PROGRESS REPORT

ON

CAUSES OF CLEAVAGE FRACTURE IN SHIP PLATE, TESTS OF RESTRAINED WELDED SPECIMENS AND HATCH CORNER SPECIMENS OF MILD STEEL

BY

A. BOODBERG AND E. R. PARKER

University of California
Under Bureau of Ships Contract NObs-31222

COMMITTEE ON SHIP CONSTRUCTION

DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

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Dear Sir:

Attached is Report Serial No. SSC-27 entitled "Causes of Cleavage Fracture in Ship Plate; Test of Restrained Welded Specimens and Hatch Corner Specimens of Mild Steel." This report has been submitted by the contractor as a progress report of the work done on Research Project SR-92 under Contract Nobs-31222 between the Bureau of Ships, Navy Department and the University of California.

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,

C. Richard Soderberg

C. Richard Soderberg, Chairman
Division of Engineering and
Industrial Research

CRS:mh
Enclosure

PREFACE

The Navy Department through the Bureau of Ships is distributing this report to those agencies and individuals who were actively associated with the research work. 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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PROGRESS REPORT

U. S. Navy Research Project NObs-31222

CAUSES OF CLEAVAGE FRACTURE IN SHIP PLATE, TESTS OF RESTRAINED WELDED SPECIMENS AND HATCH CORNER SPECIMENS OF MILD STEEL

From: University of California
Berkeley, Calif.

Report Prepared by:

Alexander Boodberg
Earl R. Parker

ABSTRACT

This report summarizes the results of a series of tests conducted as a supplementary program to the research investigation that was carried out on the behavior of high yield strength structural steels under the U. S. Navy Research Contract NObs-31222. The main objective of this auxiliary program was to provide a basis for comparison of results from the high yield strength structural steels and the extensive results that were obtained in the numerous investigations conducted on the ship quality mild steels. The temperatures at which the mode of fracture changed from shear to cleavage type were determined for two of the mild steels by means of tests on several types of specimens.

Several widely different types of specimens were used in this investigation. The first type of specimen was made in two different sizes but with the same thickness of steel plate. They were made to provide restraint to plastic flow at a corner produced by welding together steel plates set along three mutually perpendicular planes. Other specimens were in the form of

simple notched plates of different sizes. Also, tensile tests were made on 3/4-inch thick flat plate specimens. Some of these contained welds only along their longitudinal axes while others had both transverse and longitudinal welds.

The results of the tests on the two sizes of large restrained welded specimens indicated that the width and height of this type of specimen apparently had little or no effect on the transition temperature. The results of the tests performed on notched plate specimens showed that the transition temperatures determined by tests of the two sizes of this type of specimen were in good agreement with each other, but that the transition temperatures as determined by notched plate tests were considerably lower than those obtained with large restrained welded specimen tests.

Tension tests of simple welded flat plate specimens indicated that the transition temperatures of the steels were not materially affected by the introduction of a single longitudinal weld along the loading axis or by the presence of two intersecting welds at the center of the unnotched plate specimen.

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INTRODUCTION

The work described in this part of the report was done as an auxiliary program to the research conducted on the behavior of high yield strength structural steels[1] under the U. S. Navy Research Contract NObs-31222. In order to make possible the comparison of data obtained from the high strength steel tests with those that were gathered through a period of years by various investigators on ship quality mild steels,[2,3,4,5] additional tests were made on the mild steels B_r and C that had been previously investigated.[3,4]

The primary objective of this auxiliary program was to obtain the transition temperatures and additional information on the behavior of steels B_r and C when tested in the form of restrained welded specimens identical to the ones used in the high yield strength structural steel investigation.

The minor objective of the program was to investigate the effect of longitudinal and cross welds on the transition temperature of unnotched flat plate specimens of mild and alloy steels.

The physical properties and chemical compositions of the mild, ship quality steels used in this program are shown in Table I.

EXPERIMENTAL WORK

Test Program

Tension tests were conducted at various temperatures on specimens containing abrupt changes in section produced by welding together four pieces of plate set along three mutually perpendicular planes. These pieces were cut from a 3/4" x 72" x 120" plate according to the layout shown in Fig. 1 and were assembled to form a "restrained welded specimen", shown in Fig. 2a and 2b, the same type of specimen that was used in the high yield strength structural steel

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1,2,3,4,5 See References

investigation[1]. These specimens were similar in construction, but were considerably smaller than the previously tested "hatch corner specimens"[3] shown in Fig. 3a and 3b.

The transition temperatures (the temperatures at which the mode of fracture changed from the ductile shear type to the brittle cleavage type) were determined for Steel B_r by tests of hatch corner type specimens as well as by tests of restrained welded specimens (Fig. 2a and 2b). Since the transition temperature of Steel C, as determined by tests of hatch corner specimens, had been previously established[3], and sufficient stock of that steel was unavailable, two of the smaller restrained welded specimens of Steel C were tested.

Additional tension tests were carried out on 12-inch wide centrally notched specimens (Fig. 4a) and 3-inch wide edge notched specimens (Fig. 4b) on Steels B_r and C, in order to augment the information previously obtained[4], and to establish more closely the transition temperatures for these steels.

Tension tests were made on 3/4-inch thick by 6-5/8 inch wide unnotched flat plate specimens (Fig. 4c), some of which contained longitudinal welds and some that had intersecting welds, in order to determine the effect of the welds on the transition temperatures of the steels.

Test Procedure

The hatch corner and restrained welded specimens were tested in tension at several temperatures in order to establish the temperature vs. energy absorbed relationship for the steels. SR-4 strain gages were used on two restrained welded specimens made of a high strength steel and one specimen made of C steel in order to determine the stress distribution in the various members of these specimens and to compare the results with those obtained from similar studies made on the hatch corner type of specimen[5]. Manganin wire extensometers, shown in Fig. 5, were used on all specimens to measure the overall elongation of the specimens at the various loads. From the load-strain curves thus obtained, the energy absorbed during the test was determined. Specimens were loaded until fracture occurred and the energy to the maximum load and to failure were both recorded. The specimens were maintained at the desired temperature ($\pm 5^{\circ}F$) by circulating air (cooled in a special heat exchanger by dry ice or heated by means of electric heaters) through a plywood box or a canvas bag which totally enclosed the specimen. Thermocouples at various positions on the specimen were used to check the temperatures.

The two types of flat plate notched specimens were also tested in tension at various temperatures to determine the transition temperatures for the steels. The 12-inch wide centrally notched specimens were made by flame cutting and a 3/4-inch diameter hole was drilled in the center of each specimen. One-inch long hacksaw cuts were made from this hole outward, toward the edges of the specimen, and the notch thus formed was made more severe by extending the hacksaw cuts for an additional 1/8 of an inch by means of a 0.010-inch thick jeweler's saw. The specimen was then welded to pulling heads and tested in tension with arrangements for heating or cooling similar to the ones used for the large welded specimens.

The 3-inch wide edge notched specimens were prepared by flame cutting and making 1/2-inch deep inward notches at mid-length of each edge with a 0.042-inch thick saw blade. The specimens were clamped directly in the grips of the testing machine and the temperature was controlled by means of a jacket fastened on each side of the specimen. The cooling or heating medium was circulated through this jacket. For low temperatures, alcohol cooled with dry ice was used; heated water was used for temperatures over $70^{\circ}F$. Energy absorbed to the maximum load and to failure was measured by means of clip gages and the percent of fracture surface which failed by shear was recorded for each of the

12-inch and 3-inch wide notched specimens.

The effect of welds on the transition temperature of steels was studied by means of tests on 3/4-inch thick by 6 5/8-inch wide unnotched flat plate specimens shown in Fig. 4c. Three groups of these specimens were tested: one group contained no welds, one had longitudinal welds only, and the third group had both longitudinal and transverse welds intersecting at the center of the specimen. All of these specimens were tested in tension at various temperatures, in a manner similar to the 12-inch wide center-notched specimens, in order to determine their transition temperatures. The longitudinal welds on these specimens were deposited with an Unionmelt machine in 3/8-inch deep flame gouged grooves about 10 inches long, made on the centerlines of both surfaces of the specimens. The weld overbuilds were partially machined off and then ground flush with the surface of the plate. The transverse welds were made in a similar manner. As these specimens were flame cut from a large plate the edges at the center section were carefully ground to eliminate any small notches that may have been produced by the cutting. The type of fracture was recorded, and the energy absorption was measured by means of clip gage extensometers for each of the specimens tested.

Welding Technique

All of the hatch corner and restrained welded specimens were welded according to the sequence and type of weld shown in Figs. 2a and 3a. Type E 6020 and E 6010 electrodes were used for welding these specimens with no preheat employed. Voltage and current values used were those recommended by the manufacturers of the electrodes. All specimens were welded by the same team of welders and extreme precautions were used to insure good penetration at the critical areas near and around the corner of the specimens.

For the flat plate unnotched specimens, the welds were made with a Unionmelt machine using 1/4-inch rod at approximately 9 inches/min. with 29 volts and 825 amps.

A period of from 24 to 48 hours was allowed to elapse between the completion of the welding and the actual test of the specimens.

RESULTS

General

The primary objective of these tests was to determine, by means of several types of specimens, the transition temperatures of two mild steels and thus to establish a basis for comparison of the results from the extensive investigations on mild steels[2,3,4,5], with those obtained from the tests on the high yield strength structural steels.

The term "transition temperature", as used in this report, is defined as a temperature at which the mode of fracture changes from the shear type to the cleavage type. When a sufficiently large number of specimens is tested, the transition temperature can be established very closely. However, the expense of testing a large number of hatch corner and restrained welded specimens is prohibitive. Consequently, in this investigation it was necessary to approximate the transition temperature of a steel by arbitrarily choosing a point halfway between the two test temperatures - one that resulted in a predominantly shear fracture and the other that gave a predominantly cleavage fracture. The transition temperature thus determined may be considerably in error because the increments between the test temperatures were sometimes large.

The transition temperatures as determined by tests of the notched specimens and the small unnotched welded specimens were established to within $\pm 10^{\circ}F$ because a large number of tests could be conducted rapidly and inexpensively.

Four hatch corner type specimens of Steel B_r were tested to establish the transition temperature for that steel and for that type of specimen. The results are shown in Figs. 6a and 6b. Data from another report[1] showing results of tests of restrained welded specimens of high yield strength structural steels are included in these figures for comparison. Properties of these steels are listed in Table IV. The transition temperature for Steel B_r, as determined by tests on the hatch corner type of specimens was approximately $+40^oF$ as compared to about $+58^oF$ as determined by tests on the restrained welded specimens. The transition temperature for Steel C was determined in previous tests[3] and appeared to be about $+95^oF$ as determined by tests of hatch corner specimens. Since only two specimens of Steel C of the restrained welded type were tested, the transition temperature could not be determined accurately, but appeared to be about $+100^oF$. These transition temperatures for the large welded specimens are subject to considerable error because of the small number of tests conducted.

The apparently higher transition temperatures for both mild steels, as determined by tests on restrained welded specimens, may have been due to the higher degree of restraint that was present in this type of specimen because of the use of full penetration welds. Full penetration welds presumably create a more severe notch condition at the corner of the specimen. The use of a continuous longitudinal member in the restrained welded specimen may also have increased the severity of stress concentration at the welded corner.

Studies of stress distribution, by means of SR-4 gages (Fig. 7) near the corner of the two types of large welded specimens, have been made, and the results for the restrained welded specimens of mild Steel C are shown in Fig. 8. Fig. 9 shows the results of a similar stress distribution study that was previously made[3] on the hatch corner type of specimen. The general stress distribution is similar for the two types of specimens with the exception of the stresses on the inboard surfaces of the plates that made up the hatch corner, and the stresses in the immediate vicinity of the corner in the deck member "MS". This change in stress distribution pattern may account for the differences in transition temperatures for the two types of specimens. Figs. 10 and 11 show the results of a stress distribution study that was made on two restrained welded specimens of a high yield strength structural steel. Comparison of these two figures with Fig. 8 shows that the results are very similar to those obtained from the specimen of mild steel.

Notched Specimens

Transition temperatures of the two mild steels B_r and C were determined in a previous investigation[4] by means of tension tests on 12-inch wide centrally notched and 3-inch wide edge notched specimens. However, additional tests were conducted to check these, and the combined results are presented in Figs. 12, 13, 14 and 15. The results show that there is very little difference in transition temperatures as determined by tests of the 12-inch wide centrally notched plates and the 3-inch wide edge notched specimens. Similar results were also obtained in the tests of the high yield strength structural steels[1].

Table III shows a comparison of transition temperatures as determined by tests of various types of specimens used by several investigators[3,4]. The results show that the restrained welded specimen indicates the highest transition temperature for Steel B_r, with the hatch corner specimen showing a slightly lower transition temperature, and most of the notched specimens giving approximately the same results. For Steel C, all of the tests, with the exception of the Charpy indicate a transition temperature of +90°F to +100°F.

For the alloy steels[1] and mild Steel B_r the transition temperatures determined by tests of 3-inch wide edge notched specimens were invariably 40°

to 50°F lower than the ones determined by tests of restrained welded specimens. This is not true for Steel C, the one "project" semi-killed mild steel that was found to be extremely notch sensitive. These results, also substantiated in part by results on the rimmed "project" Steel E[4,5], indicate that for highly notch sensitive steels the transition temperatures do not seem to be influenced by the size or configuration of the specimens used in their determination.

Flat Plate Unnotched Specimens Containing Welds

The effects of welds, upon the transition temperature of mild Steels B_r and C, as well as of normalized alloy steel 1[1], were studied by means of tension tests at various temperatures on the type of unnotched flat plate specimens shown in Fig. 4c. The results of these tests, shown in Figs. 16 and 17, indicate that there is a slight shift of the transition temperature to a higher value caused by the introduction of welds on plates of the mild steels. A relatively larger shift in the transition temperature was observed for the normalized alloy Steel 1. Unfortunately this steel was not of uniform quality and contained many laminations and thus these results are not to be regarded as conclusive or indicative of the performance of alloy steels in general.

It is of interest to note that the transition temperature of Steel C as determined by tests of 3/4" x 6-5/8" unnotched flat plate specimens, the edges of which were carefully ground to eliminate any small notches that may have been left by the flame cutting operation, was found to be about +20°F. This transition temperature is about 70°F lower than those determined by tests of the various notched-type specimens. A similar low transition temperature for this steel was found previously[6] in tests that were conducted on 3-inch wide specimens, the edges of which were carefully machined.

The transition temperature of -10°F for Steel B_r, determined by tests of 3/4" x 6 5/8" unnotched flat plate specimens, was also found to be considerably lower than any of the transition temperatures determined by tests of the various notched specimens of that steel.

From the results of this investigation it appears that the slow tension tests which use notched types of specimens for determination of transition temperatures of steels are more discriminative than those using other forms of specimens.

SUMMARY

1. Transition temperatures of the two mild steels B_r and C, as determined by tests of hatch corner type specimens, were found to be lower than those determined by tests on the restrained welded specimens.
2. Although smaller in size, the restrained welded specimen was more rigid and thus offered more restraint to plastic flow because of the use in its construction of a continuous longitudinal member and of full penetration welds.
3. The transition temperature for Steel C was found to be about $+90^{\circ}F$ by tests of all types of <u>notched</u> specimens (except the Charpy type).
4. The transition temperatures of notch sensitive steels (such as "project" Steels C and E) did not seem to be affected by the size or the configuration of the <u>notched</u> specimen used in their determinations.
5. The stress distribution in a restrained welded specimen under a tensile load was found to be almost identical for the mild and the alloy steels.
6. Transition temperatures of steels, as determined by tests of unnotched specimens containing welds, are slightly higher than those determined by tests of the same type of specimens without welds.
7. The transition temperature of Steel C as determined by means of tension

tests on unnotched flat plate specimens was found to be considerably (70°F) lower than that determined by tests of the various notched specimens.

8. The transition temperature of Steel B_r, as determined by tests of unnotched flat plate specimens, was also found to be considerably lower than that determined by tests of notched specimens.

9. Notched type specimens, when used for the determination of transition temperatures of steels by means of slow tension tests, appear to be more discriminative than other types of specimens.

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3. Final Report "Causes of Cleavage Fracture in Ship Plate: Hatch Corner Tests," E. P. DeGarmo and J. L. Meriam. Bureau of Ships, Navy Department, Contract NObs-31222, Serial No. SSC-5. October 1946.

4. "Causes of Cleavage Fracture in Ship Plate: Tests of Wide Notched Plates," A. Boodberg, H. E. Davis, E. R. Parker and G. E. Troxell. The Welding Journal, Vol. XIII, No. 4, April 1948, P. 186-s to 200-s.

5. "Cleavage Fracture of Ship Plates as Influenced by Size Effect", W. M. Wilson, R. A. Hechtman and W. H. Bruckner. The Welding Journal, Vol. XIII, No. 4, April 1948, p. 200-s to 215-s.

6. Final Report "Causes of Cleavage Fracture in Ship Plate: Flat Plate Tests and Additional Tests on Large Tubes." H. E. Davis, G. E. Troxell, E. R. Parker and A. Boodberg. Bureau of Ships, Navy Department, Contract NObs-31222 Serial No. SSC-8, January 1947.

TABLE I. PHYSICAL AND CHEMICAL PROPERTIES OF THE MILD STEELS USED IN THIS INVESTIGATION

STEEL CODE LETTER	STEEL B_r		STEEL C	
Chemical Composition	a	b	a	b
C	0.16	0.18	0.24	0.24
Mn	0.74	0.73	0.49	0.48
Si	0.03	0.07	0.043	0.05
P	0.011	0.008	0.015	0.012
S	0.030	0.030	0.033	0.026
Ni	-	0.05	-	0.02
Al	-	0.015	-	0.016
Cu	-	0.07	-	0.03
Cr	-	0.03	-	0.03
Mo	-	0.006	-	0.005
Sn	-	0.012	-	0.003
N	-	0.005	-	0.009
TYPE	Semi-killed As rolled		Semi-killed As rolled	
PHYSICAL PROPERTIES				
Yield Point, psi	35,800		39,000	
Ult. Strength, psi	59,600		67,400	
Elong. % in 8 in.	26		25.5	
DEOXIDATION PRACTICE	8-1/2 lb./ton of ferro-manganese, 1-1/8 lb./ton ferro-silicon and 2-1/2 lb./ton of Al-Si in Ladle; small amount of Al added in mold.		6 lb./ton of 80% ferro-manganese and 2.6 lb./ton of 50% ferro-silicon in ladle; 1/3 lb. per ton of Al in mold.	

Notes: a - Analysis furnished by the Steel Manufacturer

b - Analysis performed by Mr. S. Epstein (Bethlehem Steel Co.) for this investigation.

TABLE II. PRINCIPAL RESULTS OF THE INVESTIGATION

Specimen No.	Steel Code Letter	Test Temp. ≠ °F	Nominal Maximum Stress psi	Energy Absorbed Inch-lbs. To Max. Load	Energy Absorbed Inch-lbs. To Failure of Long. Memb.	Gage Length for Energy Meas. in.	Type Fract. % Shear
S-1B	B_r	72	29,800	110,000	210,000	54	90
S-2B	B_r	37	31,000	155,000	155,000	54	0
S-3B	B_r	46	33,000	132,000	132,000	54	0
S-4B	B_r	2	31,000	67,000	67,000	54	0
S-1C	C	70	23,100	51,000	51,000	54	0
S-2C	C	130	25,000	101,000	134,000	54	100
L-1B	B_r	72	28,000	1,490,000	2,060,000	143	100
L-2B	B_r	47	27,400	1,420,000	1,580,000	143	84
L-3B	B_r	32	25,700	532,000	1,590,000	143	0
L-4B	B_r	25	26,600	746,000	746,000	143	0
11 *	B_r	32	25,700	340,000	522,000	143	0
8 *	B_r	66	27,000	Not measured		-	80
5 *	C	68	24,000	Not measured		-	0
10 *	C	32	23,600	180,000	180,000	143	0
14 *	C	120	25,600	284,000	484,000	143	100
15 **	C	70	32,600	1,046,000	1,046,000	143	0
17 *	C	72	24,800	Not measured		-	0
18 **	C	70	32,800	1,358,000	1,358,000	143	0
25 *	C	142	29,200	560,000	900,000	143	100
26 *	C	100	27,400	342,000	342,000	143	50

* Results from previous investigation see Reference 3.

** Welded using 400°F preheat.

TABLE III. APPROXIMATE TRANSITION TEMPERATURES OF MILD STEELS B_r AND C DETERMINED BY MEANS OF DIFFERENT SPECIMENS

TYPE OF SPECIMEN		STEEL B_r		STEEL C
Hatch Corner		+40		+95*
Restrained Welded		+58		+100
108" Notched Plate**	below	+32	above	+32
72" Notched Plate**	about	+32		+90
48" Notched Plate**	about	+30	about	+90
24" Notched Plate**	below	+32	about	+88
12" Notched Plate		+18		+95
3" Edge Notched** Net section 2½" x 3/4"	about	+10	about	+90
3" Edge Notched Net section 2" x 3/4"		+20		+95
Charpy V notch**	about	-5	about	+20
Special Unnotched 3/4" x 6-5/8"		-10	about	+20

Temperatures in table are in degrees Fahrenheit

Transition temperature taken as the temperature halfway between two test temperatures - one that resulted in a predominantly shear fracture and the other that gave predominantly cleavage fracture.

* Results obtained in a previous investigation, see Reference 3

** Results obtained in a previous investigation, see Reference 4

TABLE IV. PROPERTIES OF HIGH YIELD STRENGTH STRUCTURAL STEELS

STEEL NO. TYPE & TREATMENT	1 ALLOY Quenched & Drawn	2 ALLOY Quenched & Drawn	3 ALLOY Quenched & Drawn	4 ALLOY Quenched & Drawn
Physical Properties				
Yield Strength, Psi	66,000	80,000	80,000	84,000
Tensile Strength psi	89,000	97,000	100,000	100,000
Elong. in 2",%	26	22	20	23
RA %	64	60	60	68
Chemical Composition, %				
Carbon	.19	.14	.16	.16
Manganese	1.08	.75	1.45	.27
Silicon	.24	.77	.21	.17
Molybdenum	.42	.16	.48	.20
Chromium	-	.60	-	1.13
Zirconium	-	.09	-	-
Phosphorus	.014	.023	.017	.014
Sulphur	.023	.028	.038	.021
Vanadium	-	-	.08	-
Nickel	-	-	.53	2.32

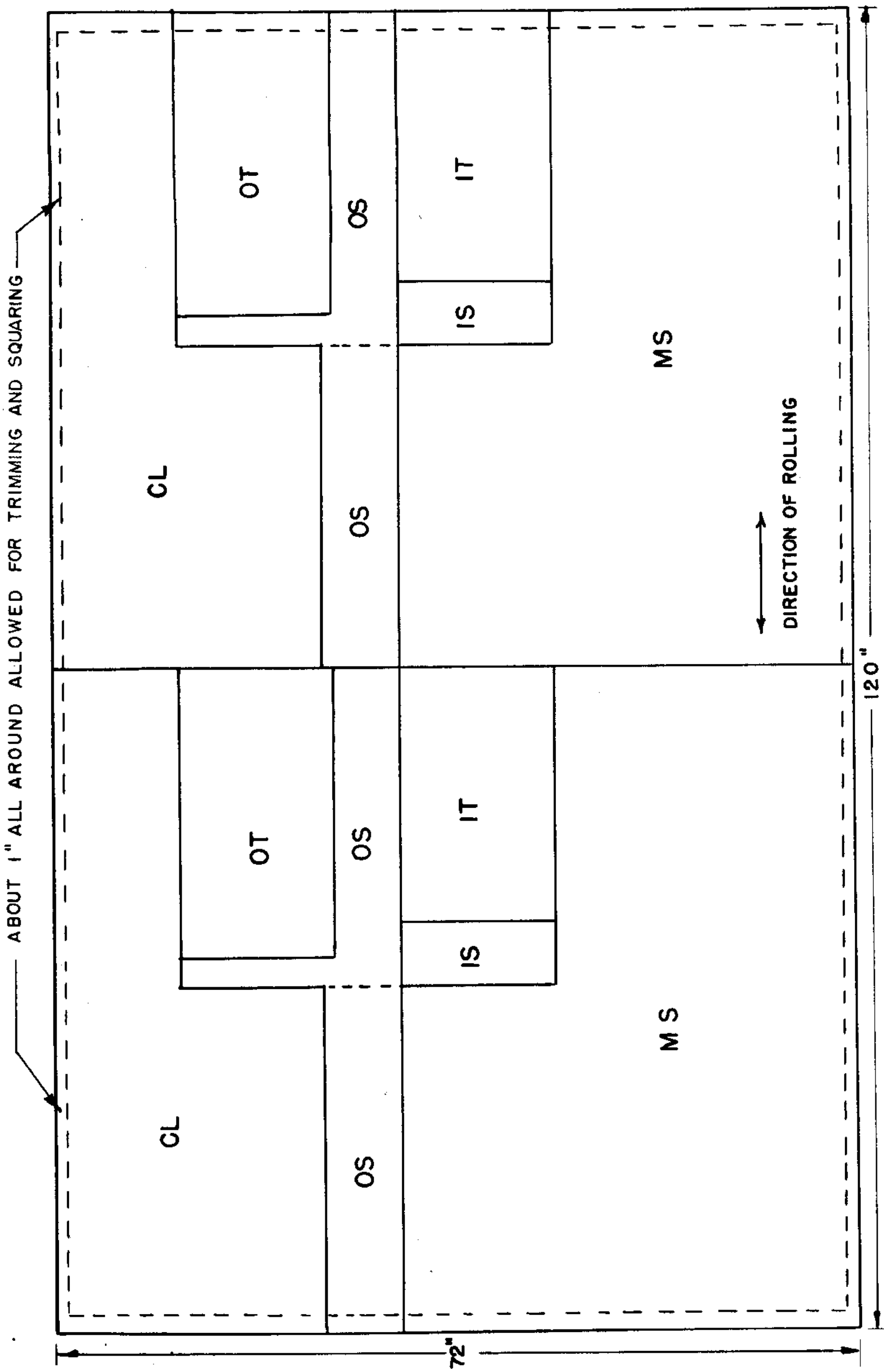


FIG. 1 LAYOUT FOR CUTTING PARTS FOR TWO RESTRAINED WELDED SPECIMENS FROM A 6 FT. BY 10 FT. PLATE OF 3/4" THICK STEEL.

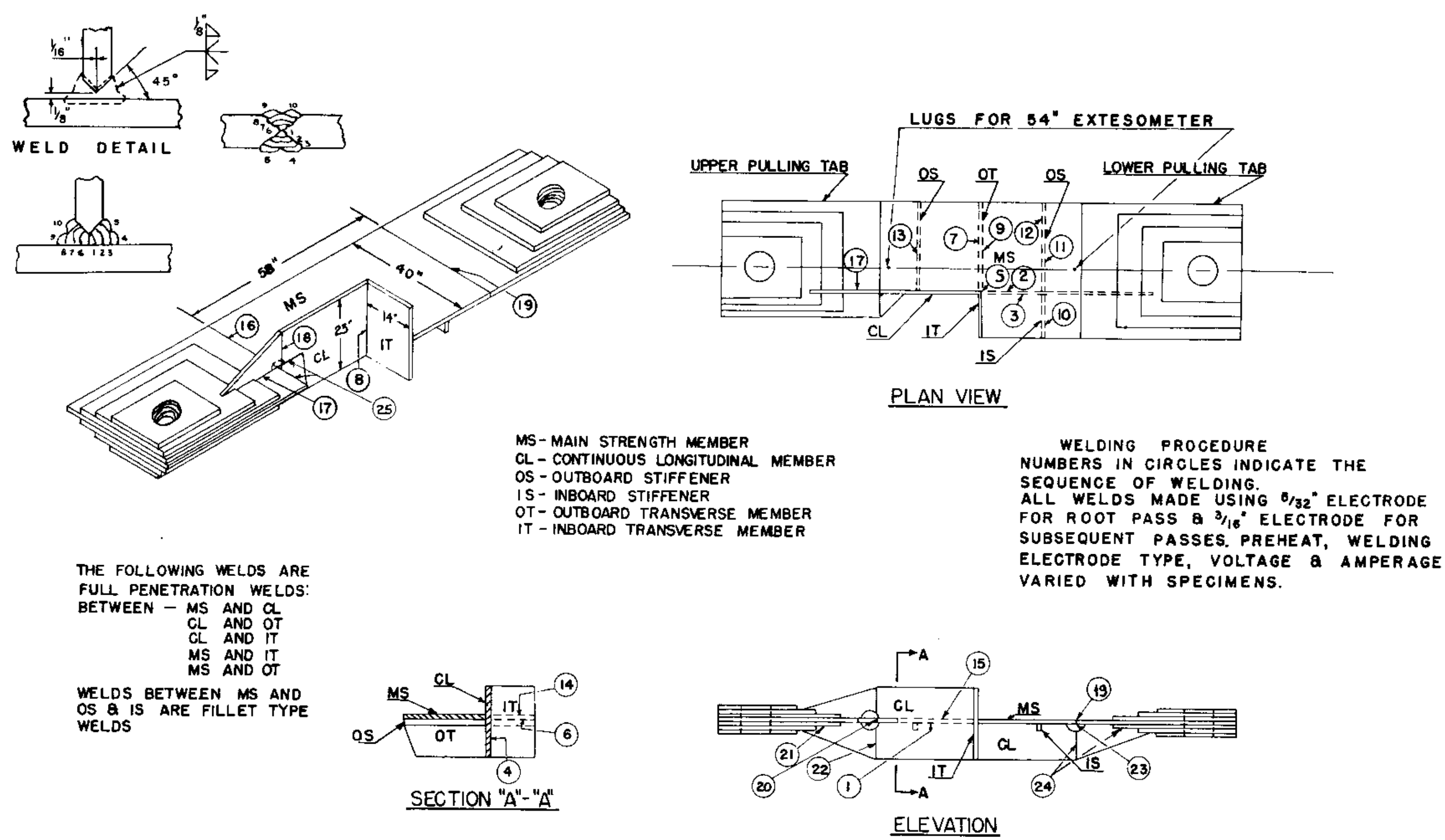


FIG. 2a RESTRAINED WELDED SPECIMEN USED FOR TESTS OF HIGH TENSILE STRENGTH STEELS AND AUXILIARY TESTS ON MILD STEELS B_r & C

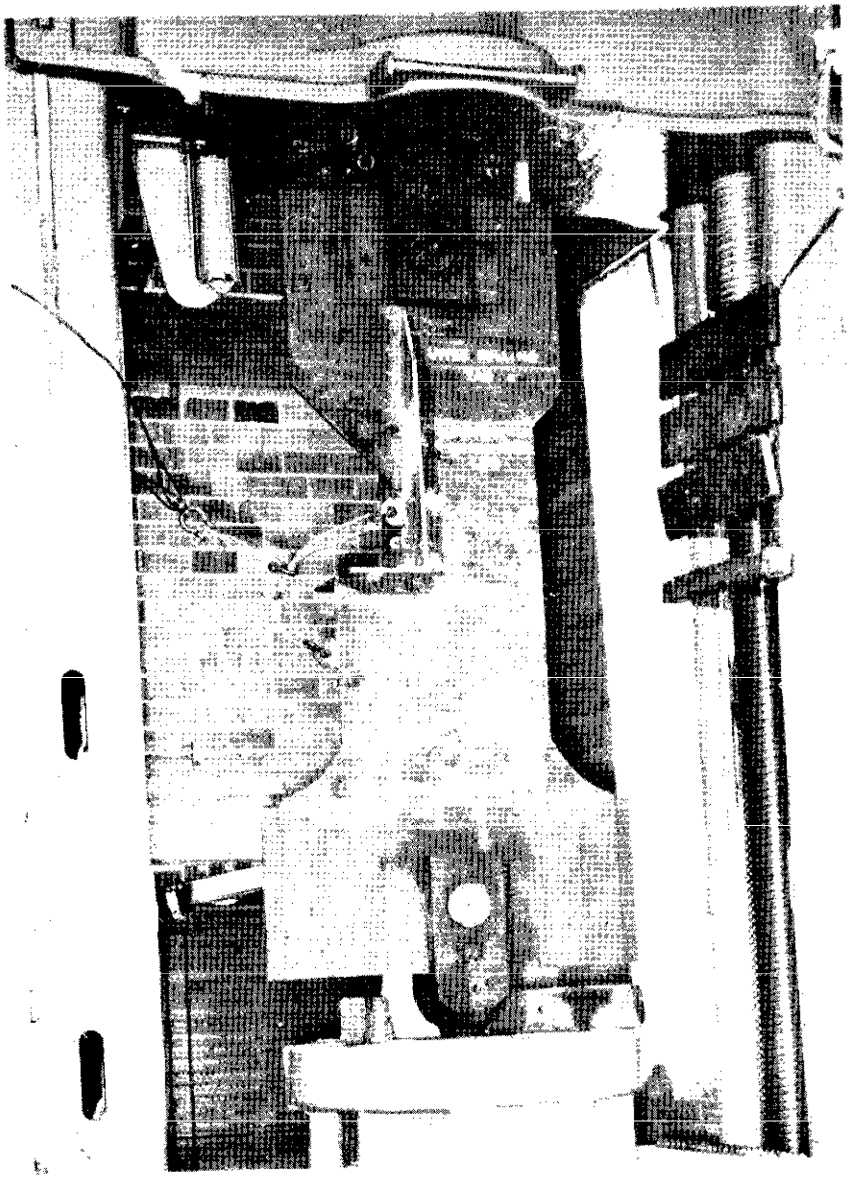


FIG. 2b - RESTRAINED WELDED SPECIMEN IN TESTING MACHINE, SHOWING PULLING TABS AND MANGANIN WIRE EXTENSOMETER.

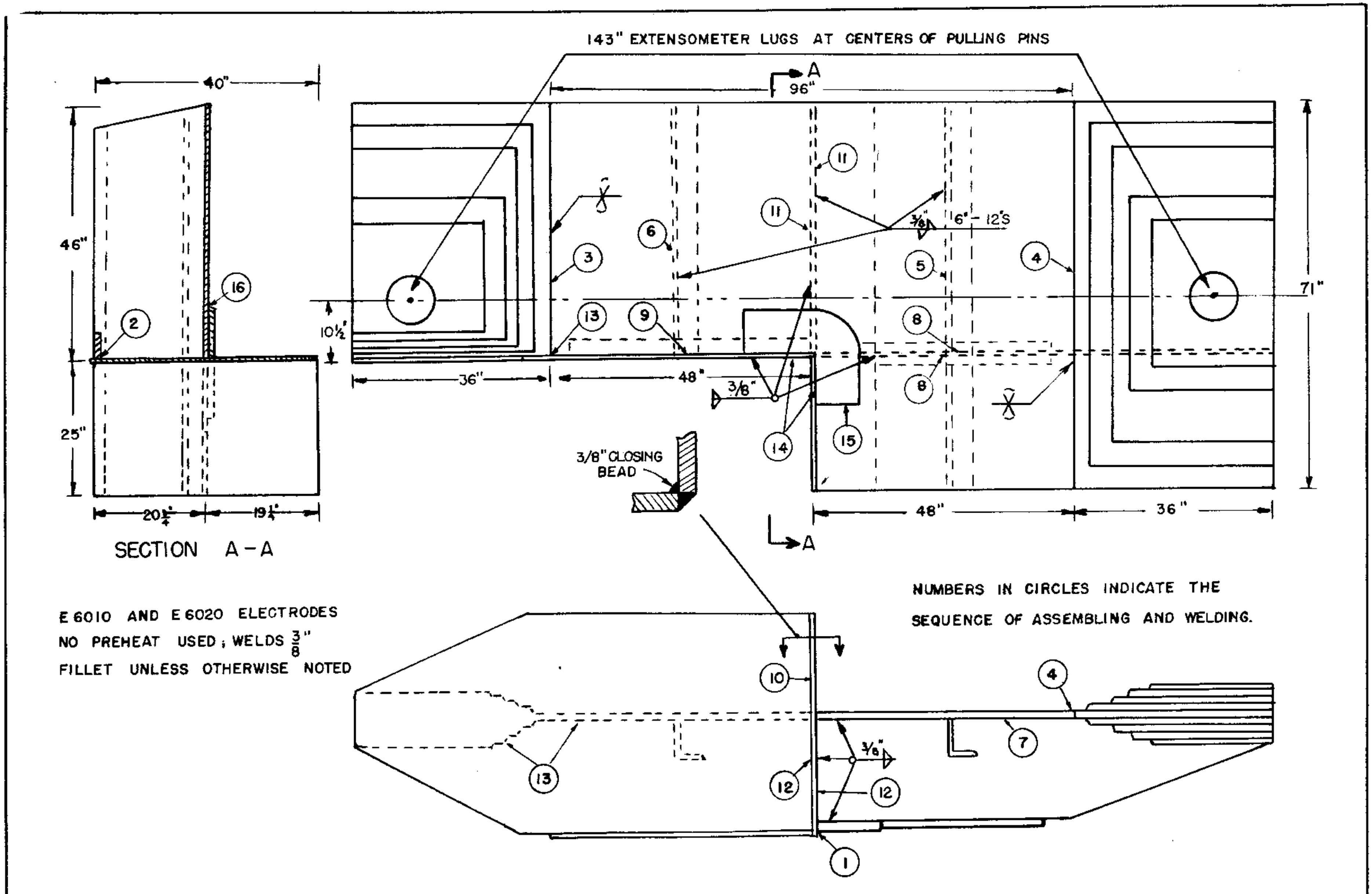


FIG. 3a HATCH CORNER TYPE SPECIMEN USED IN THE INVESTIGATION

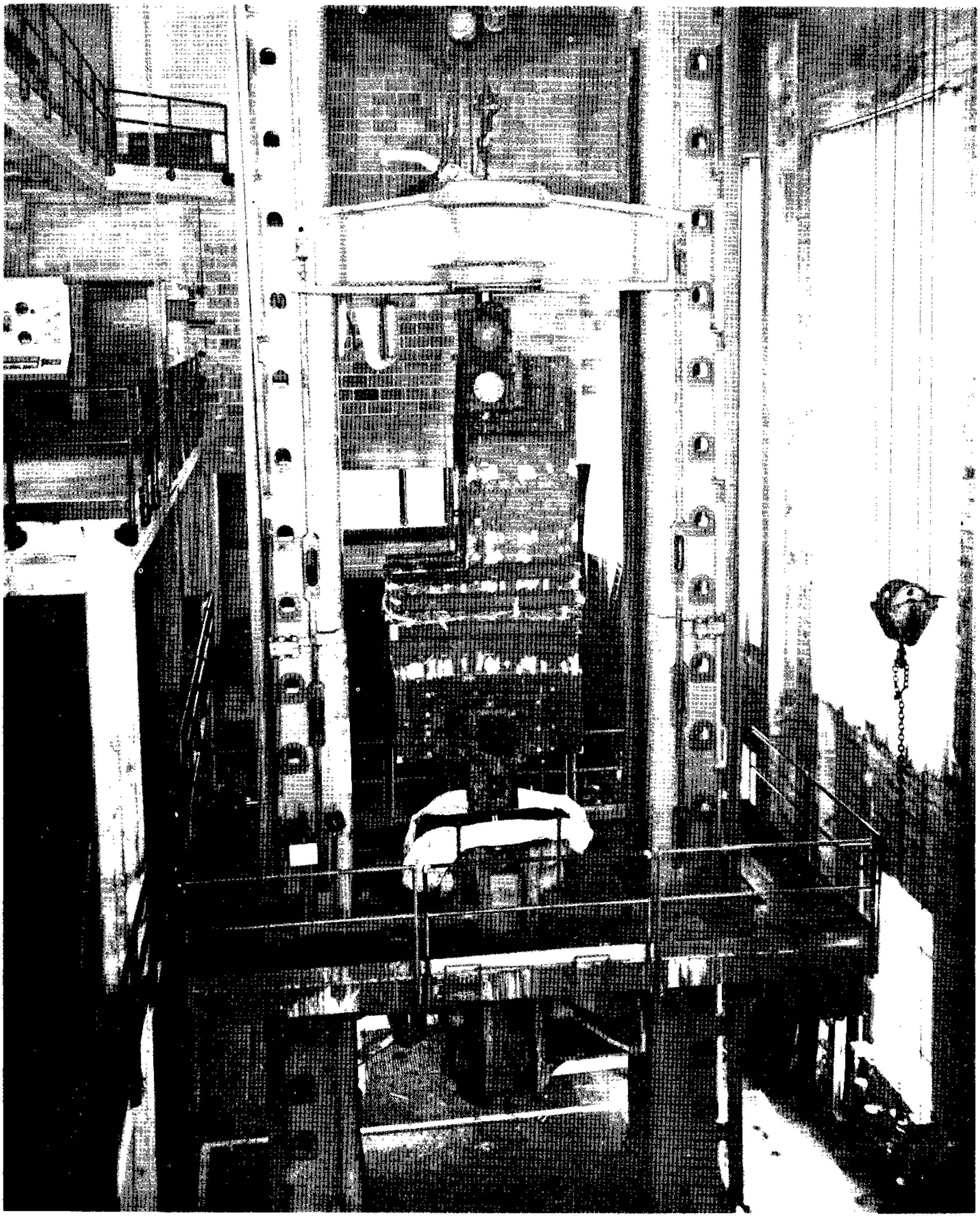
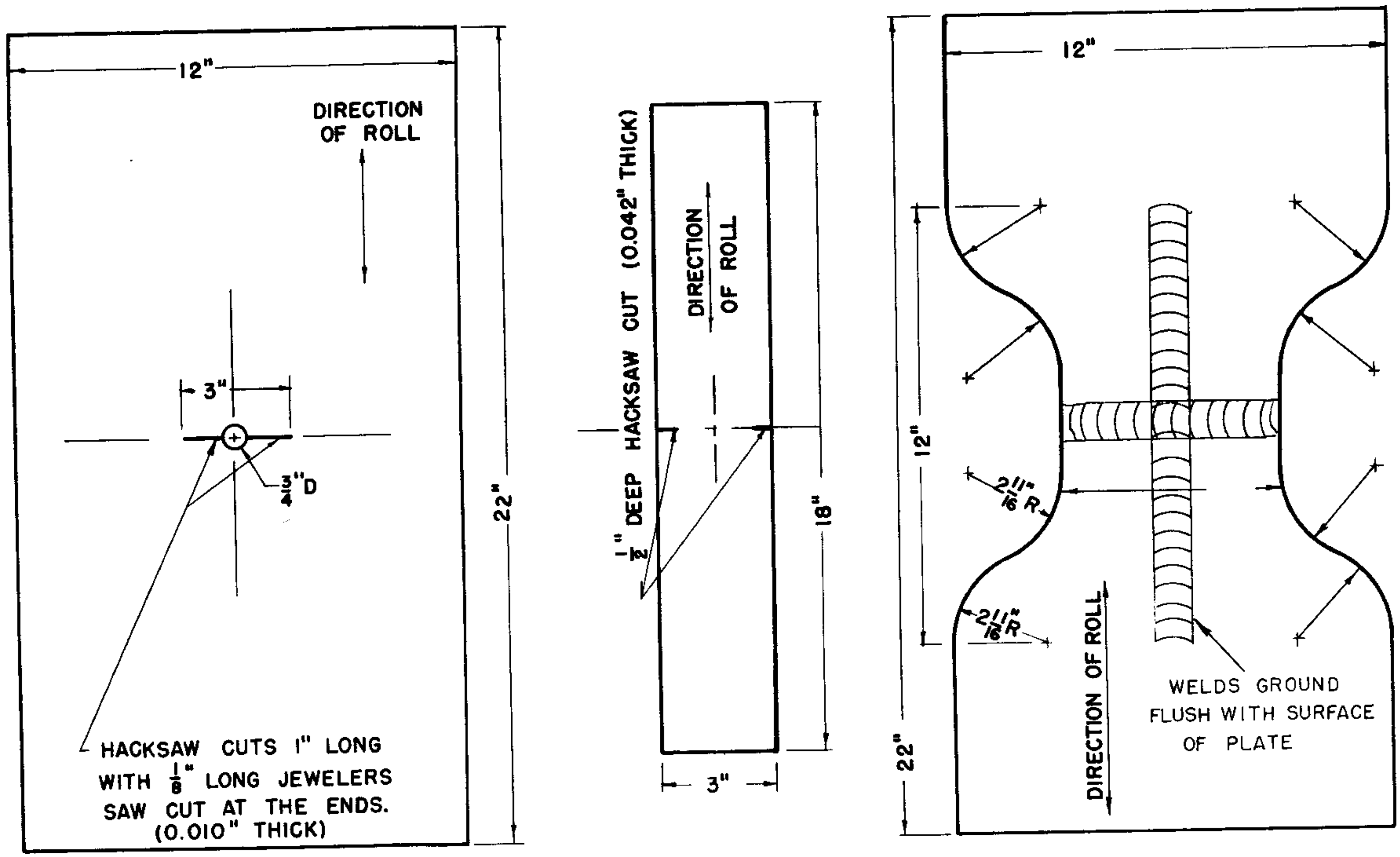


FIG. 3b -- HATCH CORNER SPECIMEN IN TESTING MACHINE
SHOWING PULLING TABS AND SR-4 STRAIN GAGE INSTALLATION



12" CENTER NOTCHED
4A

3" EDGE NOTCHED
4B

4C

FIG. 4 VARIOUS TYPES OF AUXILIARY SPECIMENS.

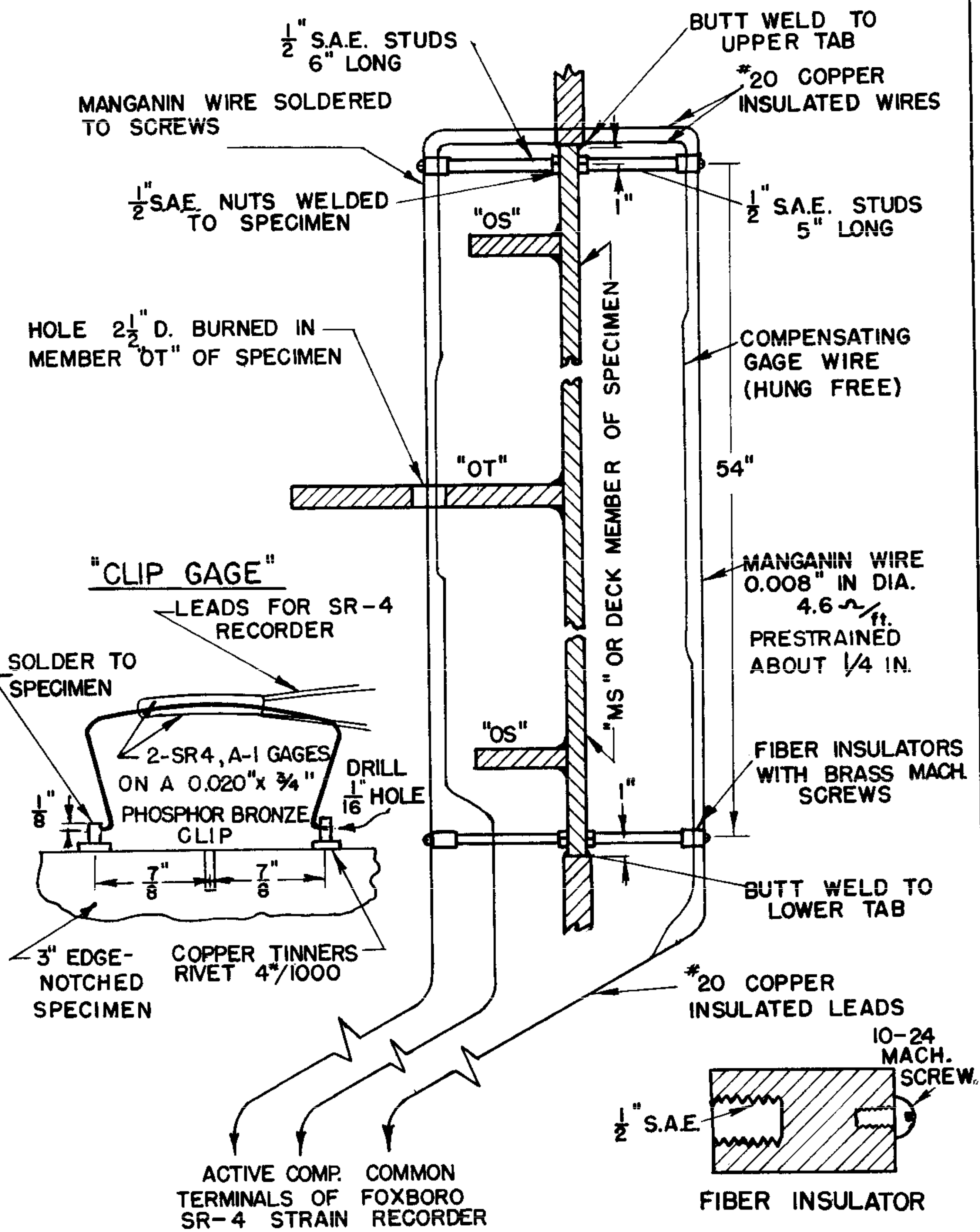


FIG. 5 TWO TYPES OF EXTENSOMETERS USED FOR STRAIN MEASUREMENTS.

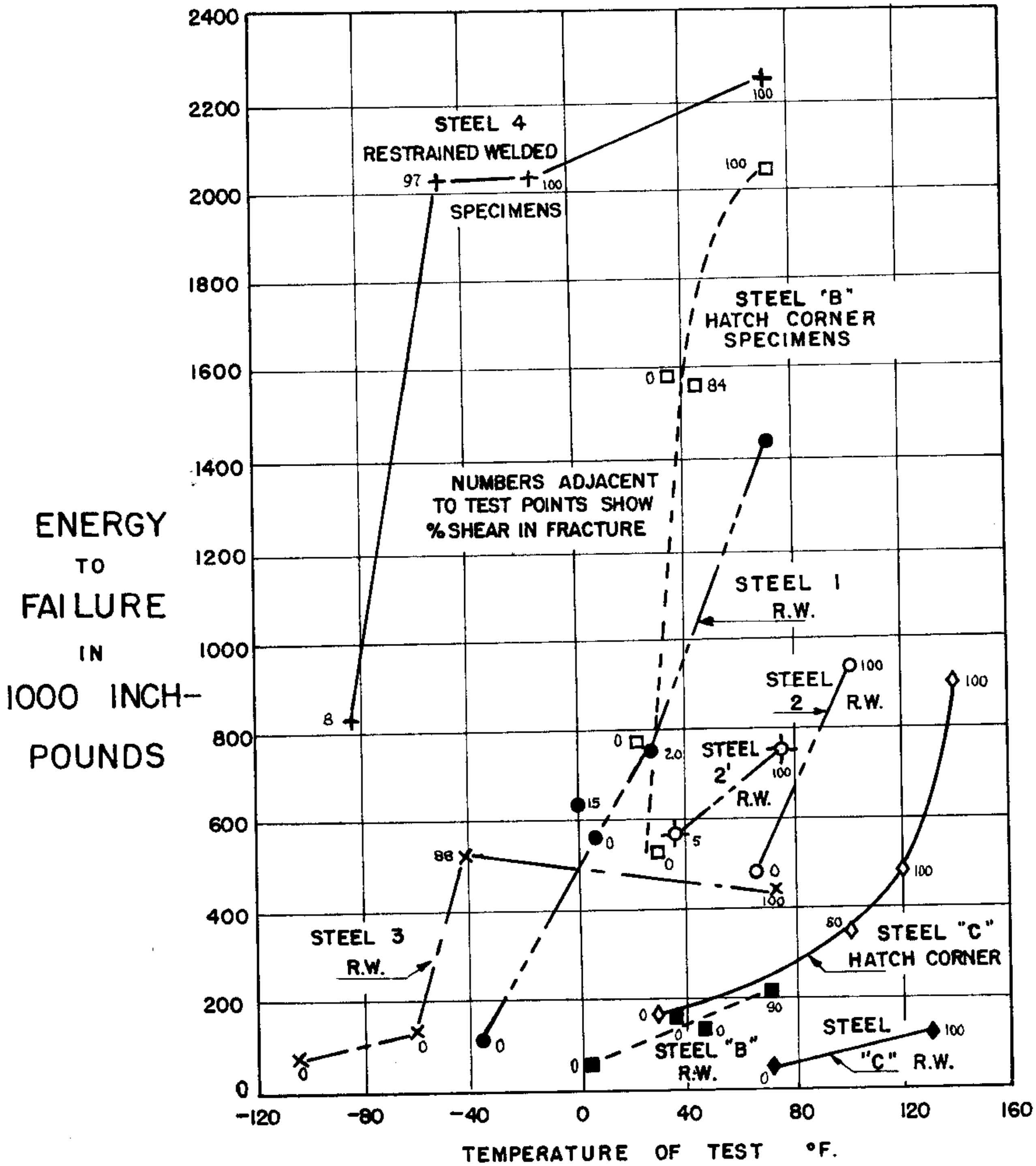


FIG. 6a ENERGY TO FAILURE VS. TEMPERATURE RELATION FOR RESTRAINED WELDED AND HATCH CORNER TYPE SPECIMENS OF MILD AND HIGH YIELD STRENGTH STRUCTURAL STEELS.

STEELS 1,2,2',3 and 4 ARE H.Y.S.S. STEELS; STEELS "B" and "C" ARE MILD STEELS.

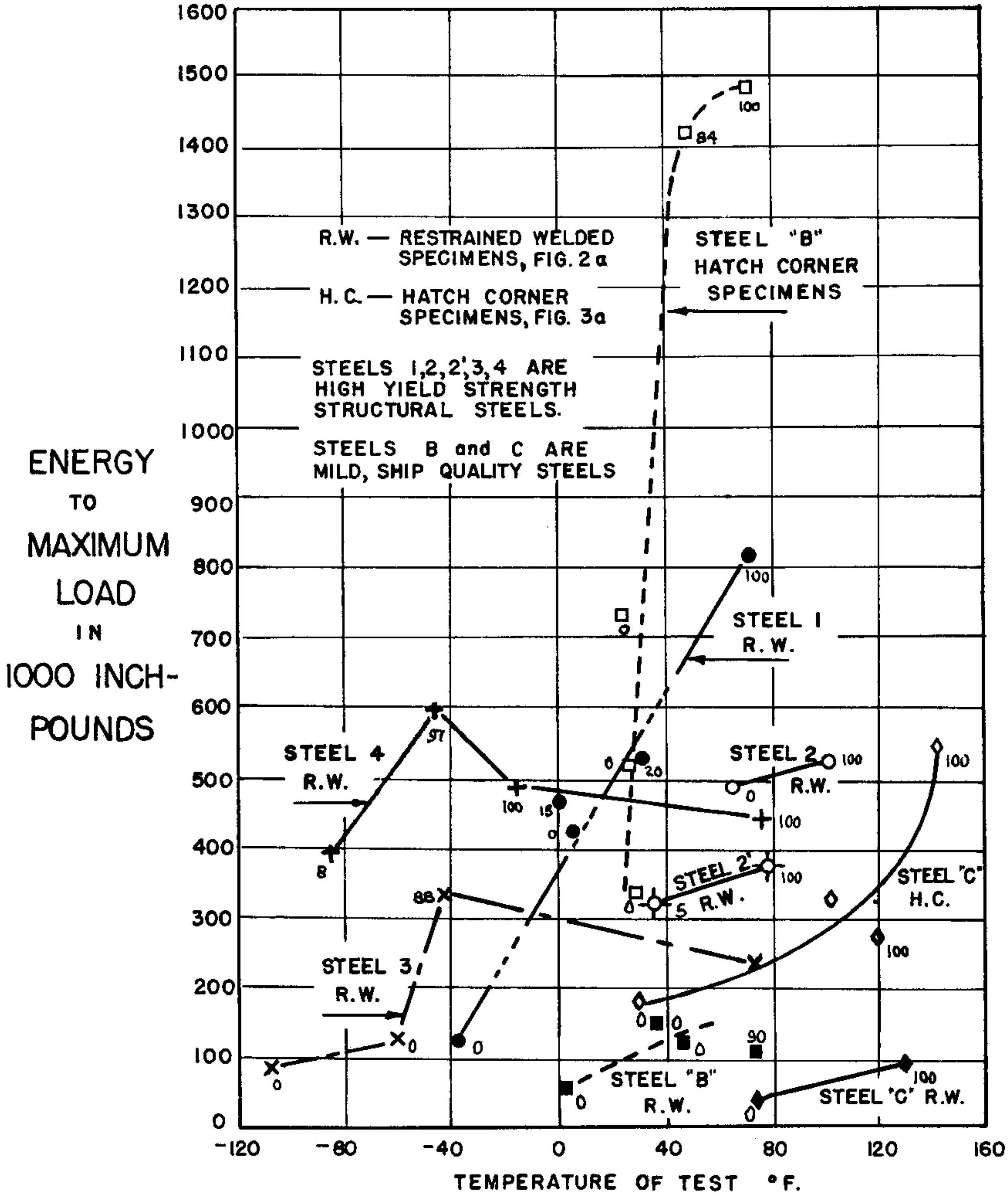


FIG. 6 b ENERGY TO MAXIMUM LOAD VS. TEMPERATURE RELATION FOR RESTRAINED WELDED AND HATCH CORNER TYPE SPECIMENS.

NUMBERS ADJACENT TO TEST POINTS INDICATE THE PERCENTAGE OF FRACTURE IN SHEAR.

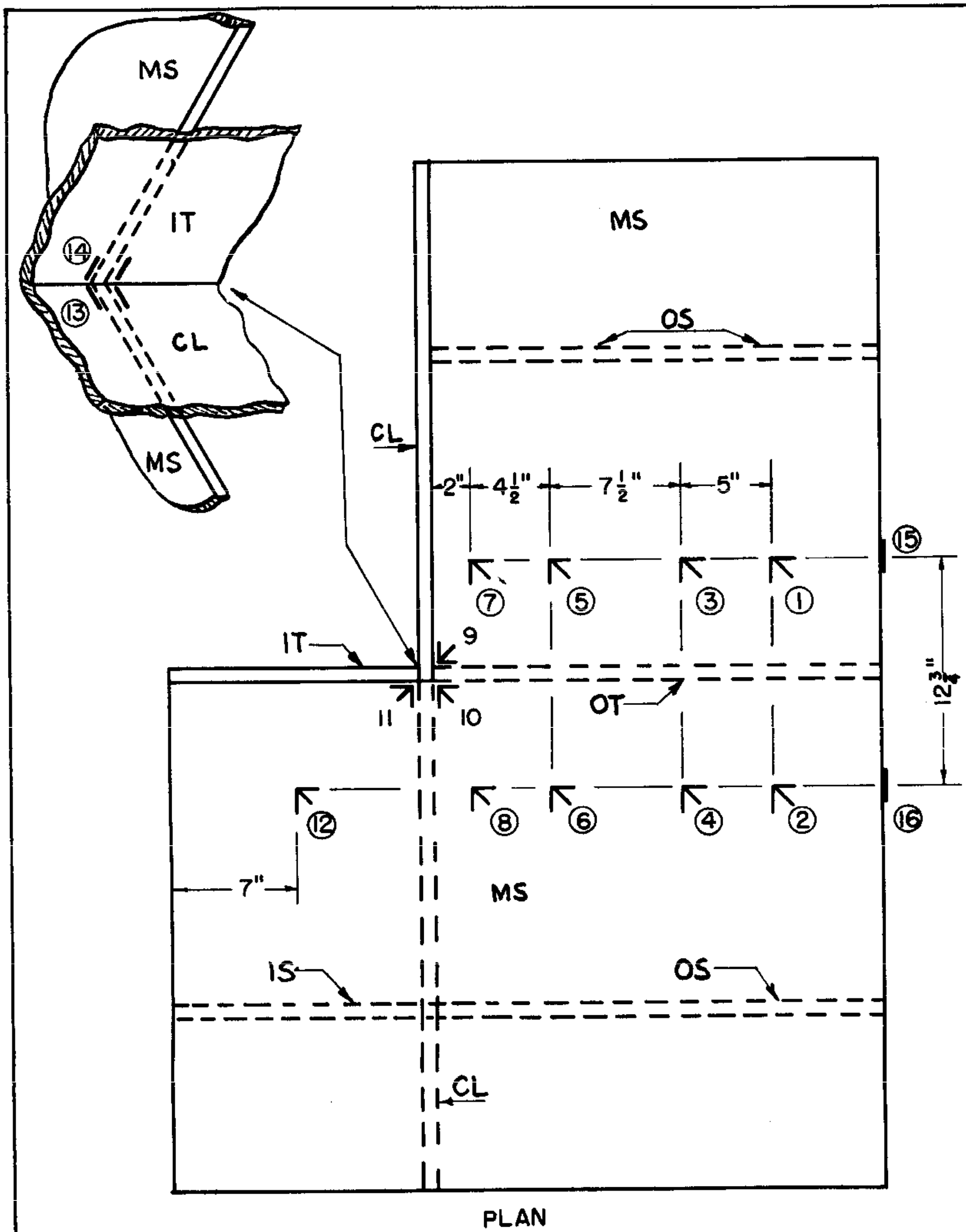


FIG. 7 GAGE LAYOUT USED FOR CHECKING STRESS DISTRIBUTION IN RESTRAINED WELDED SPECIMENS.

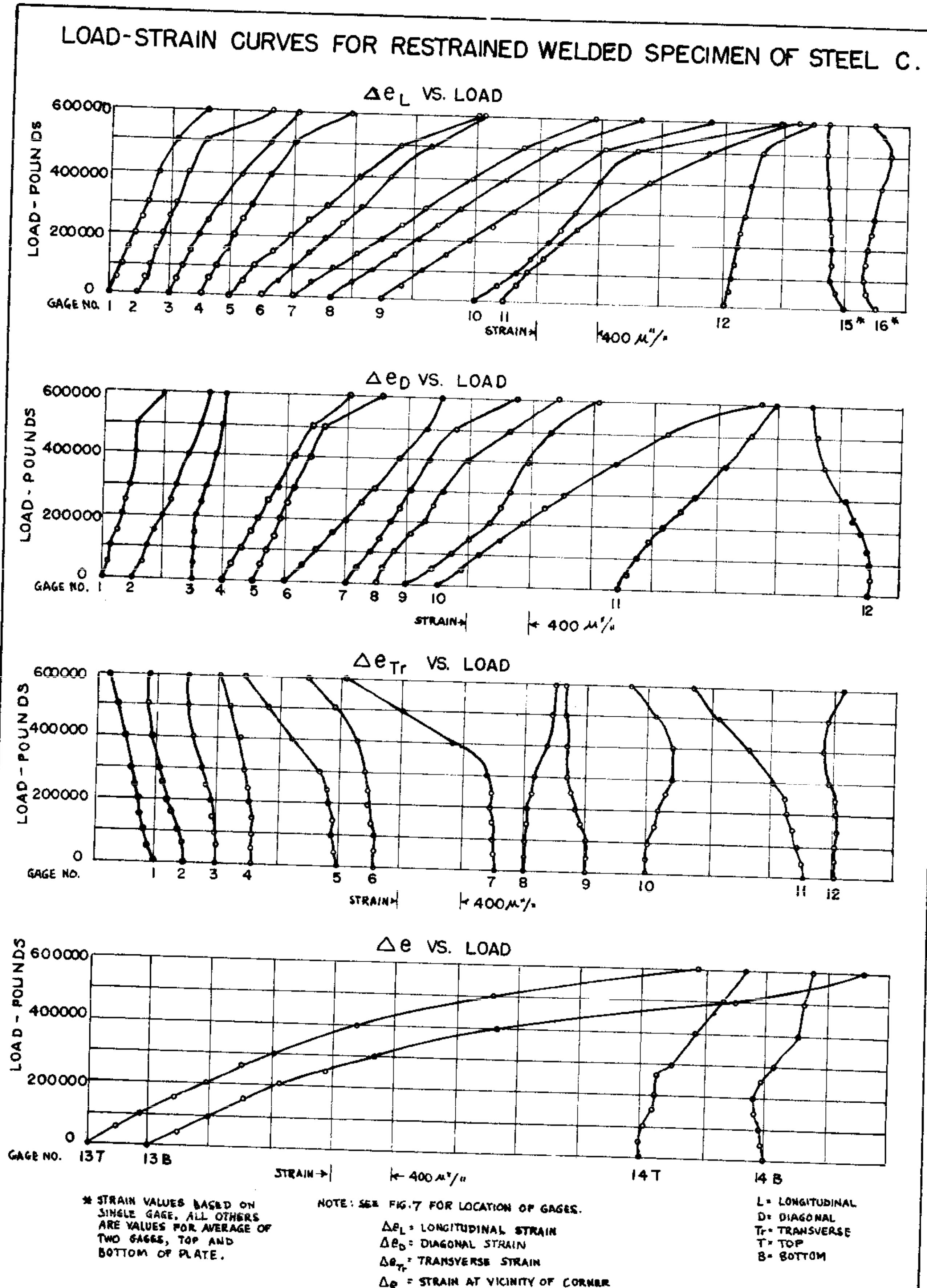
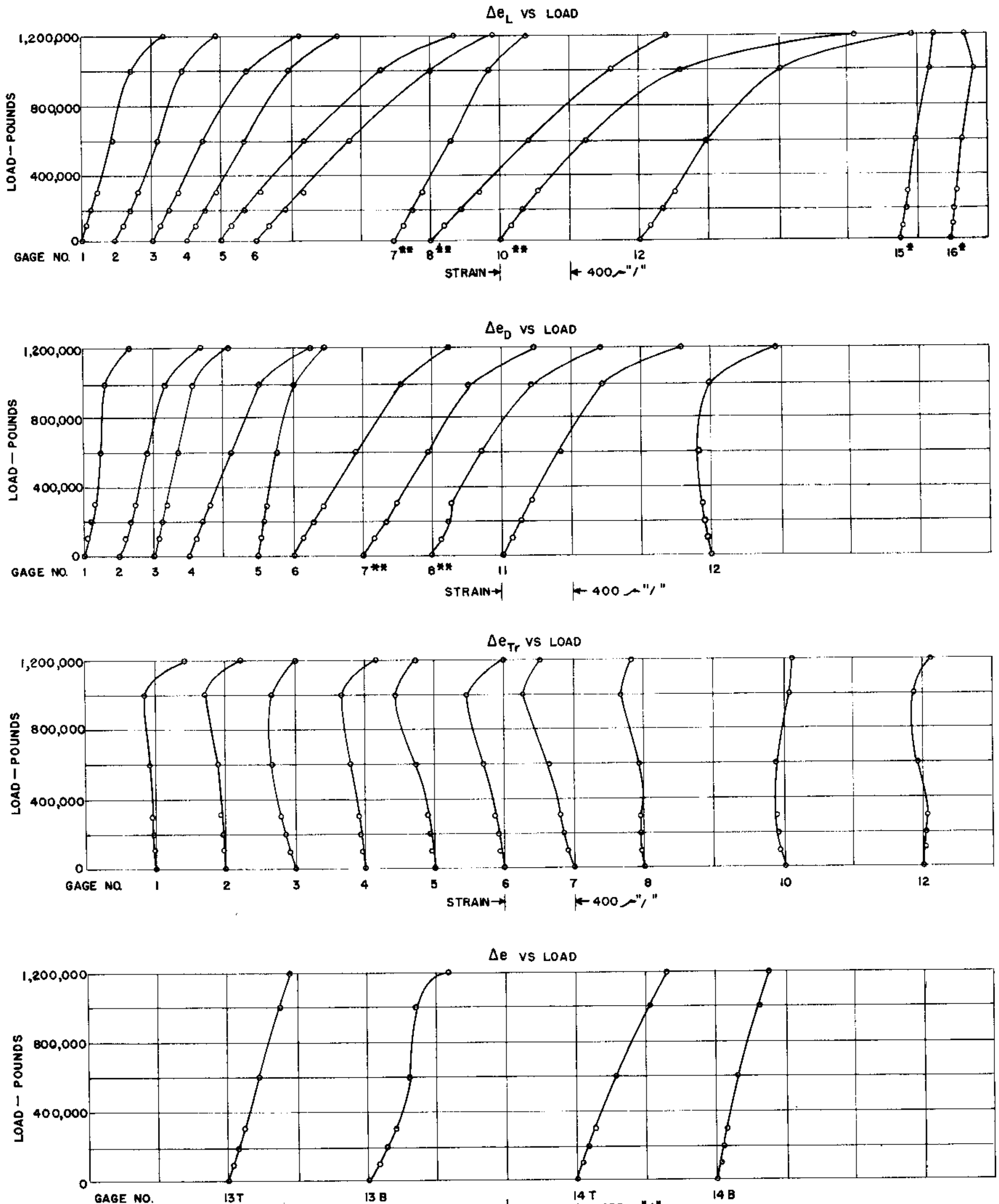

LOAD-STRAIN CURVES FOR RESTRAINED WELDED SPECIMEN OF STEEL C.
ΔeL VS. LOAD
LOAD - POUNDS
600000
400000
200000
0
GAGE NO. 1 2 3 4 5 6 7 8 9 10 11 12 15* 16*
STRAIN
400 μ"/"
ΔeD VS. LOAD
GAGE NO. 1 2 3 4 5 6 7 8 9 10 11 12
ΔeTr VS. LOAD
GAGE NO. 1 2 3 4 5 6 7 8 9 10 11 12
Δe VS. LOAD
GAGE NO. 13T 13B 14T 14B
* STRAIN VALUES BASED ON SINGLE GAGE. ALL OTHERS ARE VALUES FOR AVERAGE OF TWO GAGES, TOP AND BOTTOM OF PLATE.
NOTE: SEE FIG. 7 FOR LOCATION OF GAGES.
ΔeL = LONGITUDINAL STRAIN
ΔeD = DIAGONAL STRAIN
ΔeTr = TRANSVERSE STRAIN
Δe = STRAIN AT VICINITY OF CORNER
L = LONGITUDINAL
D = DIAGONAL
Tr = TRANSVERSE
T = TOP
B = BOTTOM

FIG. 8

LOAD-STRAIN CURVES FOR HATCH CORNER SPECIMEN OF MILD STEEL "C"



* STRAIN VALUES BASED ON SINGLE GAGE. ALL OTHERS VALUES ARE AVERAGE OF TWO GAGES, TOP AND BOTTOM OF PLATE.

** GAGES MOUNTED ON DOUBLER PLATE IN THIS TYPE OF SPECIMEN.

NOTE: SEE FIG. 7 FOR LOCATION OF GAGES.

THERE ARE NO GAGES ON THIS TYPE OF SPECIMEN THAT CORRESPOND TO GAGE LOCATIONS 9 & 11.

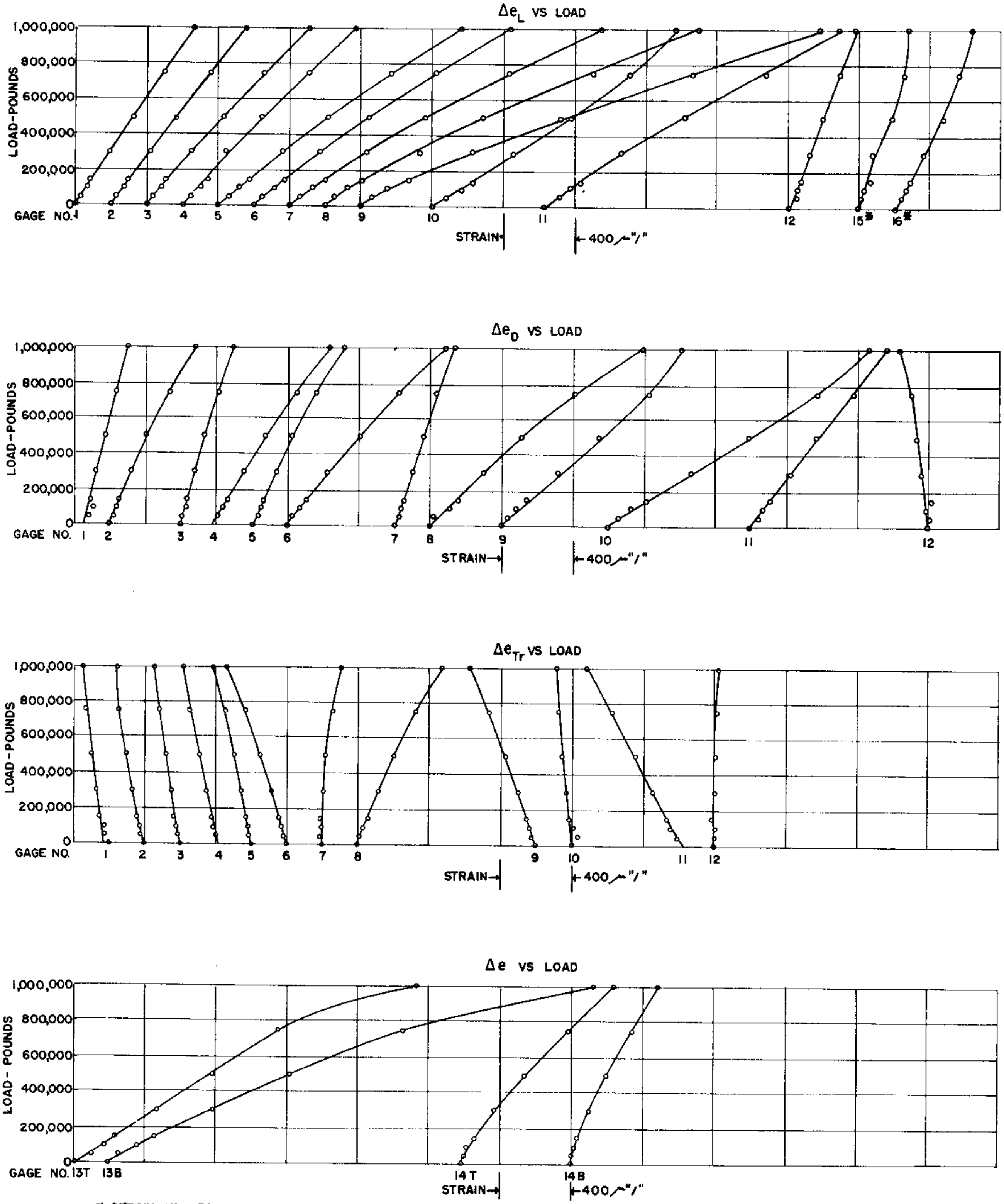
LOCATION 10 IS FARTHER REMOVED FROM CORNER IN THIS TYPE OF SPECIMEN.

L = LONGITUDINAL
D = DIAGONAL
Tr = TRANSVERSE
T = TOP
B = BOTTOM

Δe_L = LONGITUDINAL STRAIN
Δe_D = DIAGONAL STRAIN
Δe_{Tr} = TRANSVERSE STRAIN
Δe = STRAIN AT VICINITY OF CORNER
13 — LONGITUDINAL
14 — TRANSVERSE

FIG. 9

LOAD-STRAIN CURVES FOR HIGH TENSILE STRENGTH STEEL RESTRAINED SPECIMEN I-S



* STRAIN VALUES BASED ON SINGLE GAGE. ALL OTHER VALUES ARE AVERAGE OF TWO GAGES, TOP AND BOTTOM OF PLATE.

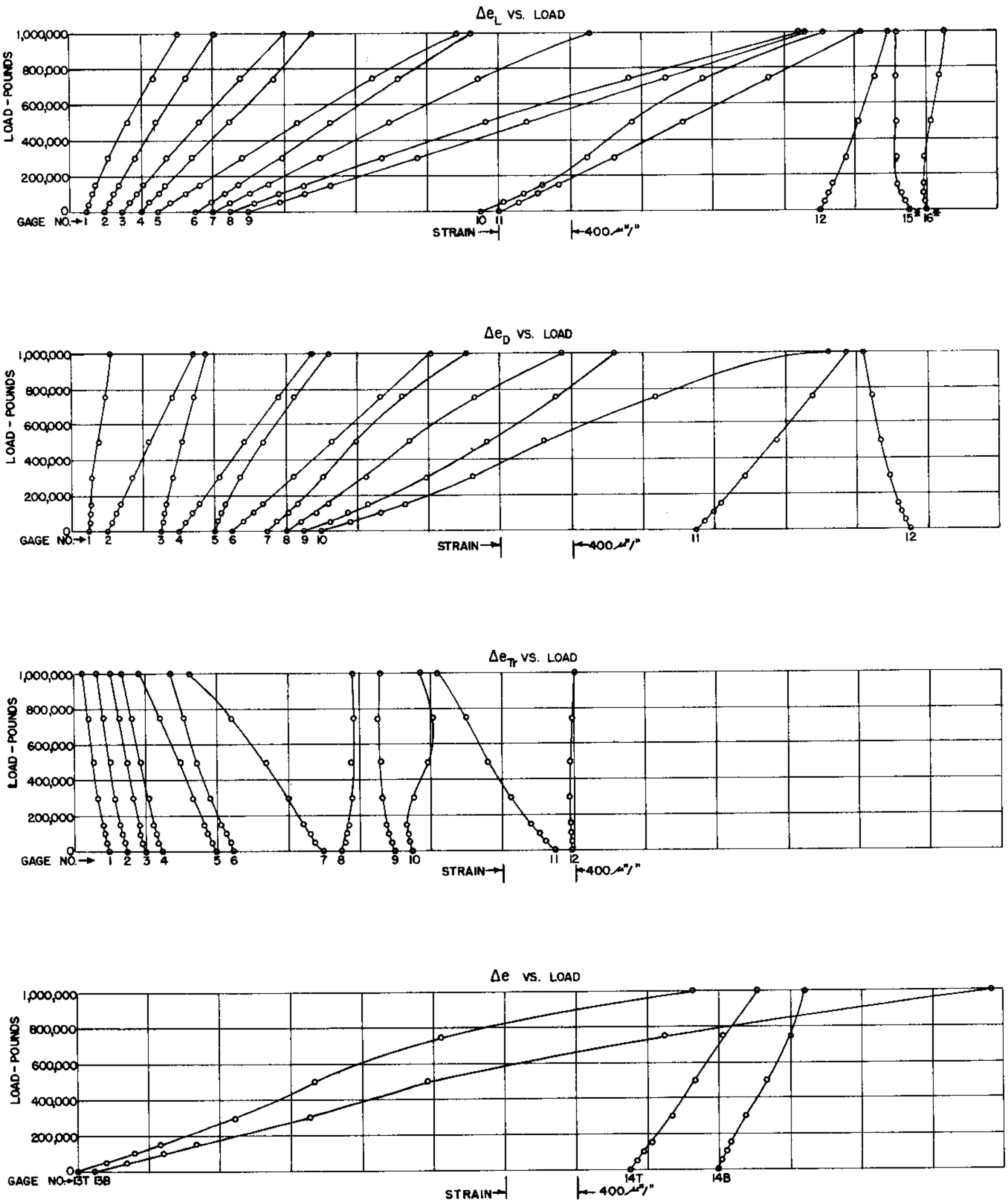
NOTE: SEE FIG. 7 FOR LOCATION OF GAGES.

L = LONGITUDINAL
D = DIAGONAL
Tr = TRANSVERSE
T = TOP
B = BOTTOM

Δe_L = LONGITUDINAL STRAIN
Δe_D = DIAGONAL STRAIN
Δe_{Tr} = TRANSVERSE STRAIN
Δe = STRAIN AT VICINITY OF CORNER. 13-LONGITUDINAL; 14-TRANSVERSE.

FIG. 10

LOAD-STRAIN CURVES FOR HIGH TENSILE STRENGTH STEEL RESTRAINED SPECIMEN 2-S



* STRAIN VALUES BASED ON SINGLE GAGE. ALL OTHER VALUES ARE AVERAGE OF TWO GAGES, TOP AND BOTTOM OF PLATE.

NOTE: SEE GAGE LAYOUT FOR LOCATION OF GAGES.

L = LONGITUDINAL
D = DIAGONAL
Tr = TRANSVERSE
T = TOP
B = BOTTOM

Δe_L = LONGITUDINAL STRAIN
Δe_D = DIAGONAL STRAIN
Δe_{Tr} = TRANSVERSE STRAIN
Δe = STRAIN AT VICINITY OF CORNER, 13-LONGITUDINAL; 14-TRANSVERSE

FIG. 11.

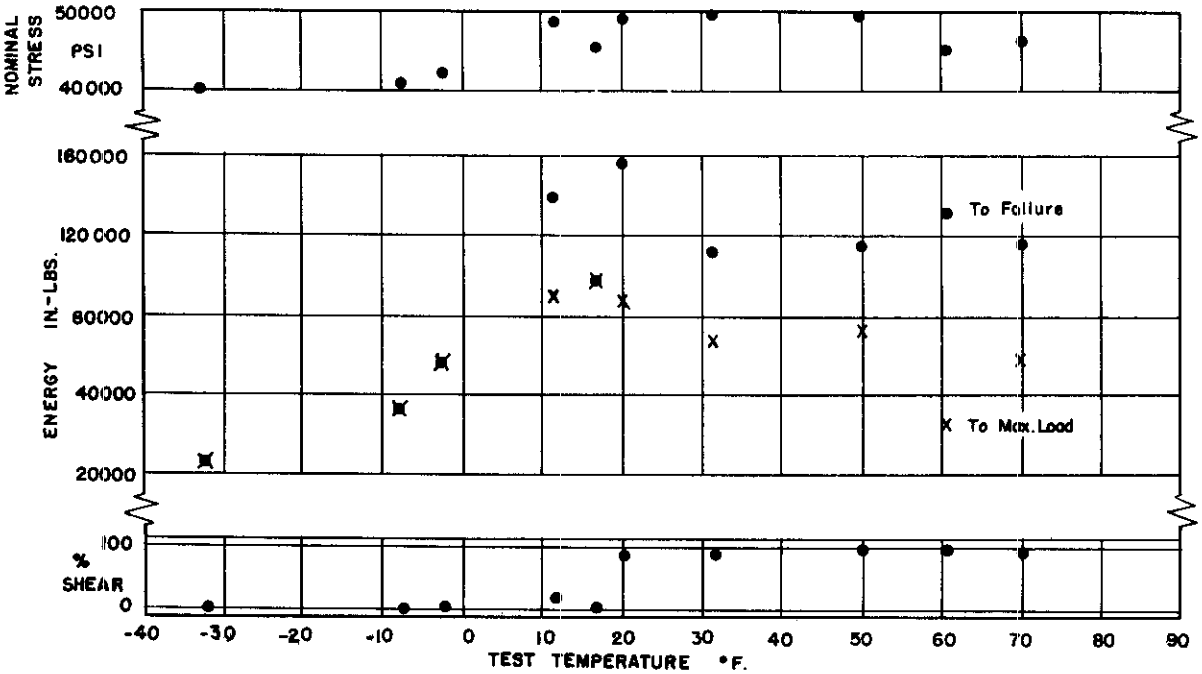


FIG. 12 NOMINAL STRESS AT MAXIMUM LOAD, ENERGY ABSORPTION AND MODE OF FRACTURE VS. TEMPERATURE OF TEST RELATIONS FOR MILD STEEL B_r

12-IN. WIDE CENTER-NOTCH SPECIMENS.

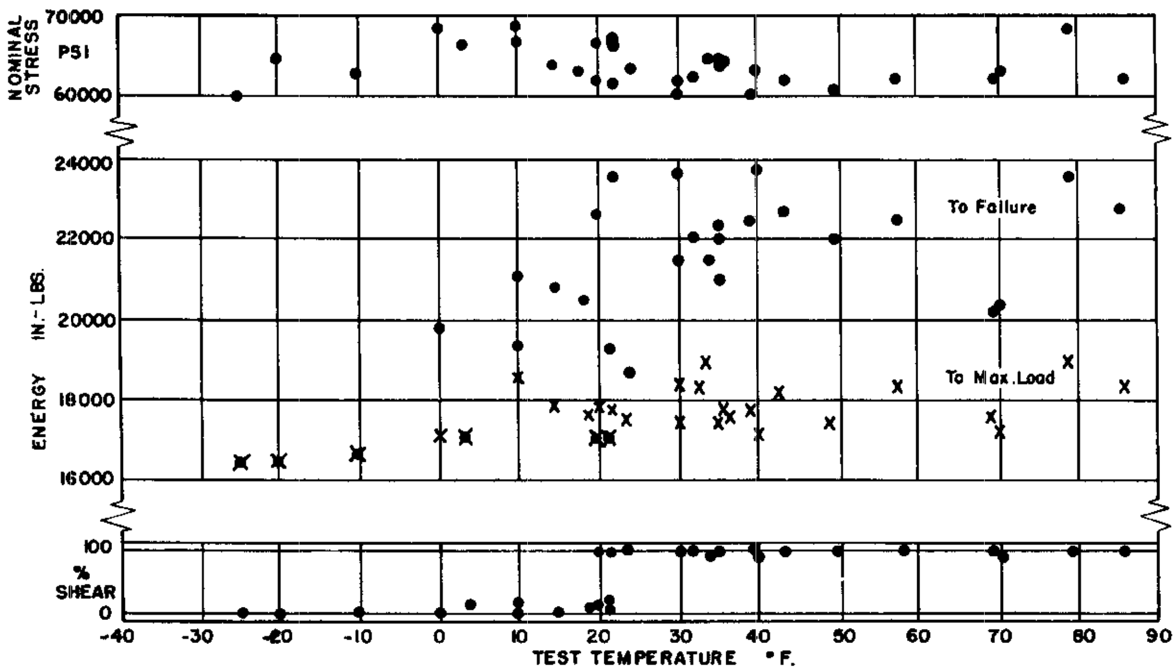


FIG. 13 NOMINAL STRESS AT MAXIMUM LOAD, ENERGY ABSORPTION AND MODE OF FRACTURE VS. TEMPERATURE OF TEST RELATIONS FOR MILD STEEL B_r

3-IN. WIDE EDGE-NOTCHED SPECIMENS.

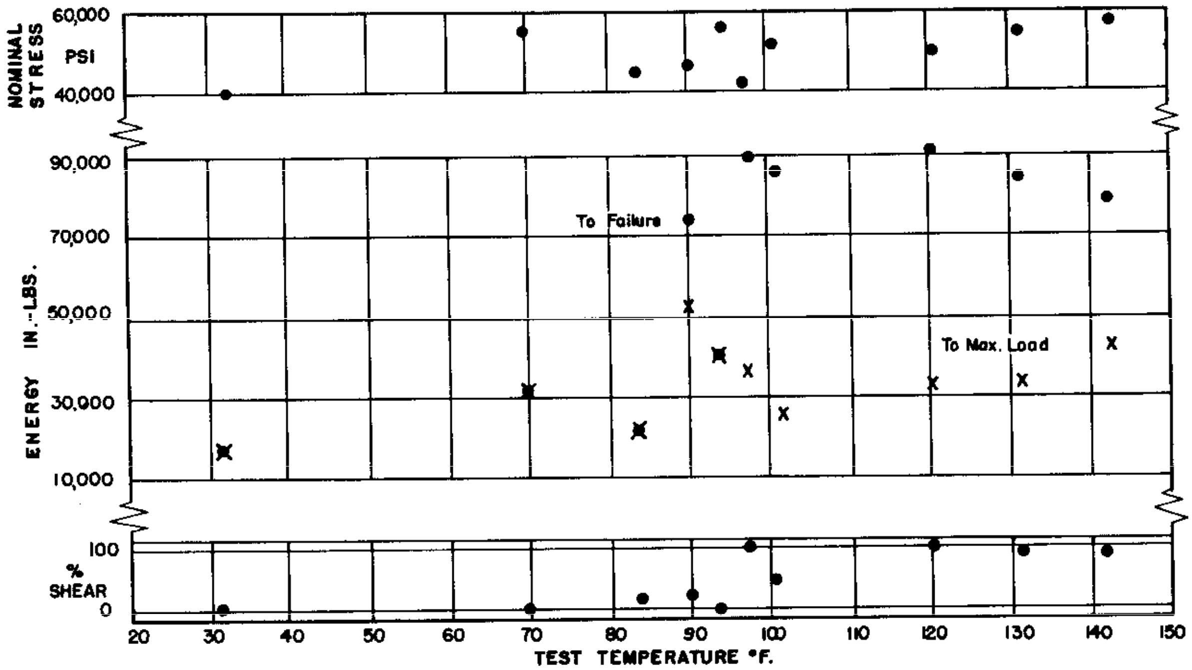


FIG. 14 NOMINAL STRESS AT MAXIMUM LOAD, ENERGY ABSORPTION AND MODE OF FRACTURE VS. TEMPERATURE OF TEST RELATIONS FOR MILD STEEL C
12- IN. WIDE CENTER-NOTCH SPECIMENS.

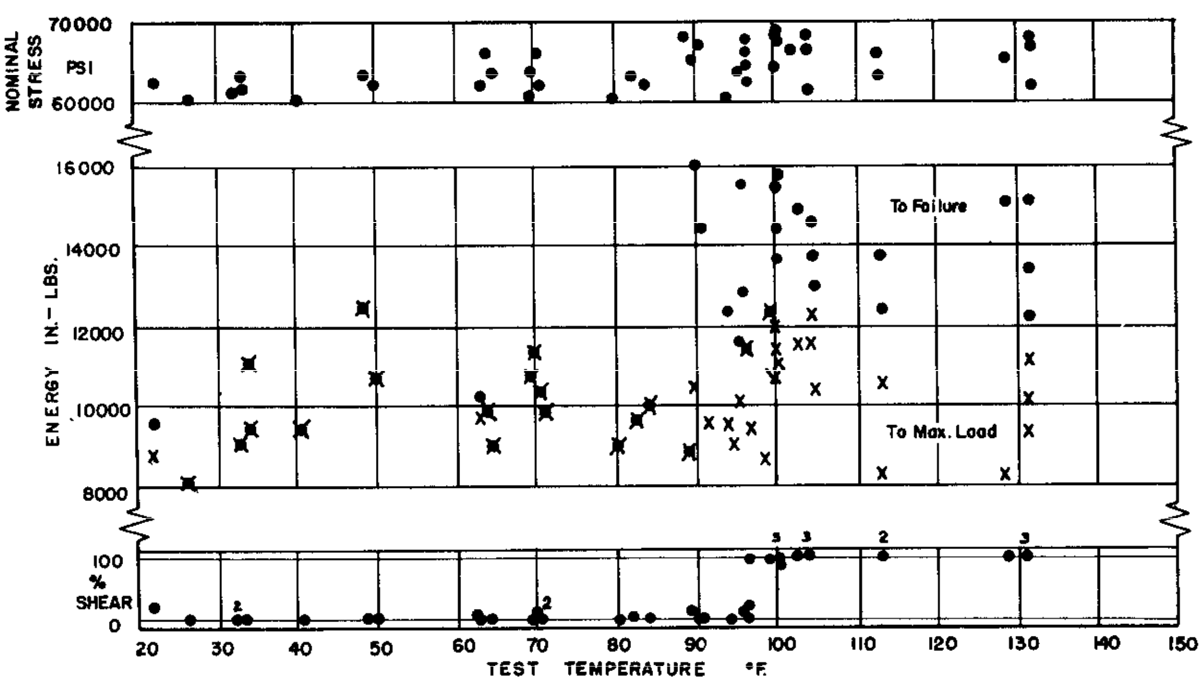


FIG. 15 NOMINAL STRESS AT MAXIMUM LOAD, ENERGY ABSORPTION AND MODE OF FRACTURE VS. TEMPERATURE OF TEST RELATIONS FOR MILD STEEL C.
3- IN. WIDE EDGE-NOTCHED SPECIMENS.

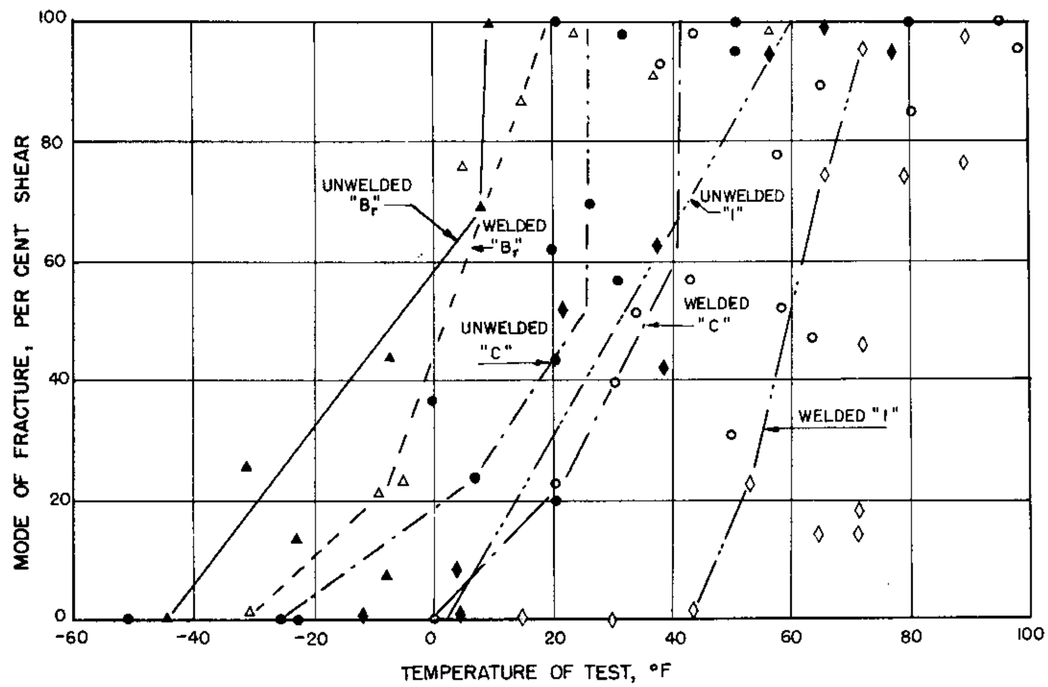


FIG. 16 VARIATION WITH TEMPERATURE OF TEST IN THE MODE OF FRACTURE FOR ¾" BY 6⅝" UNNOTCHED SPECIMENS WITH LONGITUDINAL WELDS - STEELS "B_r", "C", & "I" UNIONMELT WELDS ON BOTH SIDES OF SPECIMEN, WELDS GROUND FLUSH.

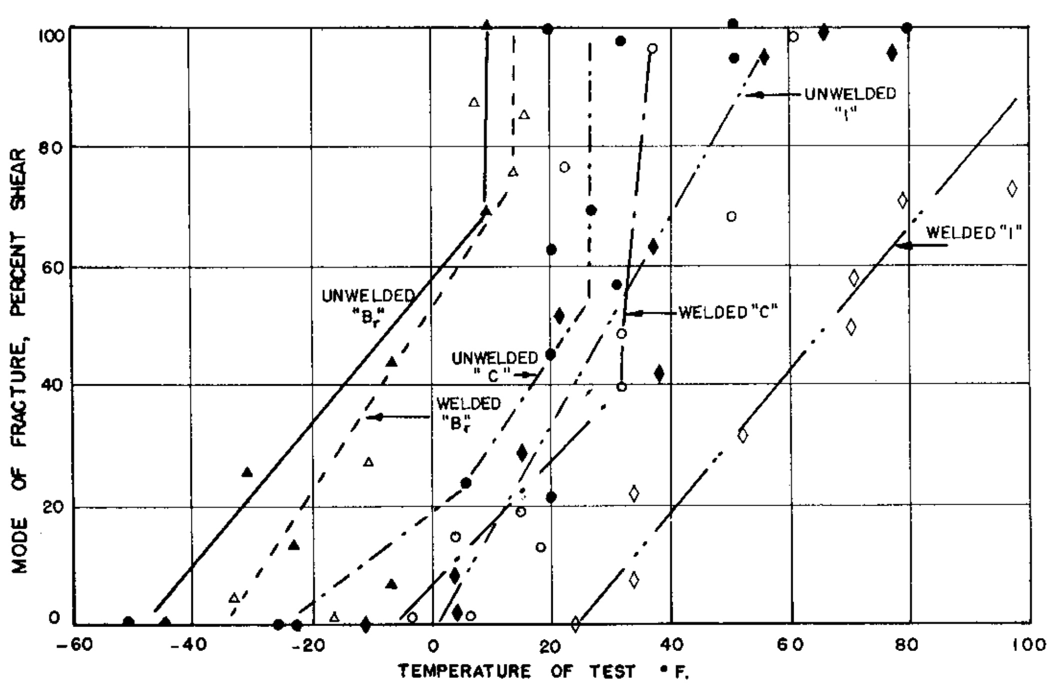


FIG. 17 VARIATION WITH TEMPERATURE OF TEST IN THE MODE OF FRACTURE FOR ¾" BY 6⅝" UNNOTCHED SPECIMENS WITH INTERSECTING WELDS - STEELS "B", "C" & "I".