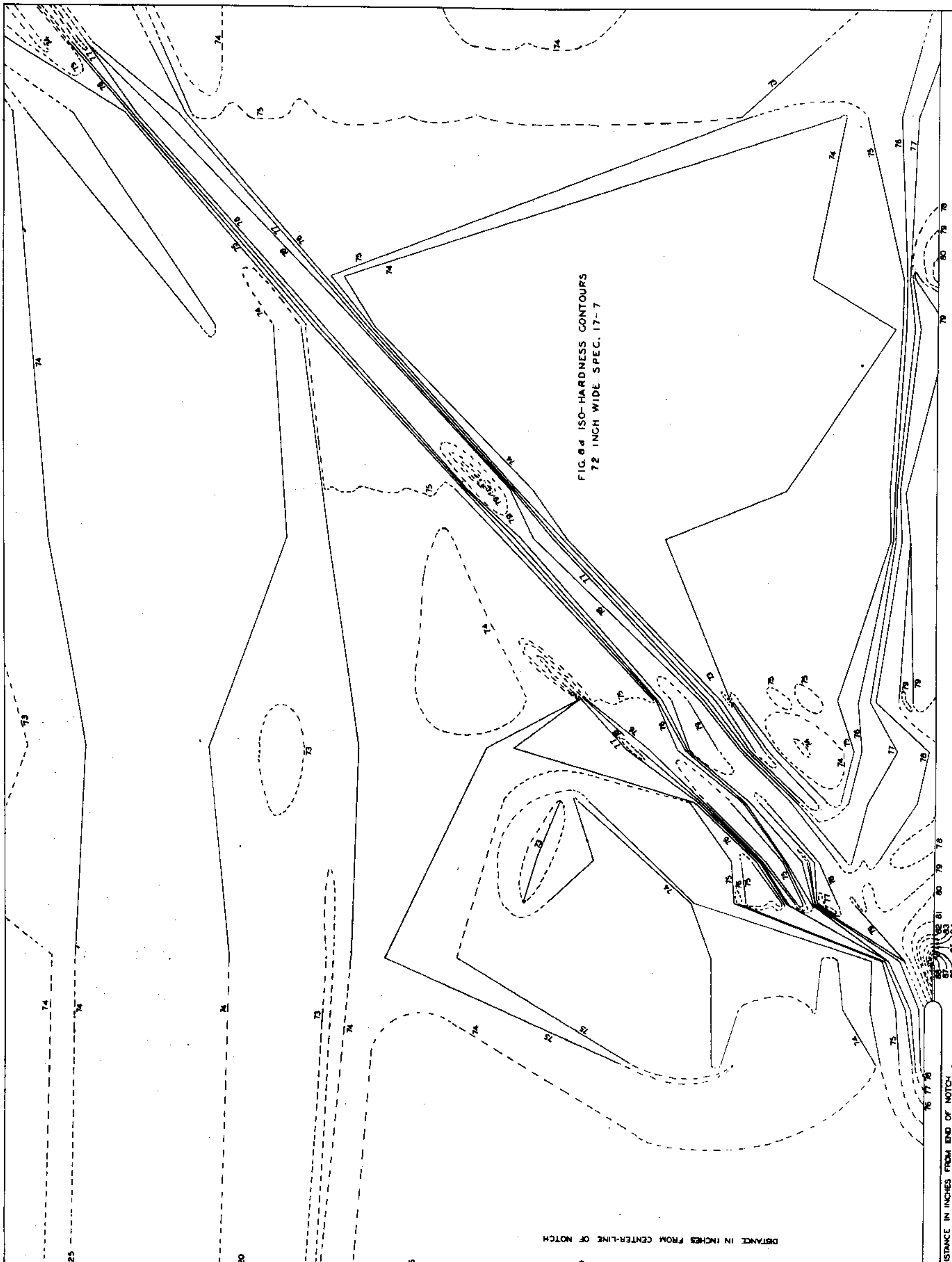


FIG. 8d ISO-HARDNESS CONTOURS
72 INCH WIDE SPEC. 17-7

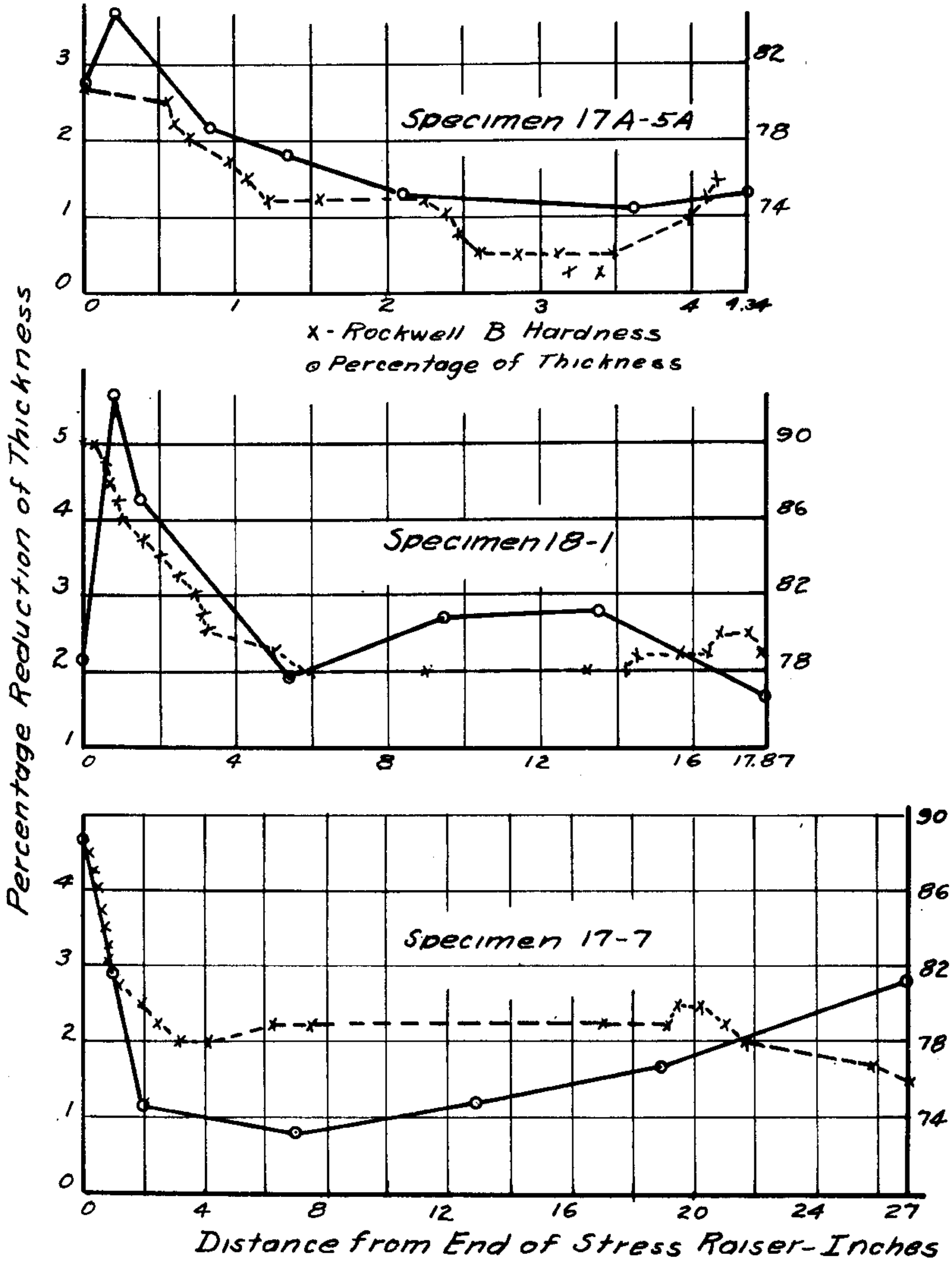


Fig. 9d.
Comparison of Hardness and Reduction of Thickness Adjacent to Fracture

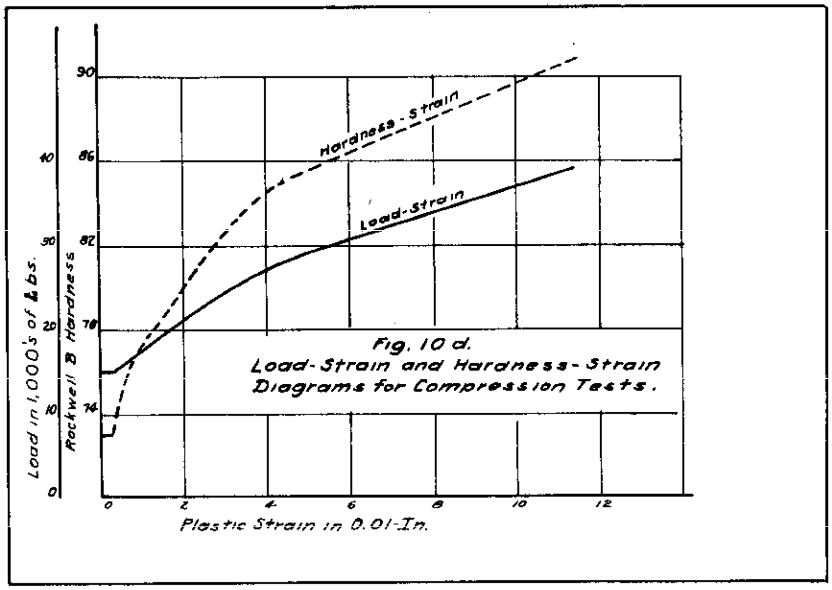


Fig. 10 d.
Load-Strain and Hardness-Strain
Diagrams for Compression Tests.

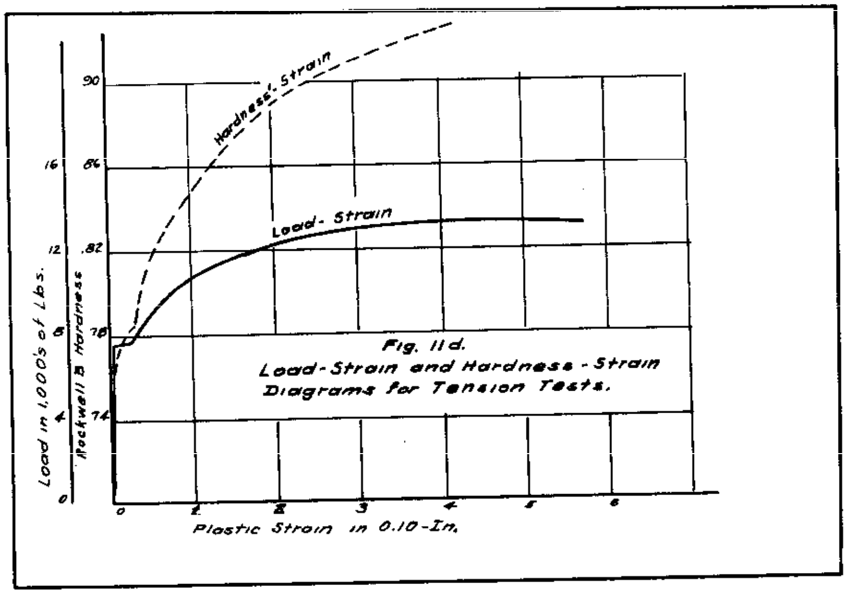


Fig. 11 d.
Load-Strain and Hardness-Strain
Diagrams for Tension Tests.

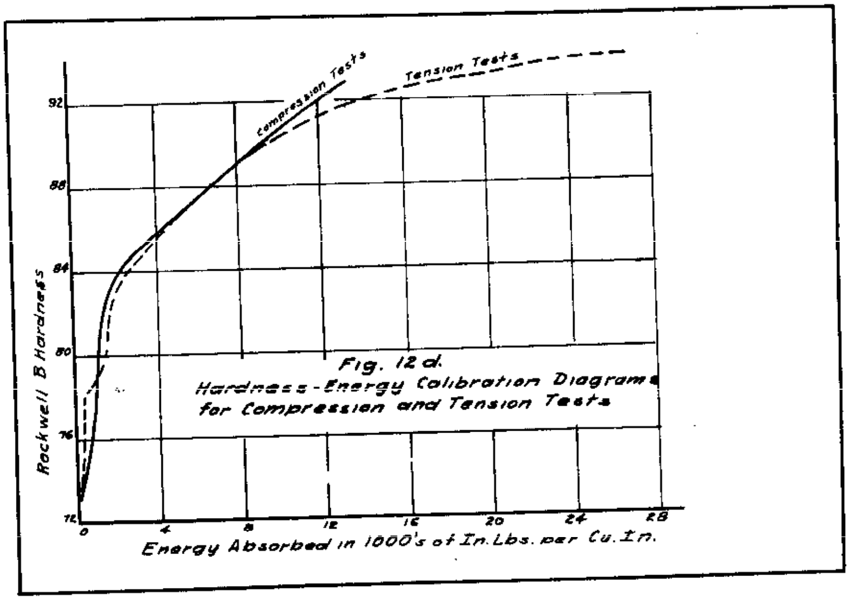


Fig. 12 d.
Hardness-Energy Calibration Diagrams
for Compression and Tension Tests

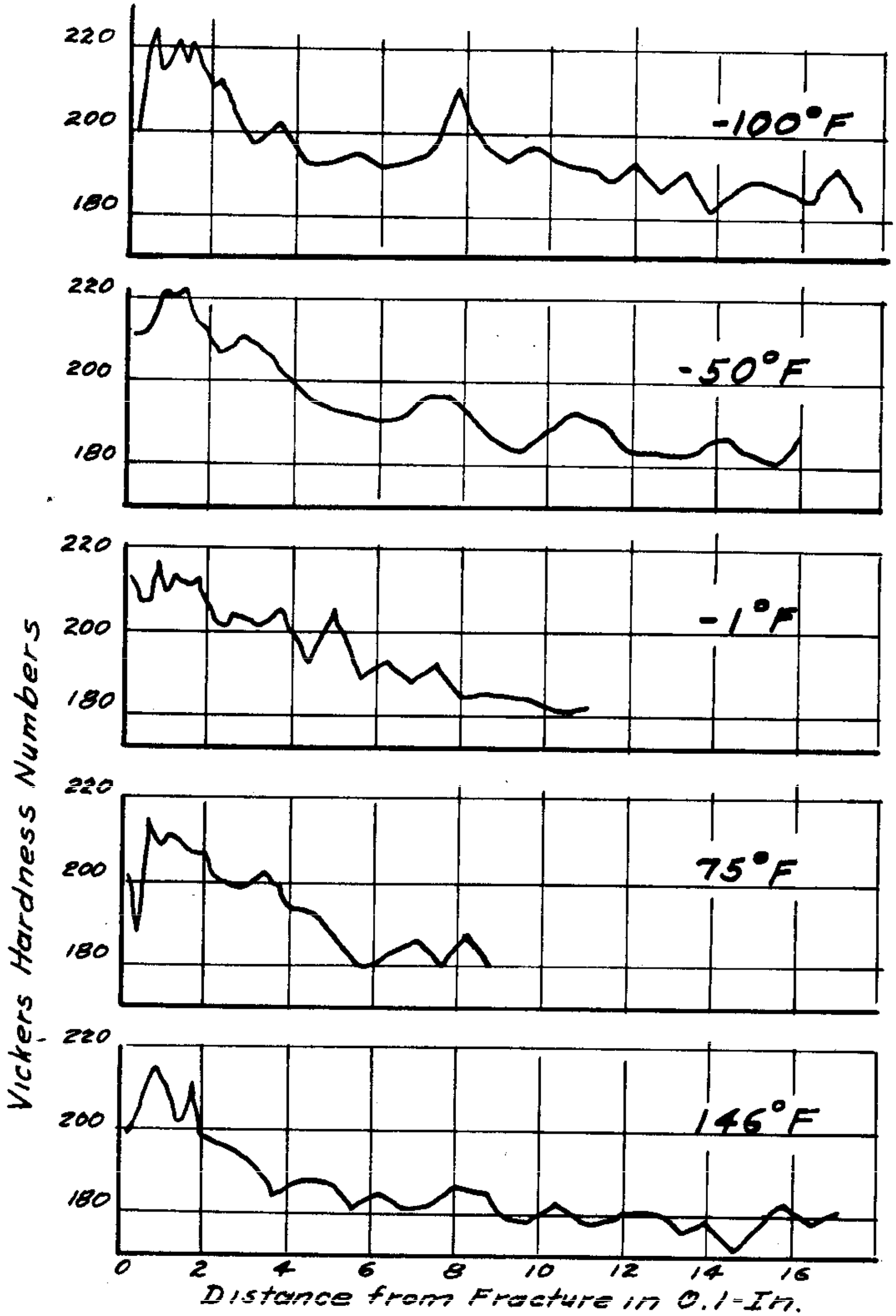


Fig. 13 d.
Vickers Hardness Gradients in Static Tensile Specimens Tested at Different Temperatures.

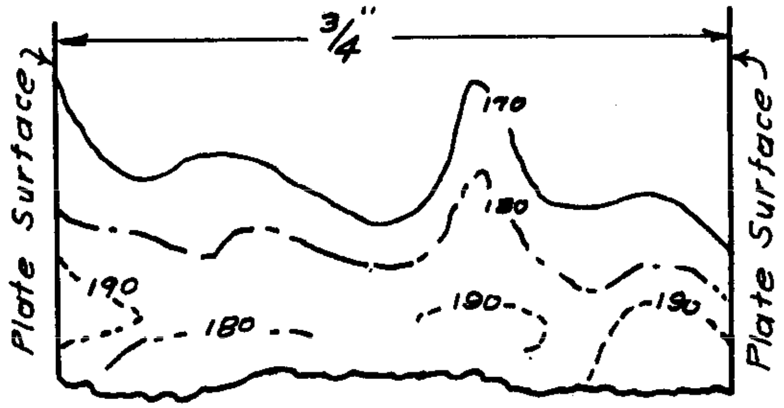
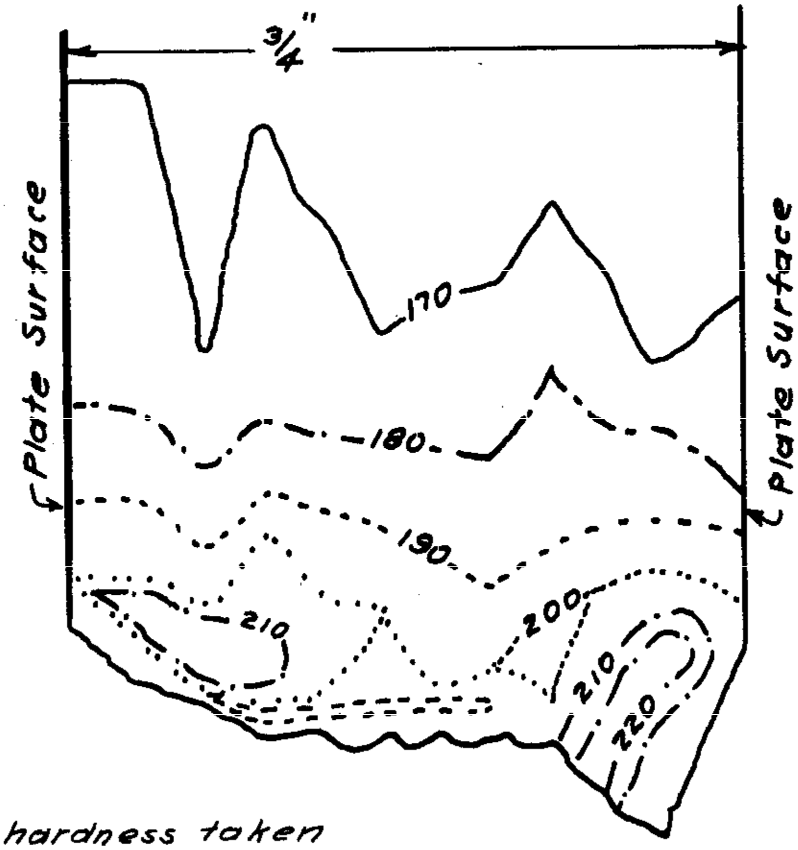
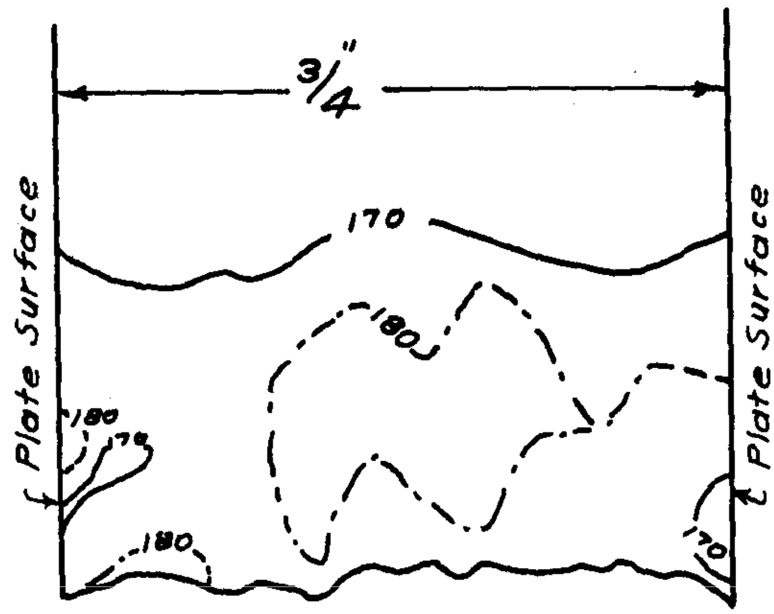


Fig. 14 d.
Iso-Hardness Contours Near Fracture
Specimen 17A-5A



Note: Iso-hardness taken 1/16-In. from End of Stress-raiser. Vickers Harndess Shown on Contours.

Fig. 15 d.
Iso-Hardness Contours Near Fracture
Specimen 18-1



Note: Iso-hardness taken 1/16-in. from end of stress-raiser. Vickers Hardness shown on contours.

Fig. 16 d.
Iso-Hardness Contours Near Fracture
Specimen 17-7

SUMMARY.

Iso-hardness contours based on Rockwell B hardness surveys were drawn for three wide plate specimens. The evaluation of energy absorbed obtained by integration of the iso-hardness contours and based on hardness-energy calibration curves did not correspond with the values of energy absorption obtained from strain gage readings.

Although the energy evaluation by means of hardness surveys did not produce a successful measure of the total energy absorbed, the iso-hardness contours nevertheless are of value in showing the manner in which the strain is localized at the stress-raiser.

Vickers hardness surveys on a longitudinal plane normal to the rolled surfaces of three wide plate specimens 1/16 inch outside of the outer end of the stress-raiser gave hardness maxima which were compared with hardness maxima for 0.505" tensile specimens tested at temperatures in the range of -100° F. to 146° F. For two of the wide plate specimens the maximum Vickers hardness was only slightly below the maximum hardness of the tensile specimens tested at corresponding temperatures, while for the other the maximum hardness exceeded the maximum value obtained in any of the tensile specimens.