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First preliminary report on the investigation of welded seat angle connections, 1934

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FIRST PRELIMINARY REPORT

on

THE INVESTIGATION OF WELDED SEAT ANGLE CONNECTIONS

by

Inge Lyse and Norman G. Schreiner

Fritz Engineering Laboratory

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SYNOPSIS

The following report presents the results ~~of tests~~ of ~~twenty-four~~ twenty-nine welded seat angle test specimens and the correlative tests of ~~two~~ four full size beam-column connections ~~for the purpose of determining the effects of the many variables on the strength of the connection~~. The test specimens consist~~s~~ of two angles welded along the ends of the vertical legs to either side of a plate with the load applied at three different positions on the outstanding leg. The full size connections were built up of stub columns with the seat angles welded thereon in the manner described above, and a twenty-inch I-beam supported on the outstanding legs being held in place by tack welds or bolts between the flange and the outstanding leg.

The results of the investigation show ~~the necessity of considering~~ the effects of the thickness of the angle, the location of the resultant reaction of the beam, ~~to a lesser degree~~ the length of the vertical leg of the angle ~~as well as~~ and the strength of the weld ~~in evaluating~~ on the total resistance of the seat angle connection. The high concentration of stress at the end of the beam and its effect upon the effective lever arm is pointed out.

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In general, the failure of this type of connection ~~is~~ was gradual and would merely cause excessive deflection of the beam ~~which it supports~~ rather than a crash of the structure. While the tests were stopped slightly beyond the load required to fracture the weld at the heel of the angle, ~~it is not to be considered that~~ th~~is~~e recorded load is ~~in anywise~~ not the maximum that this connection can carry, but it is simply the maximum that can be carried without excessive deflection.

The analysis of the results leads to the recommendations for ~~the~~ design of angles, welds and beams ~~which are~~ presented ~~in this paper.~~ in the last ~~chapter~~ section of this paper.

I. INTRODUCTION

1. Acknowledgment - This investigation was carried on as one of the projects of the Structural Steel Welding Committee of the American Bureau of Welding in cooperation with Lehigh University, using the facilities of the Fritz Engineering Laboratory. The steel necessary was furnished through the courtesy of the Bethlehem Steel Company and all fabrication was done in the laboratory shop. Acknowledgments are due to all members of the Structural Steel Welding Committee for their many helpful suggestions and criticisms and particularly to the Chairman Mr.L.S.Moisseiff, Messrs. E.H.Ewertz, H.H.Moss, H.M.Priest and W.Spraragen, to Mr.C.H.Mercer, Consulting Engineer, McClintic-Marshall Corporation and Mr.V.E.Ellstrom, Manager of Sales Engineering, Bethlehem Steel Company for their able support, to Mr.C.C. Keyser, Assistant in the Fritz Engineering Laboratory and Professor C.D.Jensen of the Department of Civil Engineering for their invaluable assistance and cooperation, and to Mr.D.M.Stewart, Research Fellow in Civil Engineering for the studies by means of photoelasticity.

2. Purpose of the Investigation - The investigation of welded seat angles was made in order to obtain experimental information from which a rational theory of design could be evolved for their economic use in welded structures. Available literature shows very little information concerning such design or tests. In general seat angles are used in two ways in structures, viz.

(a) As an erection seat, for the purpose of supporting the end of the beam during erection and prior to the attachment of the web angles which carry the end reaction. Used in this way, the strength ~~must~~ needs only be sufficient to preclude construction failure or damage in transit.

(b) As a load carrying member, transferring the end reaction of the beam to the column. Used thus the beam which they support must be held against lateral as well as vertical displacement. If the beam supports a rigid flooring, such as a concrete slab, it may be considered as adequately supported laterally. However, if the beam supports a more flexible floor or is a member of an open framework, lateral support is necessary and ~~This~~ may be accomplished by the use of a top angle or web angles, neither of which are considered to carry any vertical load. ~~In present practice neither of these adjuncts is considered as a load carrying member, indeed this support is often purely lateral without any connection suitable for accepting any of the vertical load.~~

II. GENERAL STATEMENT OF THE PROBLEM

While there are many varieties of beam seats, and structural welding engineers are ~~inventing~~ designing and using new forms whenever the opportunity presents itself, this investigation has been confined to the simplest possible type, and the one most widely used at present, namely a simple angle seat welded to the column by means of vertical fillet welds at each end of the vertical leg, ~~with~~ the lower flange of the supported beam may be welded or bolted to the outstanding leg of the angle. This type of beam seat is also in common use in riveted structures, and the results of the investigation apply equally well to these angles, with necessary corrections due to the different manner of attachment to the column.

The problem of the welded seat angle ~~type of~~ connection is illustrated in Fig.1, and may be divided into three parts.

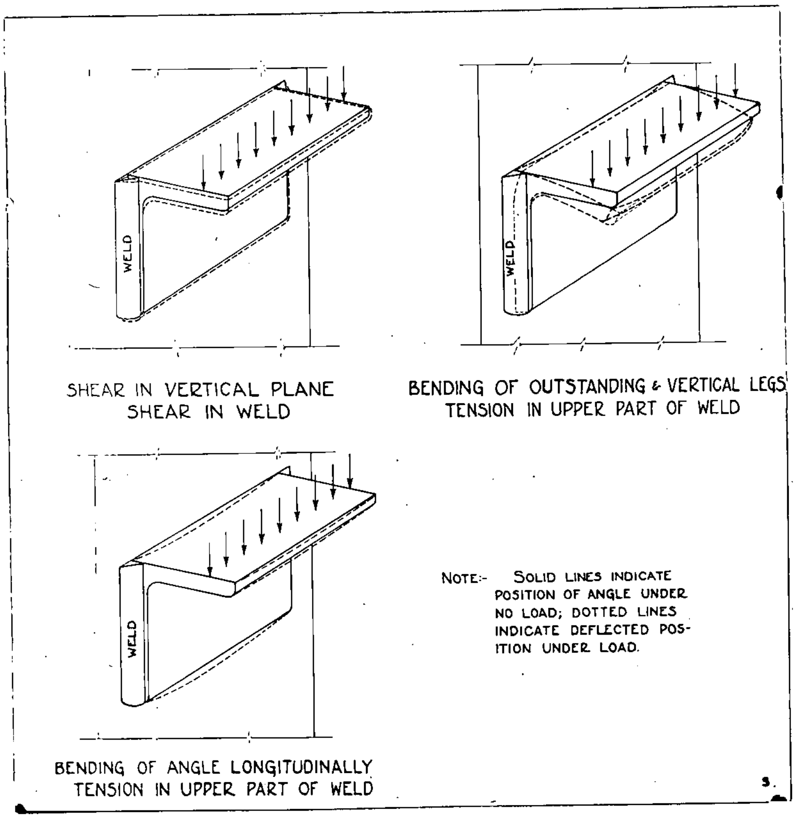


Fig.1. Illustration of the Seat Angle Problem.

(a) Due to the reaction of the load on the angle, there is a vertical shear imposed on the weld causing a downward deflection. ~~from the original position of the angle~~. ¶ (b) Due to the moment Wa (see Fig.2a), the outstanding leg bends downward and the vertical leg bends away from ~~the~~ column at the heel of the angle. For a short distance ~~from~~ the ends of the angle the vertical leg ~~is restrained by the welds~~ from bending outward, ~~which~~ introduces a warping ~~into the outstanding leg~~. This action of the vertical leg requires that a corresponding compressive reaction exist towards the toe of this leg of the angle. The compression between the back of the vertical leg and the face of the column introduces an upward frictional force offsetting part of the vertical load and reducing the downward deflection due to the vertical shear strain in the weld.

~~The third condition to be considered is that~~ the angle acts as a short, stubby beam, elastically restrained at the ends by the weld. This causes a greater deflection at the center than at the ends and further modifies the shape of the outstanding leg.

The beam flanges supported ~~on~~ the angle bend under the reaction ~~which tends~~ to be concentrated on an area under the web. The amount of this bending is determined by the relative stiffness of the flange and the outstanding leg. Since the flanges are also fastened to the outstanding leg, the two act more or less as a unit and the state of stress in the outstanding leg is altered.

The stress condition in the weld itself is rather complex and is a combination of vertical shear and bending in two directions. The vertical shearing stress is of small importance except in certain combinations of angle and weld, while the determining factors are the ~~[illegible]~~ stresses set up by the bending moments.

III. TEST PROGRAM

(1) The test program as approved by the Committee consisted of two types of specimens designated as Series A and Series B. Series A was designed ~~in order~~ to permit the study of each variable in turn at a minimum of expense ~~and fabrication~~, while Series B consisted of full size beam ~~to~~ column connections, permitting the correlation of the results on the ~~pilot~~ Series A specimens with those obtainable in actual practice. Series A consisted of 29 specimens ~~twenty-four specimens~~ and Series B of 4 specimens. ~~two specimens with four specimens remaining to be tested.~~

(a) Series A - A simple, balanced test specimen was prepared as shown in Fig.2 consisting of a central plate, on either side of which the angles were welded, care being taken to place them directly opposite to each other. The angles were loaded symmetrically through rollers thus avoiding the necessity of taking care of any eccentricity.

(b) Series B consisted of a 20" loading beam (I 20a 81.4 lb.) 18' 0-1/2" long resting on seat angles 8" long, which in turn were welded to stub columns made up of 10" H

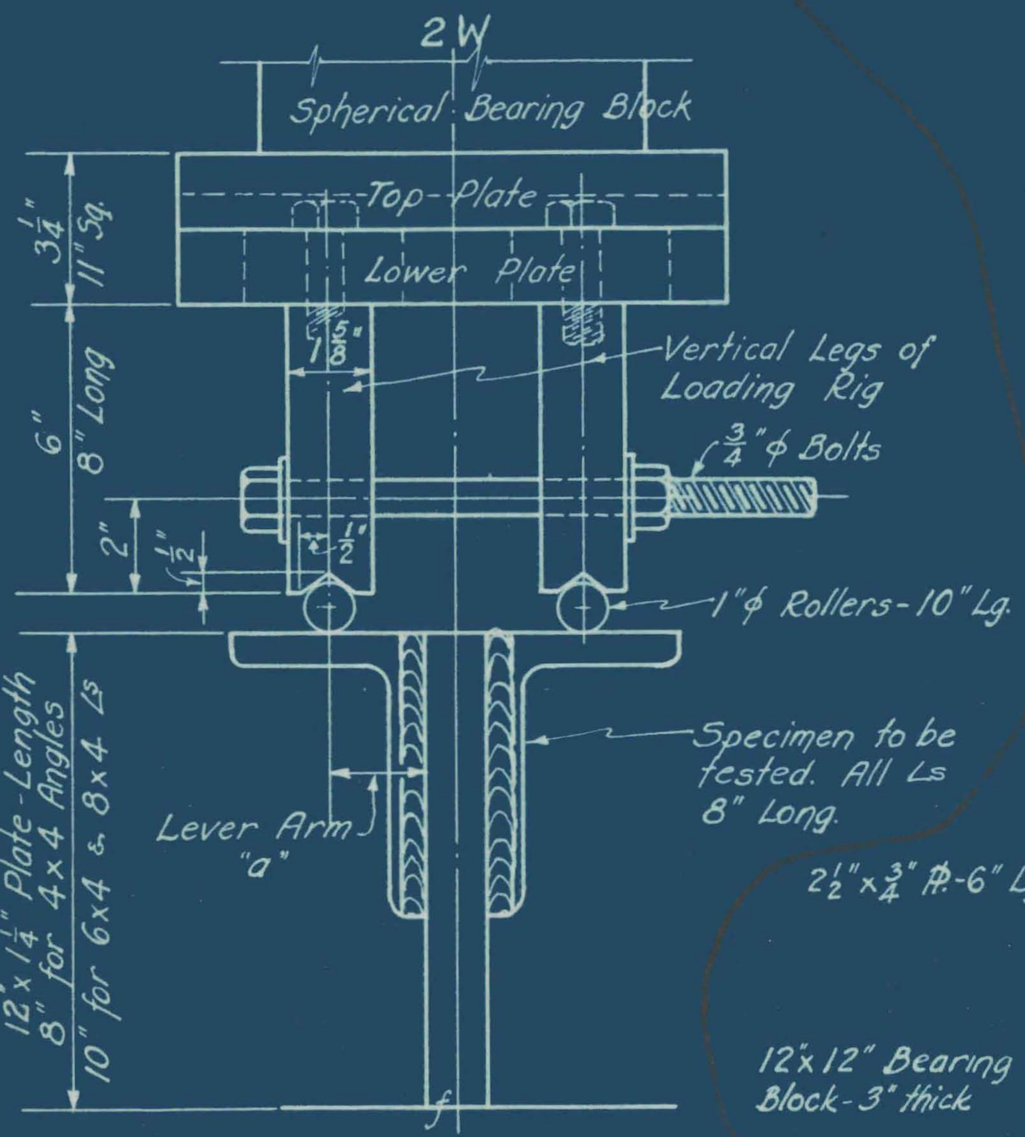


FIG. 2a. END VIEW - SERIES A SPECIMEN AND LOADING RIG.

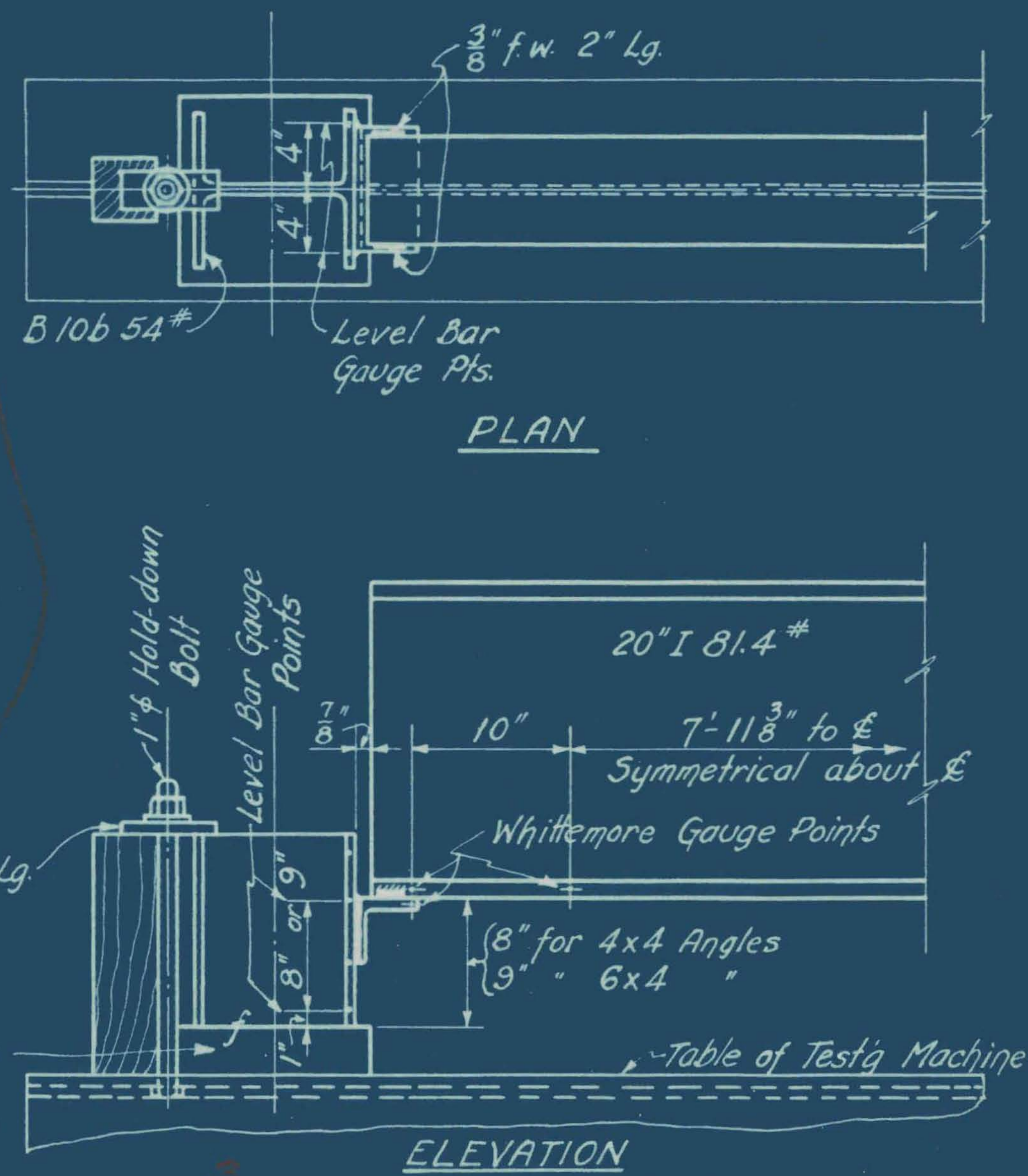


FIG. 2b. DETAILS OF END CONNECTIONS AND GAUGE POINTS - SERIES B

~~FIG. 2. TYPES OF TEST SPECIMENS.~~

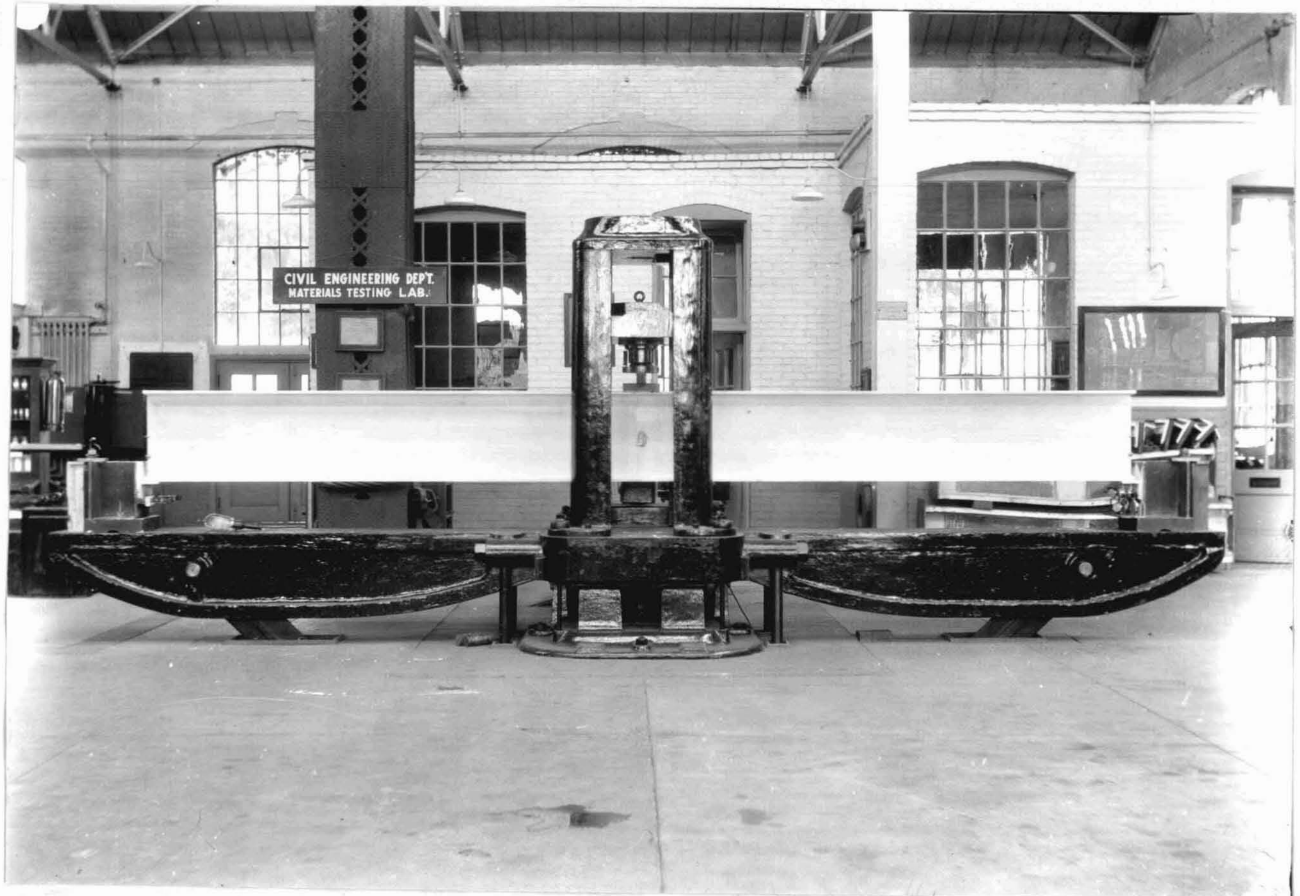


Fig. ~~2c~~ 4. ~~B444~~ - Test No.1 Series B, Setup Ready For Testing sections (B 10b 54-lb.) 12" long. Figure 2 4 shows a specimen ready for test, while Fig. 3b 3 shows the details of the end connections and gage points. The columns were restrained from tipping under the load by clips and 1" diameter hold-down bolts acting on the back flange of the stub columns. The gap between the face of the column and the end of the beam was 3/4" to 7/8". The lower flange of the beam was welded or bolted to the outstanding leg of the angle.

(c) Welding - The welding was performed in the laboratory shop under direct supervision. The operator passed the qualification tests of the Structural Steel Welding Committee, American Bureau of Welding. The welding rod for the major part of the investigation was a lightly-coated wire, conforming to AWS Specification Class E1A E40 x), of 5/32" and 3/16" diameter. The D.C. arc characteristics were, voltage 17 to 19, amperes 165 to 200, dependent on the rod diameter and size of the work. The average strength of the standard 3/8" end fillet welded qualification specimens was 13,250 lb.per linear inch, for 3/8" welds and 21,500 lb.per linear inch for the 1/2" welds tested, corrected for oversized dimensions. The required average strength per linear inch was 12,000 lb. and 16,000 lb.respectively. Insert Schreiner's note.

Where multilayer welding was specified the previous layers were carefully cleaned of scale by means of a stiff wire brush and file.

The welds were carefully gaged and without exception were within the designed limits of minus 0, plus 1/8". A

x) AWS specification for filler metal (Revised June 1, 1933) rigid specification and procedure control was laid out and followed in consequence of which uniform results were obtained. Some difficulty was encountered in obtaining perfect fusion between the heel of the angle and the plate but failure specifically due to improper fusion occurred ~~only three welds failed in this manner out of the (104) welds made~~ in three welds.

(d) Angles - The angles were of stock size, cut on a power saw to length of 8" ± 1/16". The outstanding leg in all cases was 4", while the vertical leg was 4", 6" or 8". The thickness varied from 1/2" to 1". The angles were clamped to the plate preparatory to welding, care being taken so that the outstanding legs were parallel to the bearing edge of the plate.

(e) Specimen Nomenclature - In designating the specimens, a combination of letters and numbers was used as follows:

Specimens of Series A used the series letter followed by four numbers for identification, those of Series B used the series letter followed by three numbers. For example: A 444-2

First letter - A - indicates the series to which the specimen belongs.

The first numeral 4 - indicates the length of the vertical leg of the angle in inches.

The second numeral 4 - indicates the thickness of the angle in eighths of an inch.

The third numeral 4 - indicates the size of the fillet weld in eighths of an inch.

Second letter, if used, indicates special points of difference from the general type, as explained in notes accompanying the data.

The last numeral "2 - indicates the lever arm at which the test was made, 1 indicating a 1.2" lever arm while 2 and 3 indicate 2" and 3" lever arms respectively. This final figure was omitted in the specimens of Series B since the exact location of the resultant load was unknown. In this paper the term lever arm will signify the distance from the back of the angle to the point of application of the load and will be designated by "a". See Fig. ~~2a~~ 2.

(2) Factors Studied - The following factors affecting the behavior of the connection were studied; ~~viz~~

(a) Effect of the moment arm of the load, both in longitudinal and lateral direction.

(b) Effect of the thickness of the angle.

(c) Effect of the length of vertical leg of the angle.

(d) Effect of the size of weld.

(e) Effect of the type of welding rod.

(f) ~~Effect of the type of connection of the lower flange of the beam to outstanding leg of the angle.~~ Location of the reaction of the beam on the seat angle.

(3) Description of Loading Rig and Gaging Devices

(a) Series A - The specimens of Series A were tested in the 300,000-lb. or the 800,000-lb. capacity testing machines in the Fritz Engineering Laboratory. The load was applied through an adjustable loading rig, shown in Fig 2, consisting of a top section of two steel plates, the top one of which ~~is~~ was channeled to clear the bolt heads. The lower plate ~~is~~ was slotted along the center line to provide easy adjustment of the vertical legs on which it rest~~s~~ed. The vertical legs ~~are~~ were held in any desired position by means of cap bolts passing through the slots in the plate above into the vertical legs. ~~(See Fig. 2a)~~. The load was applied by the head of the machine through a spherical bearing block resting on the top plate.

The method of holding the 1" diameter rollers through which the load was applied was changed three times as requirements indicated. In the first type, Fig. 5, used only on Specimen A 443~~-1~~, the bottom of the vertical legs of the loading rig were plane and rested on the rollers, which were thus free to roll, being restrained only by light spring steel fingers. Due to the outward deflection of the outstanding legs, the secondary horizontal force ~~forced~~ pulled the vertical legs of the loading rig apart, thus increasing the lever arm. To correct this defect, two 3/4" diameter bolts were introduced as shown in Fig. 6, thus holding the vertical legs of the loading rig in position until the welds fractured, at which point the deflection of the outstanding legs increased materially and the bolts generally yielded slightly. The maximum increase in lever arm due to this effect averaged at final load 9%, with a maximum increase of 16% in the case of specimen A 864-1. Below the load at which the weld fractured the nominal lever arm was maintained as closely as could be observed. In this set-up the rollers were still free to roll and the horizontal restraining force on the outstanding leg of the angles was considered negligible. This type of loading was used on specimens A443-2, A443-3, A 444, A 643, A 654, and A 444a.

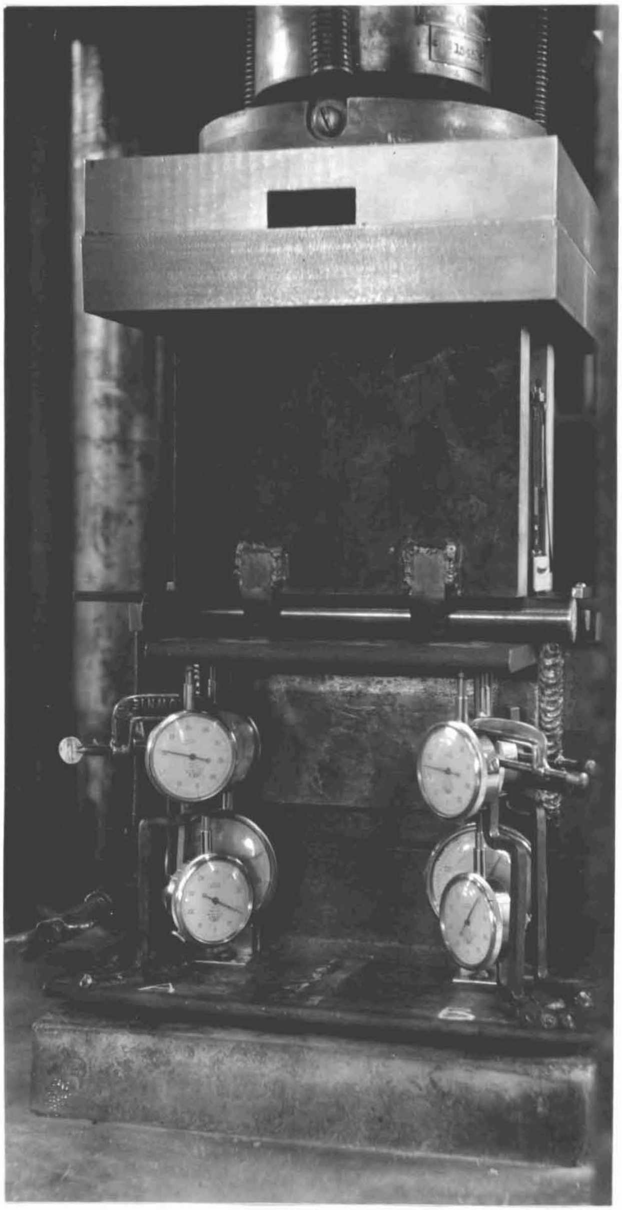


Fig.5 - Side View of First Loading Rig and Ames Dials.

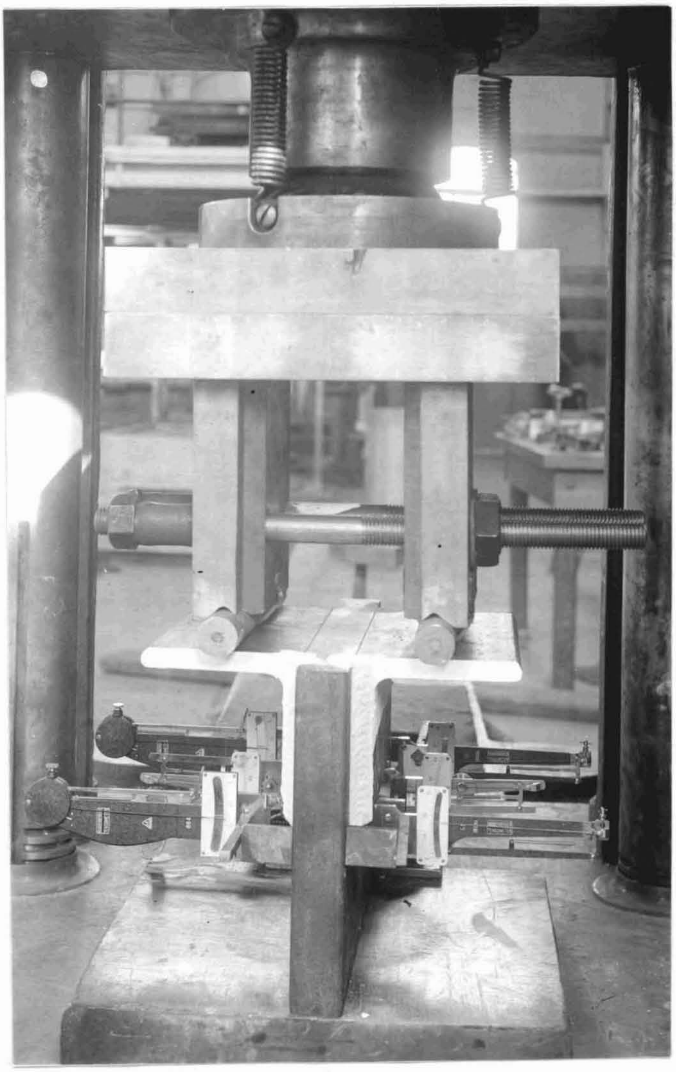


Fig. 6 - End View of Final Loading Rig Showing Bolts Restraining the Vertical Legs and V Grooves.

In the third set-up, the rollers were restrained in V's cut in the bottom of the vertical legs as shown in Fig 6. This construction prevented the rollers from ~~rolling~~ moving laterally and introduced a horizontal restraining force counteracting the tearing effect ~~of the moment on~~ at the top of the weld. ~~and changing the distribution of stress in the outstanding leg of the angle. The magnitude of this horizontal force depends on the friction developed between the roller and the top face of the outstanding leg and is estimated to be between two to three-tenths of the vertical load.~~ This type of loading rig was used on all the remaining specimens of Series A. leave in

The load was applied over the full 8" length of the angle in all specimens except A 644XA and A644YA where the loading was through a roller 1 inch and 3 inches long respectively. These rollers were centered longitudinally on the outstanding leg and observations were made at 3, 2 and 1.2 inch lever arms.

(b) Observations - Measurements of the downward deflection of the outstanding leg were taken at measured intervals by two groups of four Ames dials, each ~~set~~ group on gage lines one inch in from each end of the angle. The plungers of the dials were extended as necessary by means of hardened steel pins. The two dials closest to the vertical leg read to 0.0001-inch while the outer two dials of each group were ~~sensitive~~ graduated to only 0.001 inch. Fig. ~~4~~ 5 shows the arrangement of these dials.

The slope of the outstanding leg was ~~also~~ measured ~~on its center line~~ by means of a level bar of 1-1/2" base line, a micrometer reading to 0.0001-inch and a bubble sensitive to micrometer changes of 0.0002-inch. The slope readings, therefore, should not be in error greater than one minute of arc.

Outward strains in the top end of the welds were measured with Huggenberger Tensometers using the half-inch gage length on Specimens A 444, A 444a, A 643, A 644 and A 654. The weld was first piled up slightly during fabrication and then ~~leveled~~ filed off flush with the outstanding legs of the angle. One knife edge of the tensometer was set on the weld metal and the other on the plate, the half-inch gage length being divided equally between the weld and the plate.

Five tensometers equally spaced along the toe of the vertical leg of the angle measured the downward deflections of the angle with respect to the plate. Figure 6 shows a set-up ready for testing with tensometers on both angles, while in most tests the groups of Ames dials were placed on one test angle ~~while~~ and the five tensometers ~~were placed~~ on the opposite angle.

(c) For Series B the 20" I beam was loaded at the quarter points. A set of Ames dials measured the downward deflections of the outstanding leg of one of the test angles ~~while~~ and five ~~Huggenberger~~ tensometers measured the total downward deflections of the other test angle. Strains in the beam flange and slip between the test angle and the beam end were measured on both sides of each end over a 10" gage length with a Whittemore strain gage reading to 0.0001-inch. The deflection of the beam at the center was measured by the mirror, scale and wire method. The tilting of the columns was measured by a level bar of 3" base line at six gage points on the back of the column flange. ~~See Figs. 2b and 2c.~~

In both series of tests the specimens were completely coated with a thin mixture of hydrated lime and water in order to better observe strain lines and cracking.

4. Test Procedure

(a) Series A - ~~Readings on the instruments~~ Complete observations were taken at three lever arms on each specimen, namely 3, 2 and 1.2" in succession, up to the yield point of the specimen as determined by disproportionate deflection and/or by cracking or scaling of the whitewash. The increments of load were such that approximately six points would be obtained below the yield point. The load was applied at a head speed of 0.05 inches per minute. In the case of the 3" and 2" lever arms, the load was ~~then~~ slowly released as soon as the yield point was reached and the rollers were moved in to the next shorter lever arm. In the case of the 1.2" lever arm ~~test~~ the instruments were removed after the yield point was reached and the load continuously applied until the conclusion of the test. Observations were made of the scaling of the whitewash on the angle and welds and of the cracking of the welds at the top end. The test was concluded when the specimen refused to take any further load without excessive deflection, at which time the heel of the angle had generally been bent away from the plate approximately 3/8 of an inch. Final observations were made as to the location of the rollers, and the general appearance of the welds and angle.

(b) Series B - Readings on the instruments were taken from an initial ~~setting~~ load in small increments up to the final load. The speed of the head of the machine was 0.05" per min. Observations were made with respect to scaling of the whitewash in any part of the specimen with particular attention paid to the behavior of the welds.

IV. TEST DATA

1. Physical Properties of Materials - Two tensile specimens were cut from each angle used in the investigation, and observations made of the yield point as determined by the drop of the beam, ultimate strength, elongation in 2", reduction in area and modulus of elasticity in accordance with A.S.T.M. Specification A 9-33. The results are presented in Table I. Each value is the average of the two specimens mentioned above. The yield-point stress varied from 32,000 to 41,460 lb. per sq. in. and the ultimate strength from 56,650 to 66,800 lb. per sq. in.

final.

TABLE I

Physical Properties of Steel in the Seat Angles

Size of Angle inches	Yield Point lb./in.^{2}	Ultimate Strength lb./in.^{2}	% Elongation in 2 inches	% Reduction of Area	Modulus of Elasticity lb./in.^{2}
(1)	(2)	(3)	(4)	(5)	(6)
4x4x1/2	32 400	58 510	37.0	69.3	29 650 000
4x4x3/4	35 750	64 700	38.0	62.0	28 500 000
6x4x1/2	37 105	62 075	36.1	66.3	29 075 000
6x4x5/8	33 500	56 650	34.5	67.9	29 000 000
6x4x3/4	32 175	63 225	37.5	62.0	28 730 000
8x4x1/2	41 460	66 800	32.0	60.5	29 100 000
8x4x3/4	32 450	57 415	40.8	67.0	29 250 000
8x4x1	32 000	60 780	40.6	65.3	29 000 000

2. Seat Angle Tests - Series A

(a) The size and make-up of the test specimens is shown in Table II, columns 2 to 5 inclusive. The test results are given in the remaining portion of the table ~~and in Table III~~. ~~All these specimens were welded with a lightly-coated wire, which is known to welders as "bare wire"~~.

(b) ~~In presenting the test data,~~ It might be well to point out the general procedure of observation. As mentioned previously the instruments were removed shortly after the deformations became disproportionate to the load increments, and either the loading rig was adjusted to the next succeeding test or the loading was continued to the completion of the test. The first observation usually was a scaling of the whitewash on the fillet in the central portion of both angles simultaneously. These observations are noted in column 6, Table II. The load could then be increased approximately 17% when scaling of the whitewash on the top end of the weld would next be observed, generally on only one of the welds, but sometimes this yielding occurred in two or more welds simultaneously. These observations are presented in column 7, Table II. Consequently there was a redistribution of stress and the load could then be increased approximately 20%, at which load, (column 8, Table II) one or more of the welds would show a visible crack at the top end extending from the root of the weld outward (in many cases at an angle of approximately 30° with the end of the angle rather than directly across the throat section). From this point on the load increased slowly while the deformation was rapid with the weld slowly tearing with the increase in deformation. There usually occurred several points of yield when the head of the machine could not follow fast enough, but these seemed to have no significance. The final load column 9, Table II is that load at which the test was stopped and is significant to the extent that the specimen refused to accept any further load without excessive deformation and generally the gap between the plate and the heel of the angle was 3/8". A typical specimen at the completion of the test is shown in Fig. 7.

TABLE II

Test Results of Series A Specimens Having Bare Wire Welds

Specimen No.	Size of Angles inches	Weld Data		Lever Arm at Failure inches	Load Per Angle (Pounds)			
		Fillet Size inches	Total Length inches		Scaling of Fillet of Angle	Scaling at Top End of Weld	Crack in Top End of Weld	Final Load
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A 443-1	4x4x1/2	3/8	8	1.2"	29 950	28 550	29 325	30 430
2	4x4x1/2	3/8	8	2.0"	16 800	21 000	22 225	31 250
3	4x4x1/2	3/8	8	3.0"	10 400	12 350	13 470	13 470
A 444-1	4x4x1/2	1/2	8	1.2"	--	32 000	39 000	39 380
2	4x4x1/2	1/2	8	2.0"	18 850	18 500	24 000	24 000
3	4x4x1/2	1/2	8	3.0"	10 100	10 000	11 250	13 840
a-1	4x4x1/2	1/2	4	1.2"	--	35 900	45 800	52 230
A 463-1	4x4x3/4	3/8	8	1.2"	71 000	89 500	100 000	112 250
A 464-1	4x4x3/4	1/2	8	1.2"	73 000	91 000	101 000	133 835
A 466-1	4x4x3/4	3/4	8	1.2"	67 500	116 250	176 500	185 500
A 643-1	6x4x1/2	3/8	12	1.2"	--	33 800	38 550	41 650
A 644-1	6x4x1/2	1/2	12	1.2"	37 000	40 500	46 000	67 305
X-1	6x4x1/2	1/2	12	1.2"	22 250	40 500	44 150	67 500
Y-1	6x4x1/2	1/2	12	1.2"	25 800	40 800	43 700	78 000
A 654-1	6x4x5/8	1/2	12	1.2"	53 675	60 550	74 700	98 300
A 655-1	6x4x5/8	5/8	12	1.2"	57 000	84 500	102 000	116 000
A 664-1	6x4x3/4	1/2	12	1.2"	100 000	~~100 500~~ 116 900	136 300	183 200
A 843-1	8x4x1/2	3/8	16	1.2"	49 000	53 000	74 350	98 375
A 844-1	8x4x1/2	1/2	16	1.2"	53 000	63 000	74 030	82 050
A 864-1	8x4x3/4	1/2	16	1.2"	87 250	112 500	132 000	174 100
A 884-1	8x4x1	1/2	16	1.2"	137 500	145 000	164 500	204 000
-2	8x4x1	1/2	16	2.0"	55 000	84 000	120 500	140 150
-3	8x4x1	1/2	16	3.0"	36 150	48 000	51 450	63 175
A 886-1	8x4x1	3/4	16	1.2"	137 500	145 000	170 000	230 900

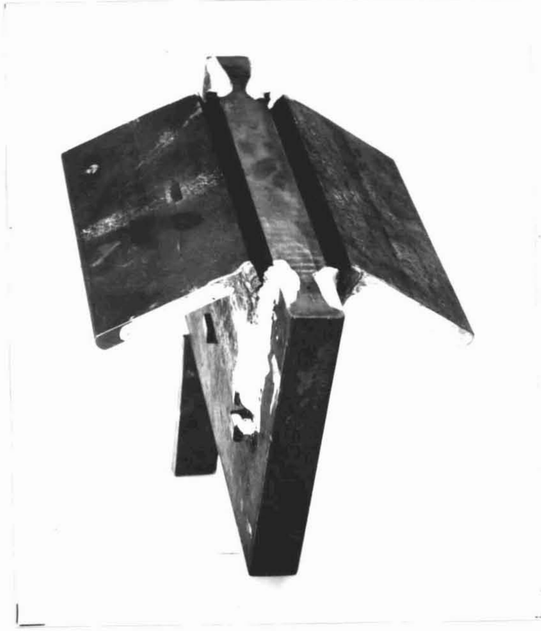


Fig. 5 - Typical Specimen at
Completion of Test.
Specimen A 443-2

(c) ~~The Ames dial observations of~~ the deflection of the outstanding leg were plotted using total load as ordinates and observed deflections under the load point as abscissas. In all cases the resulting load-deflection curve was a straight line up to a definite yield point when the ratio of the applied load to the deflection ~~became much smaller~~. Column 5, Table III shows the loads at which the slope of the above load-deflection curves was 50% greater than the initial slope. It will be noted that these figures are somewhat below those at which the whitewash on the angle scaled (column 6) but in general consistently agree. The ratio between the two is presented in column 7. Columns 3 and 4 present the deflections under the load point for varying loads below the yield point from which the initial

TABLE III

Test Results of Series A Specimens (Bare Wire Welds)

Group No.	Specimen No.	Deflection of Outstanding Leg Under Load Point: Load per Angle lbs.	Deflection of Outstanding Leg Under Load Point: Deflection inches	Yield Point Load per Angle: Inspection of Curves lbs.	Yield Point Load per Angle: Scaling of Whitewash lbs.	Ratio Col. 6 to Col. 5
(1)	(2)	(3)	(4)	(5)	(6)	(7)
		4x4 Angles				
1	A 443-1	20 000	.0083	--	29 950	--
	A 444-1	20 000	.0059 ✓	--	--	--
	A 444a-1	20 000	.0071	27 500	--	--
2	A 443-2	14 000	.0175	--	16 800	--
	A 444-2	14 000	.0155	17 500	18 850	1.08
	A 444a-2	14 000	.0145	11 000	--	--
				14 250		
3	A 443-3	6 000	.0295	--	10 400	--
	A 444-3	6 000	.0260	7 000	10 100	1.44
	A 444a-3	6 000	.0250	6 250	--	--
				6 625		
4	A 463-1	50 000	.0108	--	71 000	--
	A 464-1	50 000	.0050	60 000	73 000	1.22
	A 466-1	50 000	.0100	52 500	67 500	1.29
				60 000		
5	A 463-2	25 000	.0118	26 000	--	--
	A 464-2	25 000	.0089	21 500	--	--
	A 466-2	25 000	.0087	23 000	--	--
				23 500		
6	A 463-3	10 000	.0098	12 400	--	--
	A 464-3	10 000	.0095	14 500	--	--
	A 466-3	10 000	.0063	12 000	--	--
				13 000		
					Average	1.26

Omit

TABLE III (Cont.)

Group No.	Specimen No.	Deflection of Outstanding Leg Under Load Point		Yield Point Load per Angle		
		Load per Angle lbs.	Deflection inches	Inspection of Curves lbs.	Scaling of White-wash lbs.	Ratio Col.6 to Col.5
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			6x4 Angles			
7	A 643-1	20 000	.0059	--	--	--
	A 644-1	20 000	.0050	31 000	37 000	1.19
	A 644X-1	20 000	.0043	31 000	22 250	*
	A 644Y-1	20 000	.0045	26 750	25 800	*
8	A 643-2	14 000	.0147	--	--	--
	A 644-2	14 000	.0140	15 300	--	--
	A 644X-2	14 000	.0115	14 500	--	--
	A 644Y-2	14 000	.0140	13 250	--	--
9	A 643-3	6 000	.0230	--	--	--
	A 644-3	6 000	.0205	7 500	--	--
	A 644X-3	6 000	.0160	7 500	--	--
	A 644Y-3	6 000	.0222	7 500	--	--
10	A 654-1	35 000	.0061	39 000	53 675	1.37
	A 655-1	35 000	.0039	44 000 41 450	57 000	1.29
11	A 654-2	25 000	.0160	20 500	--	--
	A 655-2	25 000	.0130	25 500 23 000	--	--
12	A 654-3	6 000	.0135	12 125 10 250	--	--
	A 655-3	6 000	.0127	14 000	--	--
13	A 664-1	70 000	.0070	78 000	100 000	1.28
	A 664-2	30 000	.0092	37 000	--	--
	A 664-3	20 000	.0245	20 500	--	--
					Average	1.28

* Scaling of whitewash at low loads because of local yielding due to short length of rollers.

Omit -

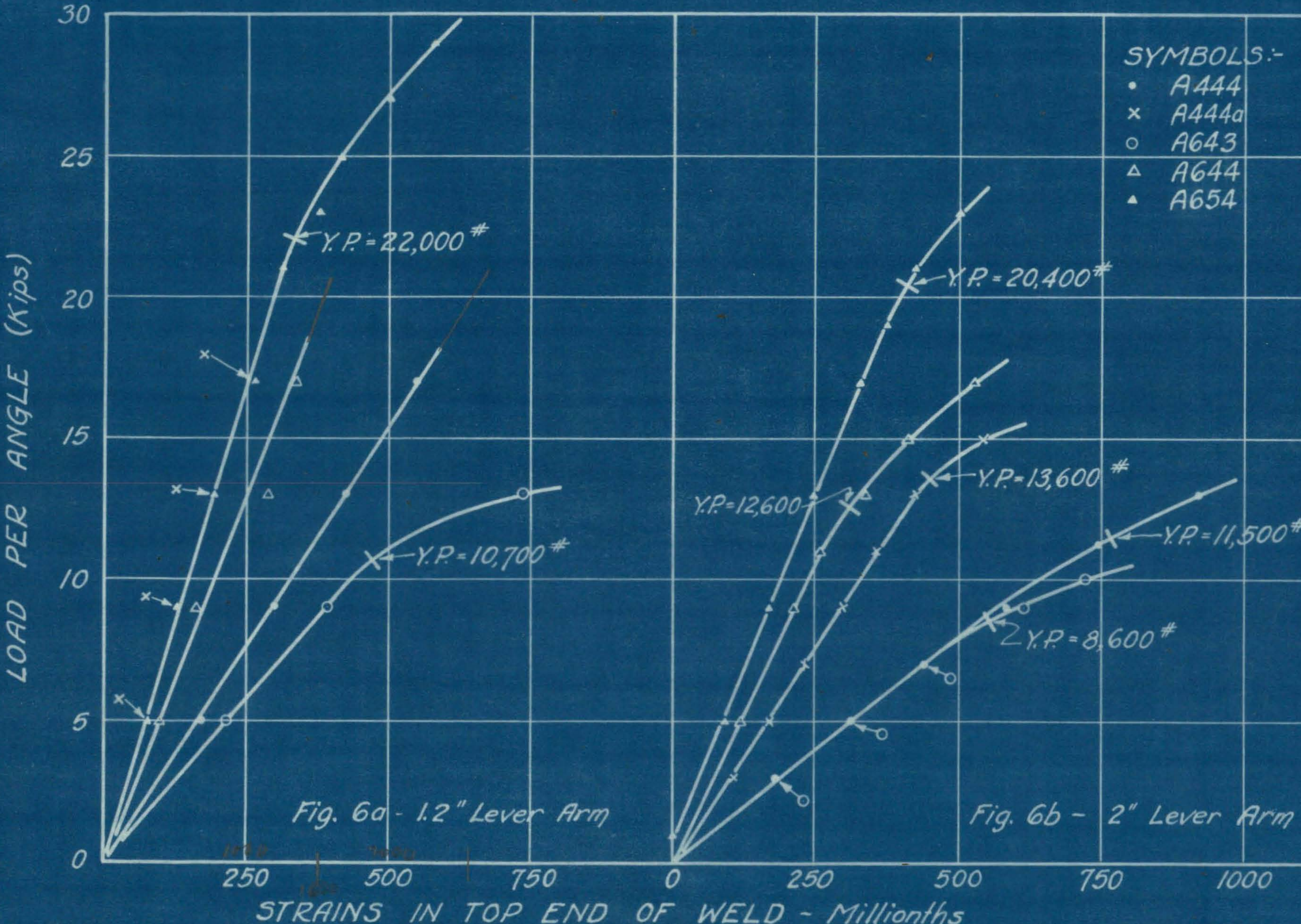
TABLE III (Cont.)

Group No.	Specimen No.	Deflection of Outstanding Leg Under Load Point		Yield Point Load per Angle		
		Load per Angle lbs.	Deflection inches	Inspection of Curves lbs.	Scaling of White-wash lbs.	Ratio Col.6 to Col.5
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			8x4 Angles			
14	A 843-1 A 844-1	40 000 40 000	.0093 .0078	42 000 45 000	49 000 53 000	1.17 1.18
15	A 843-2 A 844-2	20 000 20 000	.0197 .0176	24 000 23 000	-- --	-- --
16	A 843-3 A 844-3	6 000 6 000	.0230 .0195	10 000 11 000	-- --	-- --
17	A 864-1 A 864-2 A 864-3	50 000 30 000 15 000	.0031 .0095 .0285	~~87 500~~ 31 250 20 000	87 250 -- --	1.00 -- --
18	A 884-1 A 886-1	100 000 100 000	.0077 .0054	125 000 118 750 121 900	137 500 137 500	1.10 1.16
19	A 884-2 A 886-2	60 000 60 000	.0127 .0099	63 120 66 250 64 700	55 000 --	0.87 --
20	A 884-3 A 886-3	20 000 20 000	.0100 .0095	22 500 27 500 25 000	36 150 --	1.61 --
					Average	1.16

~~slope of the load deflection curve may be obtained.~~ These re-sults ~~are arranged in groups in which only the size of the weld is varied enabling a comparison of this effect.~~

(d) The observations of the strains in the top end of the welds by means of the tensometers were not entirely satisfactory because ~~of the high mortality rate~~ many instruments (14.5%) failed ~~in their~~ to function~~ing~~ due to the congestion ~~of the instruments and other apparatus~~ of apparatus at this location. There was some spread between the readings of the individual tensometers on the same specimen, (71% of the readings were within 20% of the average), giving some indication of the localized nature of the strains and possibly the locked-up stresses due to the welding. No correlation between these results and the method of welding seems possible. It was noted that as the load was increased to the yield point the portion of the load assumed by each weld, as measured by the tensometers, became nearly equal. It was further noted that when the four tensometer readings were averaged and plotted as abscissas against the load as ordinates, see Fig. 8 ~~9~~, the resultant curves were again straight lines up to a yield point.

(e) The observations of the five tensometers on the lower edge of the vertical leg of the angle were plotted against the load per angle. Figure 9, a typical curve shows the downward deflection of the ends of the seat angle under lever arms 1.2, 2.0 and 3.0 inches, and the center deflections under a lever arm of 1.2 inches. The "p" and "q" intercepts ~~shown in Fig 9~~ may indicate certain friction loads. ~~and there~~ It is believed that the parabolic shape of the first portion of the curve is due to the action of the frictional forces which are gradually overcome as the load increases.



30
25
20
15
10
5
0
LOAD PER ANGLE (Kips)
SYMBOLS:-
• A444
× A444a
○ A643
△ A644
▲ A654
Y.P. = 22,000#
Y.P. = 10,700#
Y.P. = 20,400#
Y.P. = 13,600#
Y.P. = 12,600
Y.P. = 11,500#
Y.P. = 8,600#
Fig. 6a - 1.2" Lever Arm
Fig. 6b - 2" Lever Arm
250
500
750
0
250
500
750
1000
STRAINS IN TOP END OF WELD - Millionths

FIG. 8.

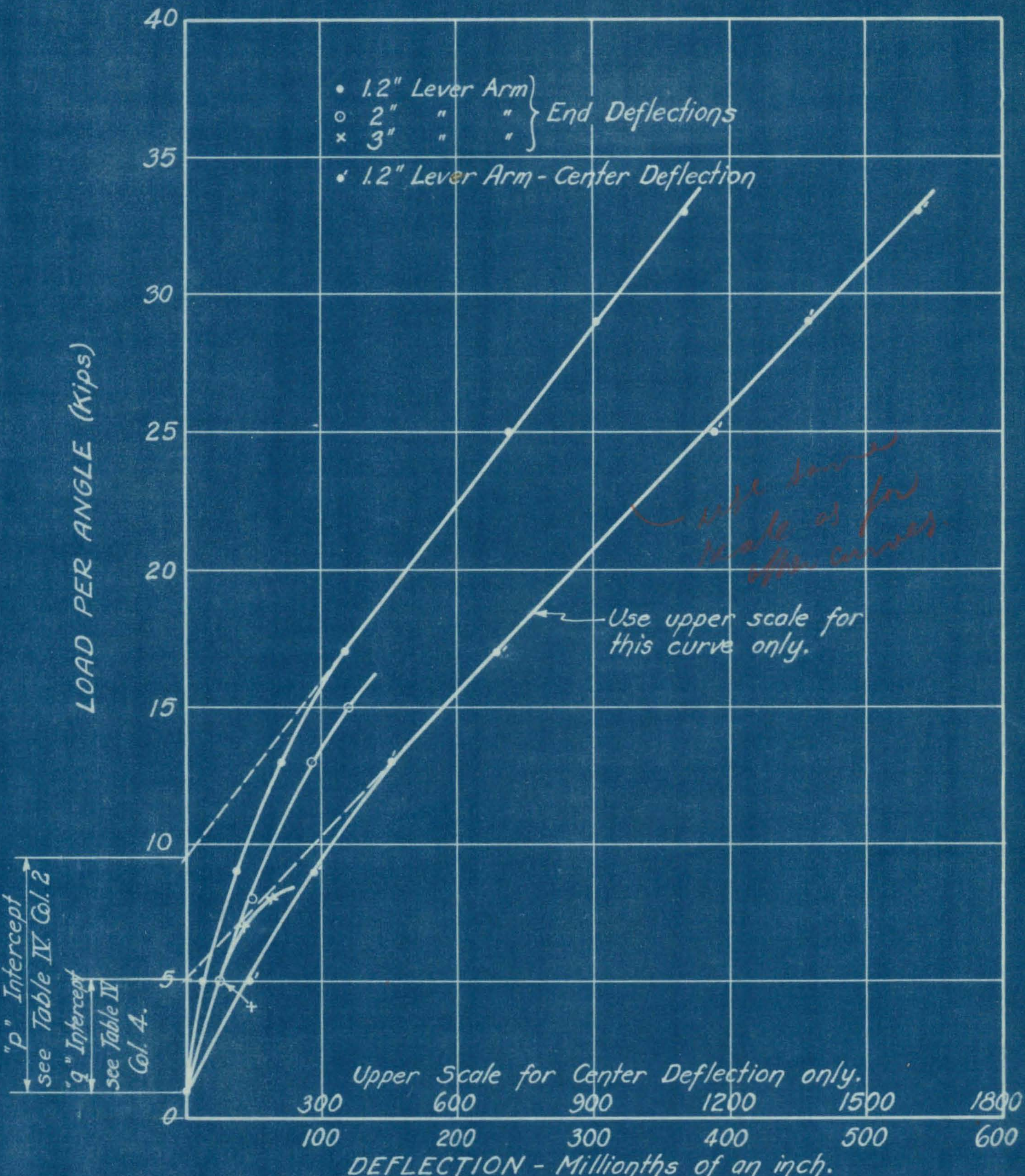


FIGURE 9. LOAD-VERTICAL DEFLECTION TYPICAL CURVE FOR BOTH SERIES.

fore Table IV has been prepared showing these values for all tests. The slopes of the straight portion of the curve are also included. An explanation of this form of curve will be attempted in the discussion to follow.

TABLE IV

TEST RESULTS OF DOWNWARD DEFLECTION OF ANGLE
See also Fig.7

Specimen No.	Total Downward Deflection			
	at Ends of Angle		at Center of Angle	
	"p" # Load per Angle	Slope millionths per Kip	"q" # Load per Angle	Slope millionths per Kip
(1)	(2)	(3)	(4)	(5)
A 443-2	3 200	27.3	1 800	108.0
444-2	0	20.0	2 000	93.0
443-3	1 400	29.3	1 400	117.0
A 463-1	28 000	45.8	12 900	85.3
464-1	26 000	43.2	4 300	71.8
466-1	18 500	32.0	11 200	88.0
A 655-1	14 000	23.2	9 000	65.0
A 664-1	21 000	29.2	FAILED	
843-1	20 000	19.5	FAILED	
844-1	11 000	16.0	5 300	42.8
864-1	0	24.5	0	50.4
884-1	66 250	36.5	27 000	48.2
886-1	60 500	34.6	45 600	55.8

3. Full Size Tests - Series B. ~~Three~~ Four tests ~~have been~~ were made ~~to date~~ under this series as follows:

B 444 Test No.1 in which the beam was loaded at the center, with a concentrated load. The yield point of the beam was reached at 85,000 lb. total load, corresponding to a maximum unit stress of 31,300 lb. per sq.in. in the beam. Since no distress was evident at the beam seats and it was not desired to harm the loading beam, the load was released and quarter-point loading was ~~provided~~ substituted. This set-up is shown in Fig. 4.

B 444 Test No.2 was the same set-up as Test No.1 except that the loads were applied at the quarter points and the loading was carried on until the welds failed.

B 643 was a similar test with quarter-point loading using the same loading beam but replacing the stub columns and seat angles. B 643

Ames dial observations of the downward deflection of the outstanding leg were plotted against the applied load. The resulting load deflection curves are straight lines up to the load at which the whitewash on the beam web at its junction with the lower flange scaled. For greater loads ~~above this~~, the deflection increased more rapidly than the load. Table III lines 5 and 6 present these ~~corresponding values~~ loads. It is necessary here to consider the relative stiffness of the beam and the angle. In these tests the beam was very stiff ~~and the~~ in relation to the angle ~~flexible~~, so that while the reaction at the beginning of the test was supposedly uniformly distributed over the outstanding leg, upon the application of the load the slope of the outstanding leg of the angle was greater than that of the end of the beam. ~~and~~ Thus the reaction became concentrated near the end of the beam. This increased the vertical shearing stress ~~at this~~ in the web at the end section which soon reached the yield point, permitting the ~~borrowing on~~ material next to the section ~~nearer the center of the beam~~ to carry part of the load, ~~and~~ thus moving the line of the resultant reaction further out on the angle. ~~towards the center of the beam~~. This increase in the lever arm accounts for the disproportionate deflections after the yielding of the web ~~from this point on~~.

The tensometer measurements of the downward deflection of the angle obtained at the other ~~end~~ column when plotted against the load showed a similar curve to that of Fig. 9. ~~The values of the intercept "p" and the slope of the straight portion are given in lines 11 and 12, Table IV.~~

The deflections of the center of the beam checked with the calculated deflections within one per cent, thus showing the negligible stiffening effect on the beam of the outstanding leg of the seat angle.

The Whittemore gage readings taken to show stresses in the lower flange of the loading beam and the slip, if any, between the seat angle and the loading beam, showed much greater strains than the common beam formula leads one to expect at these points. These readings are plotted against the load in Fig. 10 and an explanation is given in the discussion to follow. The level bar indicated that the columns tilted toward the center proportionally as the load was applied. This slope was 0.0379 and 0.0402 from the vertical for B 444 Test No.2 and B 643 respectively, at a total load of 120,000 lb. B 444 Test No.1 showed a slope of 0.0430 at 90,000 lb. total load.

The load at which the angle yielded is given in line 7 of Table III, the yield point and the load at crack of the weld in lines 8 and 9, and the final load at which yielding of the whole end connection became general is given in column 10.

V. DISCUSSION of Results.

1. Control Specimens - ~~Table I~~ shows the results of the tests of the tensile specimens cut from the different sizes of angles which were used in the investigation. It is noted that the material in all the angles complied with the requirements for structural steel (A.S.T.M. Specification A9-33). The yield point stress varied from 32000 to 41460 lbs. per square inch and the ultimate strength from 56650 to 66800 lbs. per square inch.

The results of the qualification tests of the welds are given in Section III-1c and indicate that the results obtained were well ~~above nominal~~ requirements.

~~2~~ 1. Series A - The relationship of the variables as stated in section III-2 will be discussed in order. These factors affect both the angle and the weld and the effect on each will be evaluated.

TABLE III

RESULTS OF TESTS - Series B (Bare Wire Welds)

Line No.						
(1)	Specimen No.			B 444 Test No.1	B 444 Test No.2	B 643 (B643B)
(2)	Size of Angle		in.	4x4x1/2	4x4x1/2	6x4x1/2
(3)	Weld	Fillet Size	in.	1/2	1/2	3/8
(4)	Data	Length	in.	8	8	8
(5)	Scaling of Web of Beam at Tension Flange		lbs.	30 000	40 000	19 500
(6)	Yield Point from Inspection of Curves		lbs.	27 750	45 000	22 560
(7)	Scaling on Fillet of Angle		lbs.	45 000	51 500	28 000
(8)	Scaling at Top End of Weld		lbs.	40 000	48 500	33 500
(9)	Crack in Top End of Weld		lbs.	--	54 500	59 000
(10)	Final Load		lbs.	45 000	60 000	62 500
~~(11)~~	~~"p" Load per Angle~~		~~lbs.~~		~~3 500~~	~~7 200~~
(12)	~~Slope - millionths per Kip~~			--	~~768~~	~~894~~

(a) Figure 11 shows the relation between the lever arm and the yield point strength of the angles, using the yield points presented in column 5, Table III as ordinates and the lever arm as abscissas. The parabolic shape of the curves shows that the outstanding leg may be considered as a cantilever beam whose length is the distance from the junction of the fillet of the angle with the lower surface of the outstanding leg to the point of application of the load, providing

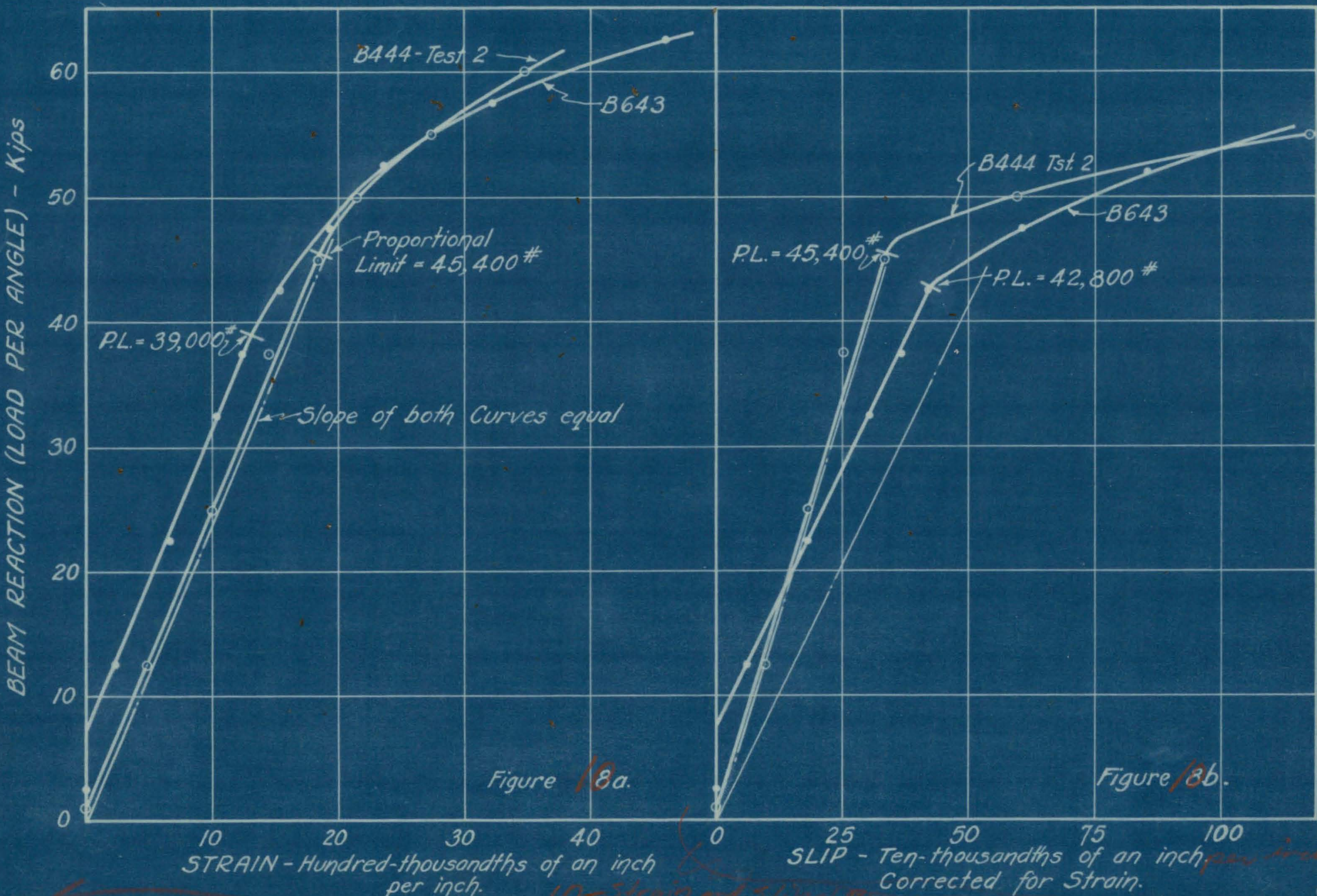


FIGURE 8. LOAD-STRAIN CURVES - SERIES B.

that the load point is out beyond this junction of the fillet and the outstanding leg by at least the thickness of the angle. If the load point is within the above limits, the assumption of cantilever action no longer holds true and yield point stress occurs on the fillet of the angle at a lesser external load than that which would cause yield point stress due to cantilever bending alone. The photoelastic analysis shows that this yield stress is a maximum principle stress composed of the bending and vertical shearing stresses. ~~and places~~ The point of this maximum stress occurs at approximately one-third of the distance around the fillet measuring from the junction of the fillet with the outstanding leg. Observation of the scaling of the whitewash on the fillet of the angle substantiates this conclusion.

Figure ~~10~~ 12 shows the effect of the lever arm on the strength of the weld. The ordinates are the values in column 7, Table II. Here the product of the load times the lever arm tends to remain constant, assuming the effective lever arm as the distance from the back of the angle to the center of the roller minus half the ~~dimension of the weld fillet~~ thickness of the leg. It is a matter of observation that the neutral axis is considerably above the midheight of the vertical leg but it was not practical to measure the location of this point. It is probable that its location varied somewhat with the lever arm and with the load itself.

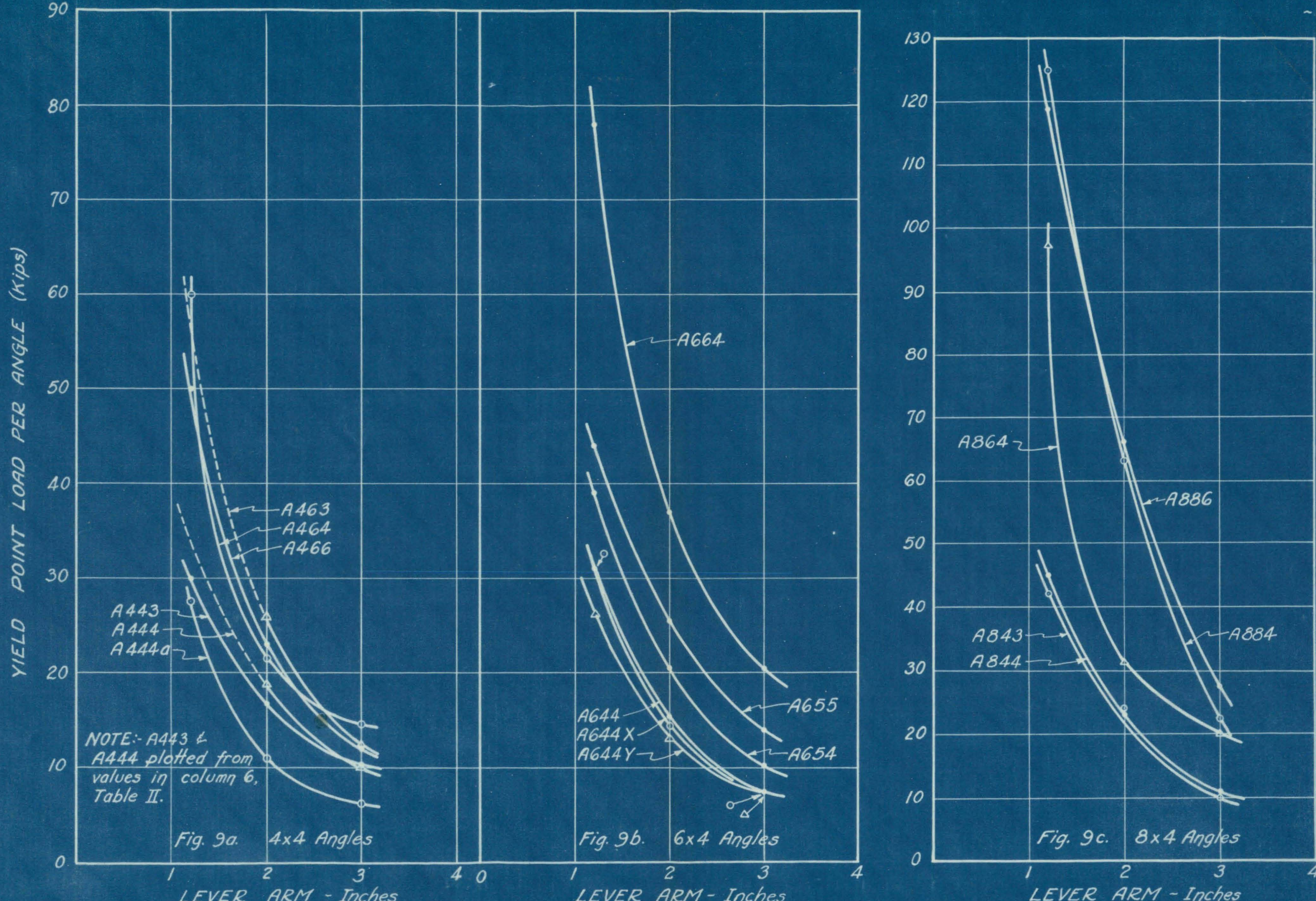


FIGURE 9. RELATION BETWEEN LEVER ARM AND STRENGTH OF ANGLES.

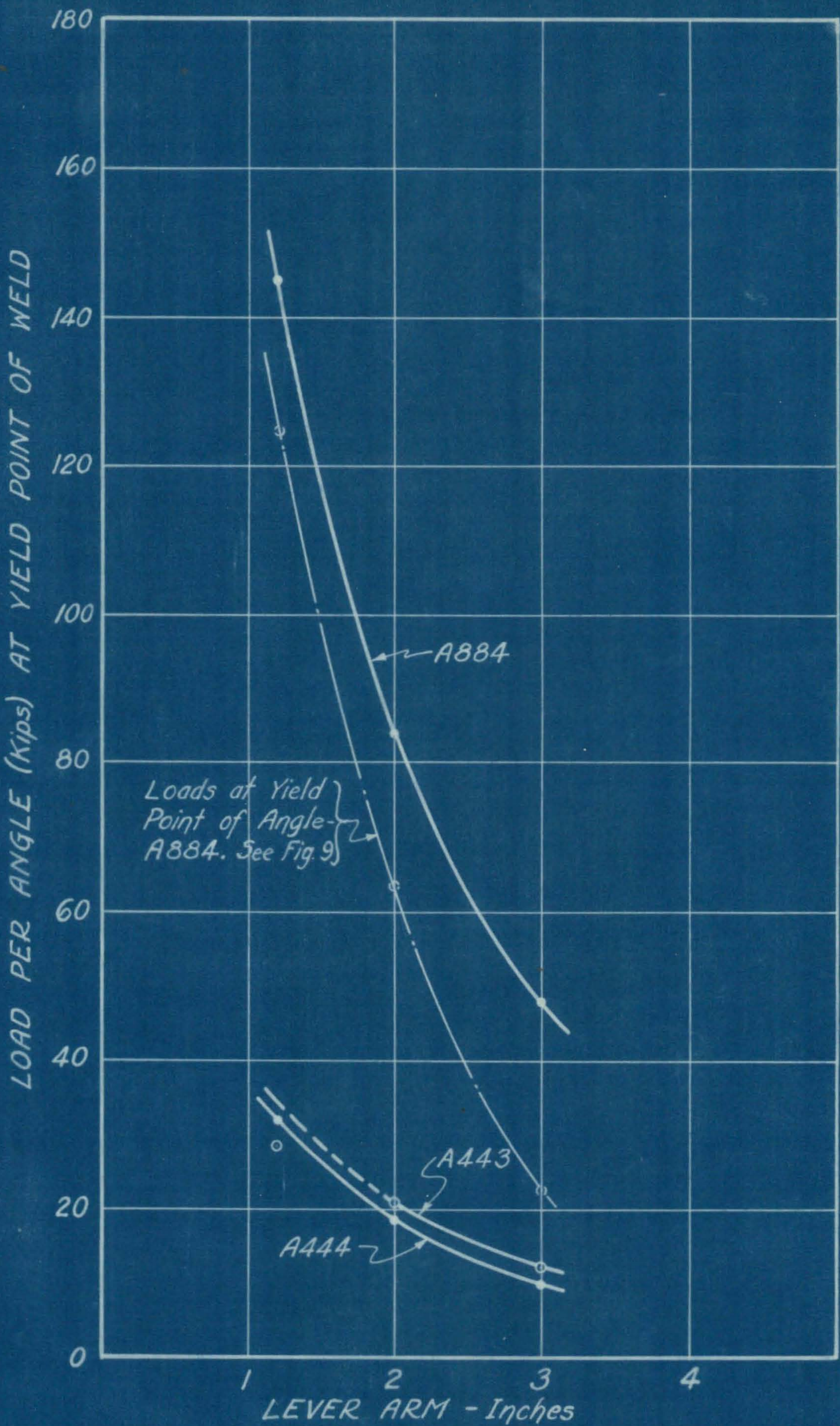


FIGURE 10. RELATION BETWEEN LEVER ARM AND STRENGTH OF WELD.

(b) A comparison of specimens A 644-1, A 644X-1 and A 644Y-1 all with lever arms of 1.2 inches but in which the load was applied respectively over the full length of the angle, through a roller one inch long centered on the outstanding leg and through a roller three inches long centered on the outstanding leg, shows negligible effects on the strength of the weld due to this concentration of load. Neither was the downward deflection of the outstanding leg nor the observed yield point of the angle greatly affected, but there was considerable local yielding immediately under the shorter rollers. From this test we may assume that variations in the bending moment in the longitudinal direction introduces but small changes in the strength of the connection.

(c) Figure 13 shows the effect of the length of the vertical leg on the yield-point load of the angles. The observed yield-point loads are corrected for variation in the value of the yield-point stress of the material as given in Table I. In general the carrying capacity of the angle did not increase directly with the length of vertical leg and in some cases there is a decrease in the yield-point load for the longer vertical legs. The trend is not well marked and it seems that the length of the vertical leg has only a small effect if any on the yield-point load of the angle.

Figure 14 shows the effect of the length of the vertical leg on the load at scaling of the weld. Only the 1/2" angles with the 3/8 and 1/2 inch welds and 3/4" angles with 1/2 inch welds are available for comparison and in all cases the increase in the strength of the weld is noticeable with the longer vertical legs. It should be noted that this increase in carrying capacity of the ~~angles~~ welds is not proportional to the increase in the length of the vertical leg.

(d) Figure ~~13~~ 15 shows the relationship between the thickness of the angle and the load carried at the yield point of the angle again corrected for variations in the yield point of the material. These curves are ~~very~~ nearly parabolas of the second degree again showing that the outstanding leg acts very nearly as a cantilever beam.

Figure 14 shows the relationship between the strength of the weld and the thickness of the angle. The curve for the 6x4 angles is a second degree parabola while that of the 8x4 angles varies by approximately 12%, being nearly a straight line.

In this discussion attention should be called to the effect of the thickness of the angle on the type of weld failure. The vertical leg of the angle will bend outward in the top part thus causing a large amount of tension in the top end of the weld and the weld will fracture soon after the angle yields. However with heavy angles and light welds at the 1.2 inch lever arm a different kind of failure occurs. The angle will yield as before and the weld will fracture at the top end, but the additional load necessary to continue deflection of the angle is so great as to overstress the weld in shear and the final failure will be one in shear throughout the full length of the weld. There are good indications that

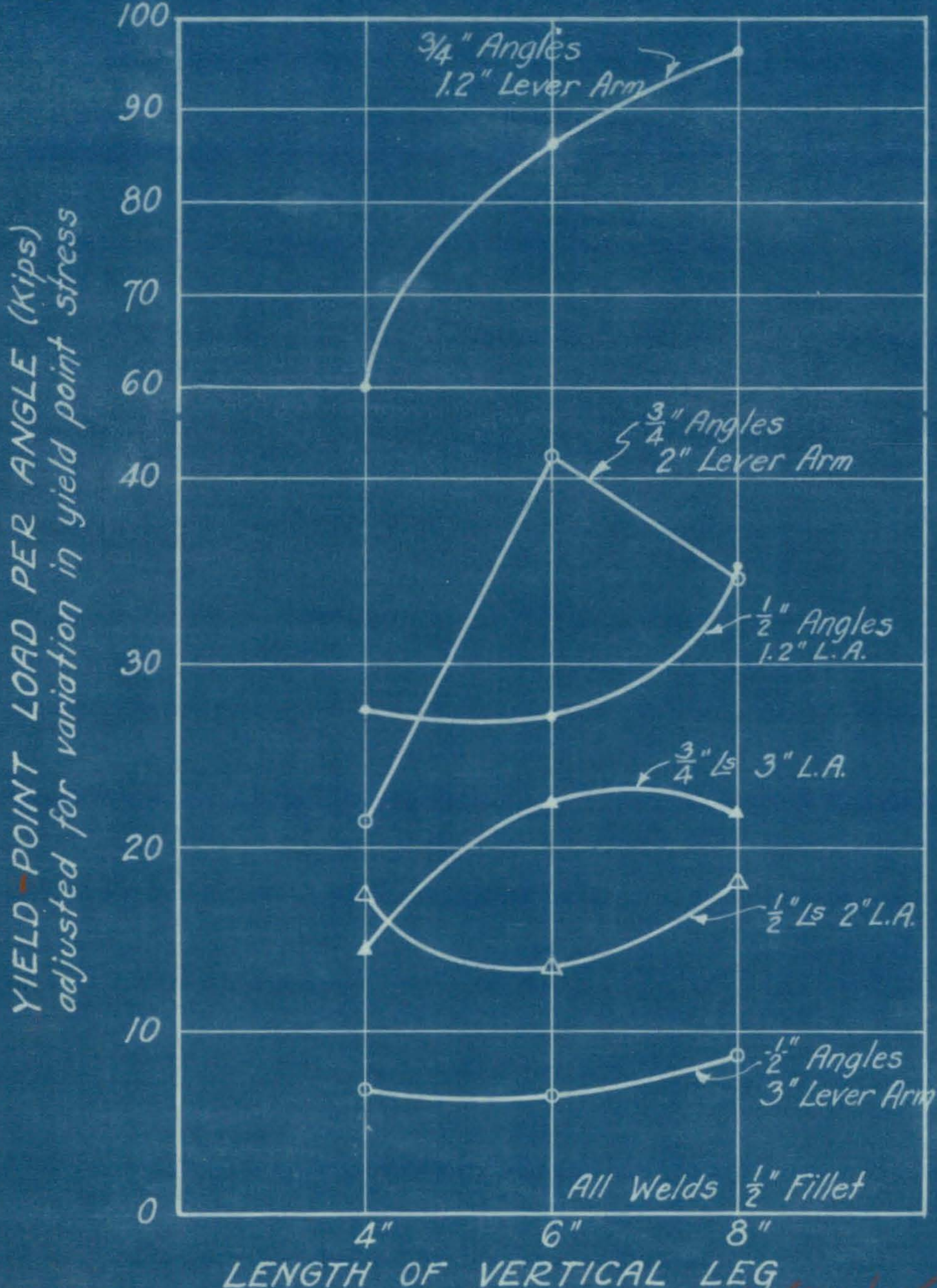


FIGURE 13.

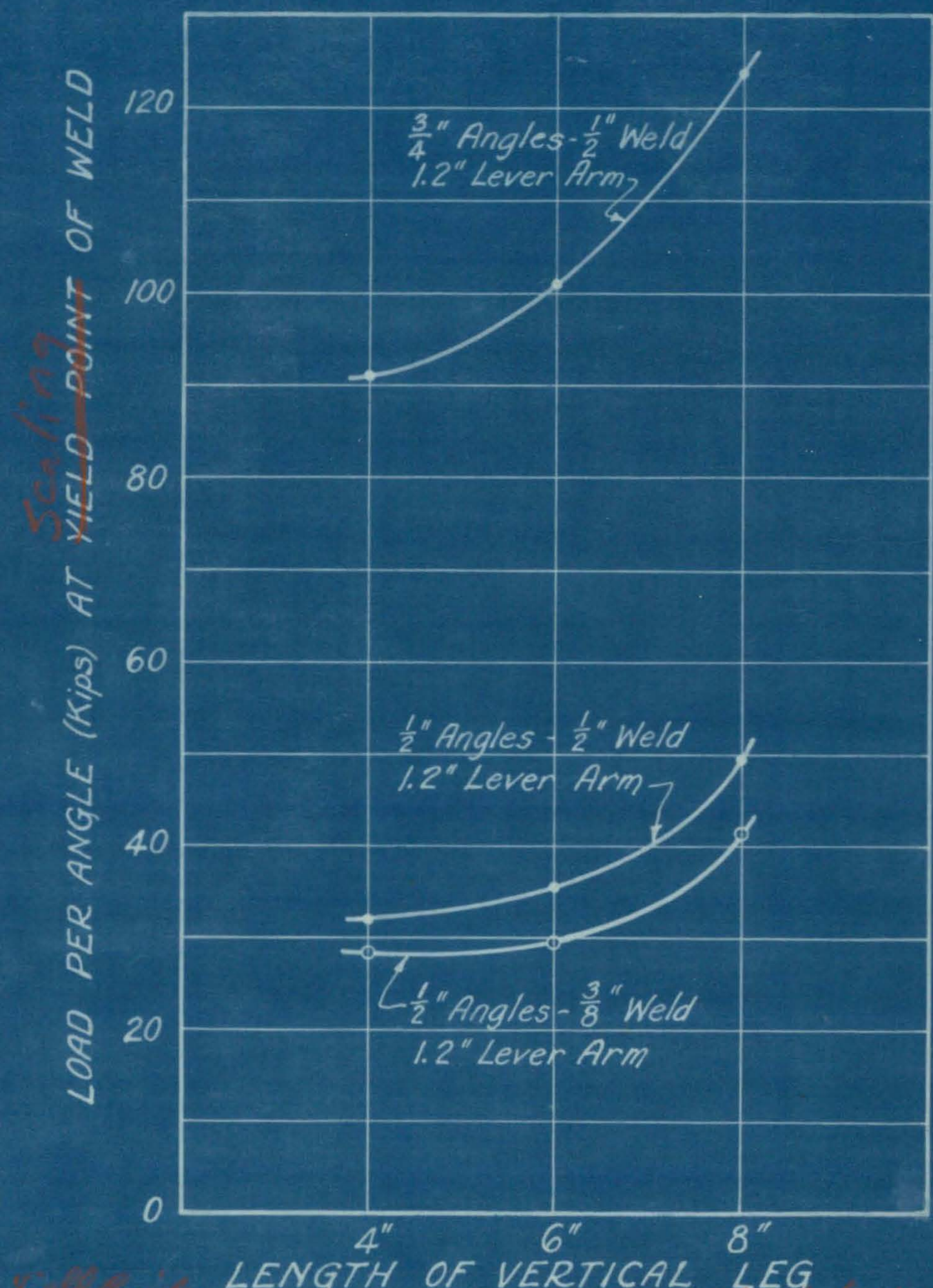


FIGURE 12.

RELATION BETWEEN STRENGTH AND LENGTH OF VERTICAL LEG OF ANGLE

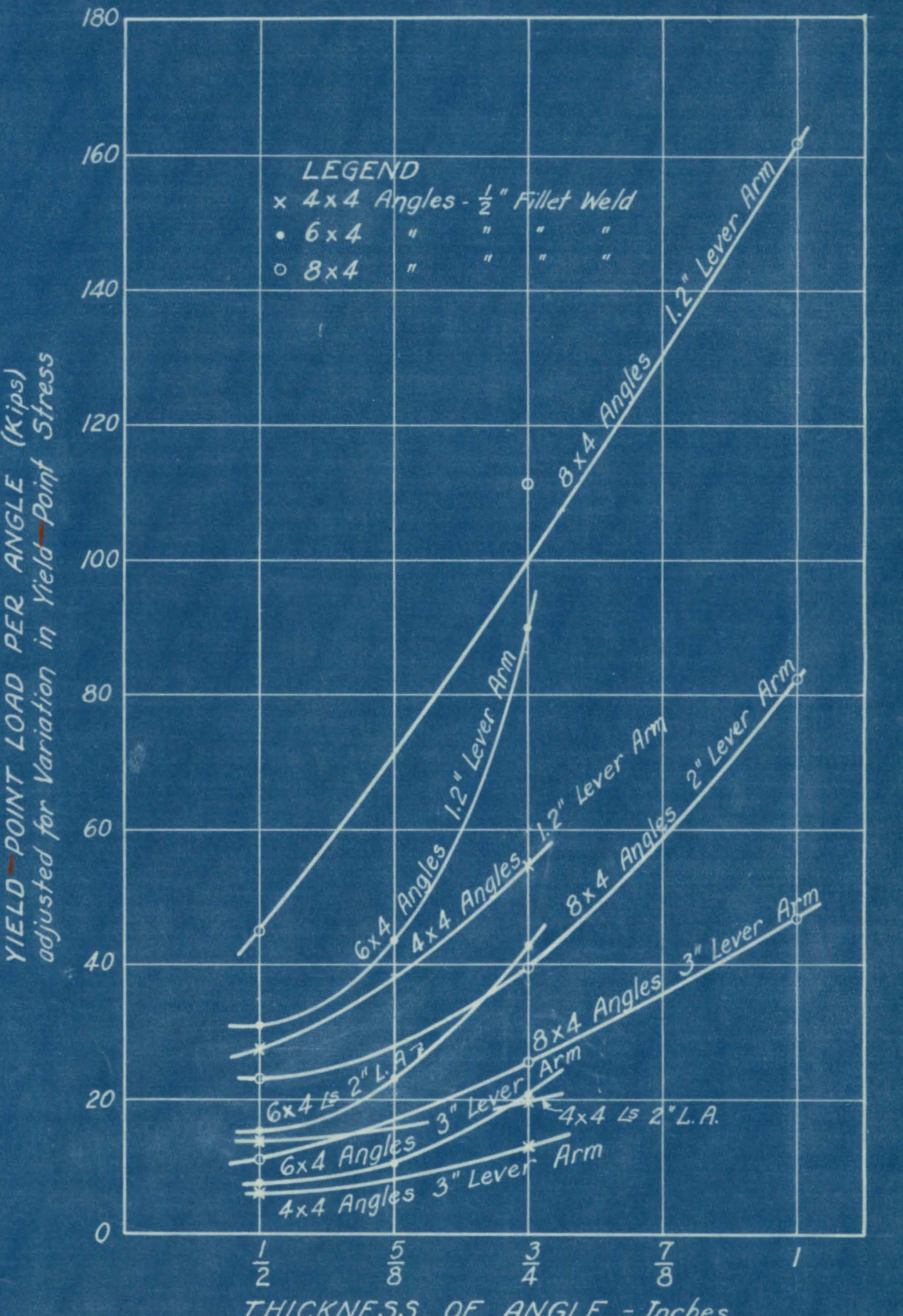


FIGURE 15.- RELATION BETWEEN STRENGTH OF ANGLES AND THICKNESS OF ANGLES

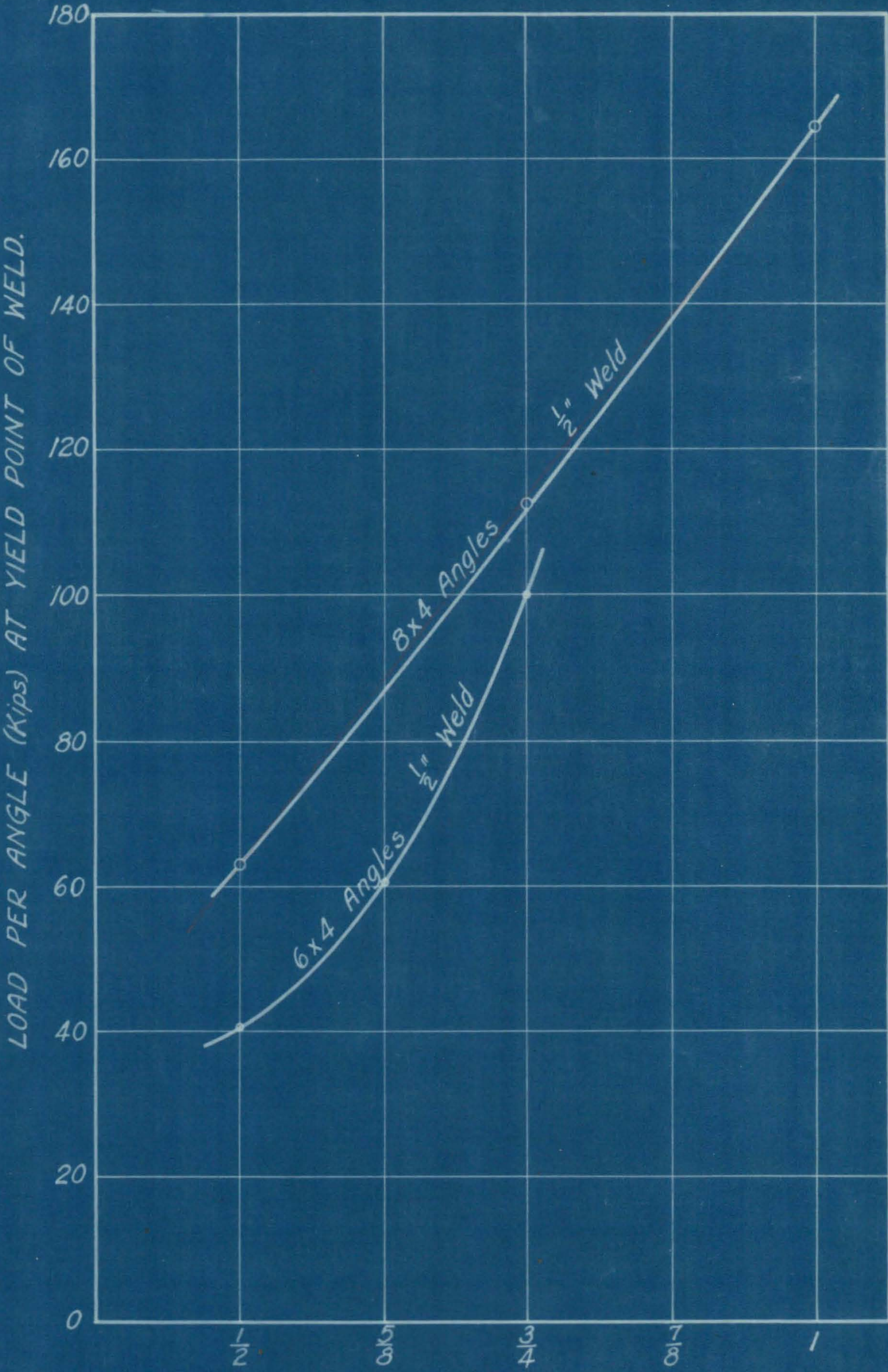


FIGURE 16.- RELATION BETWEEN STRENGTH OF WELD AND THICKNESS OF ANGLE.

the ultimate strength of the weld is first reached in the top inch but failure over the full length occurs suddenly. Specimens A 463-1, A 464-1, A 664-1, and A 884-1 failed in this way at weld stresses of 14,030, 16,700, 15,270, 12,870 lb. per linear inch respectively. Specimen A 466-1 is a border-line case, being on the point of failure in shear at a stress of 23,200 lb.per linear inch. It will be noted that in these cases the weld stress at final load which was obtained simply by dividing the final load by the total length of weld, approached and in some cases exceeded the ultimate strength ordinarily assigned to those welds. Figure 17 shows A 844-1 a typical example of this type of failure.

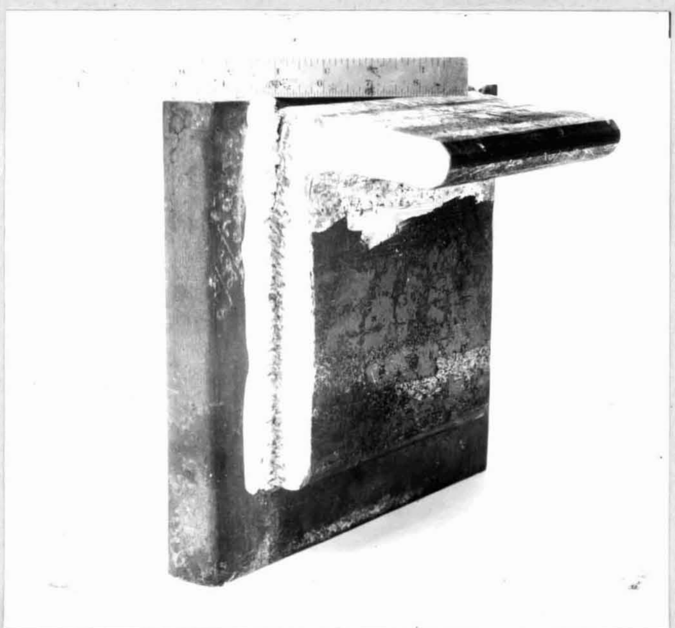


Fig.17 - Typical Example of Weld
Failure in Shear
Specimen A 884-1

(e) Effect of Size of Weld. (1) Specimens A 443 and A 444 may be compared under this heading. The ultimate load per inch of weld was 33% greater for the 1/2" than that of the 3/8" weld which is the nominal increase due to increased fillet size, while the ratio of the yield-point load of the angle is slightly less. However, this was only so at the 1.2 lever arm. At the 2" lever arm the 1/2" weld was only 8% stronger while at the 3" lever arm this difference disappeared entirely.

(2) Specimens A 463, A 464 and A 466 may likewise be compared. The specimen with the 1/2" weld shows an increase in strength of 19% (should be 33%) over that with the 3/8" weld; the specimen with the 3/4" weld shows an increase in strength of 39% (should be 50%) over that with the 1/2" weld. In each case the final loads are compared since the type of failure was similar.

(3) In comparing specimens A 643 and A 644, the 1/2" weld shows a superiority of only 15% (should be 33%) over the 3/8" weld at 1.2 lever arm.

(4) On the other hand specimens A 654 and A 655 the 5/8" weld shows a superiority of 37% (should be 25%) over the 1/2" weld.

(5) A comparison of specimens A 843 and A 844 shows a 19% (should be 33%) increase in load at the yield point of the 1/2" weld over the specimen with the 3/8" weld. For some unexplainable reason both the 3/8" and 1/2" welds cracked at the same applied load, while the final load on the specimen with the 1/2" weld was even less than that on the specimen with the 3/8" weld.

(6) Specimens A 884-1 and A 886-1 showed no marked difference in either the yield point or ultimate strengths, whereas A 886-1 should have been 50% stronger than A 884-1. A 886-1 failed prematurely due to poor fusion at the top ends of the welds for a depth of approximately three-eighths of an inch.

Summing up the data concerning the effect of weld size, it appears that the results are rather scattered. It seems safe to say that weld size does effect the strength of the connection but not in direct proportion to the increase in size.

It is evident from the economic standpoint that the weld size should be kept as small as possible. Comparison of the 1/2 inch with the 3/8 inch welds shows that while the strength increases 33% both material and labor increase about 78% for the larger weld.

(f) General Remarks - It is to be noted in Table II that the results obtained from specimen A 443-1 are somewhat low as compared to those of later specimens. This is due to the outward deflection of the vertical arms of the loading rig allowing the lever arm of the load to increase and causing a lowered carrying capacity over that normally expected.

A 444a is a special specimen having a length of weld of only 4", two inches at each end of the angle. These welds cracked at the top in the accustomed manner and upon further addition of load continued to tear until the shearing area was so reduced that one of the angles split off entirely. Figure

18 shows the result of this test, the upper part of the weld near the heel of the angle exhibiting the typical tension fracture while the lower part exhibits the silky texture of shear failure.

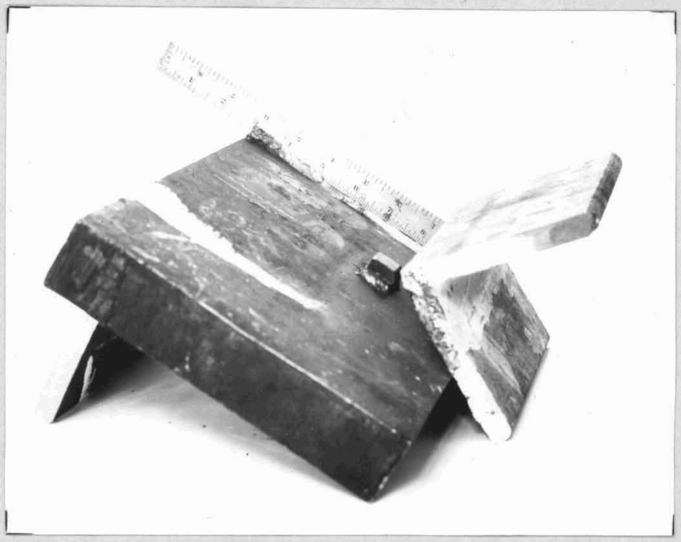


Fig. 18 - Failure of Specimen
A 444a-1

The high values of A 843-1 and A 844-1 are due primarily to the high yield-point strength of the material.

Referring to Table III it will be noted that the weld size has a definite influence on the stiffness of the connection. This is also shown in Table IV where the slope of the curve and hence the deflection decreases with an increase in the size of the angle.

An explanation for Fig. 9 is as follows. It is believed that the parabolic shape of the first portion of the curve is due to the action of the frictional forces which are gradually overcome as the load increases. These frictional forces are of two types.

(1) Those which are caused by the compressive reaction in the lower part of the vertical leg, which increases directly as the load. These forces may be considered as equal to between two-tenths and three-tenths of the compressive reaction and their line of action is upward on the face of the column.

(2) Those which are caused by the locked up stresses in the weld. As the weld is made, the metal is heated and expands. As the weld and the metal cools it contracts and tends to draw the parts closer together, particularly in the region of the weld. Hence we should expect greater frictional forces in the region of the weld and if we take the intercept on the Y axis as a measure of this force we find that it is greater here than at the center of the specimen. We should also expect a greater amount of frictional force in the larger specimens since the metal is more highly heated and thus the cooling strains are greater and this too is the case. Finally this frictional force should be of less significance as the lever arm of the load increases and this too is the case as nearly as can be ascertained.

2. Series B - In discussing the results of the few tests made ~~to date~~ in this series certain general phenomena will be pointed out which are not entirely explainable. Consideration must first be given to the action of the beam end in transferring the load to the seat angle. Figure 17 shows the strain lines of a typical failure of this type. Since

the beam flange is quite heavy relative to the outstanding leg of the angle, the reaction was concentrated near the very end of the beam causing a rapid increase in shearing stress at the junction of the flange and the web and subsequent yielding of the web at a low load. At the same time, the outstanding leg of the seat angle deflected downward as under the action of this load concentrated near the end of the beam, being restrained only to a slight degree by the fillet welds connecting the flange to the outstanding leg. The toe of the angle at the center pulled away from the bottom surface of the flange to such an extent that at 100,000 lb. total load it was possible to insert a feeler 0.040 inches thick between the flange and the toe of the angle for a distance approximately 1-1/4 inches. This threw considerable stress in the tack welds and ~~at this load~~ slight cracks were noticeable in the near ends of them. As the web yielded near the end of the beam, it borrowed on adjacent web and flange material for assistance and ~~the center of gravity of~~ the reaction tended to move outward ~~toward the center of the beam~~ thus increasing the deflection of the outstanding leg considerably. The point at which this deflection ceased to be proportional to the applied load corresponds generally with the observed yielding of the beam web, while the yield point of the angle, as determined by a slope of the curve fifty per cent greater than the original slope, corresponds generally with the observed scaling of the whitewash on the angle fillet.

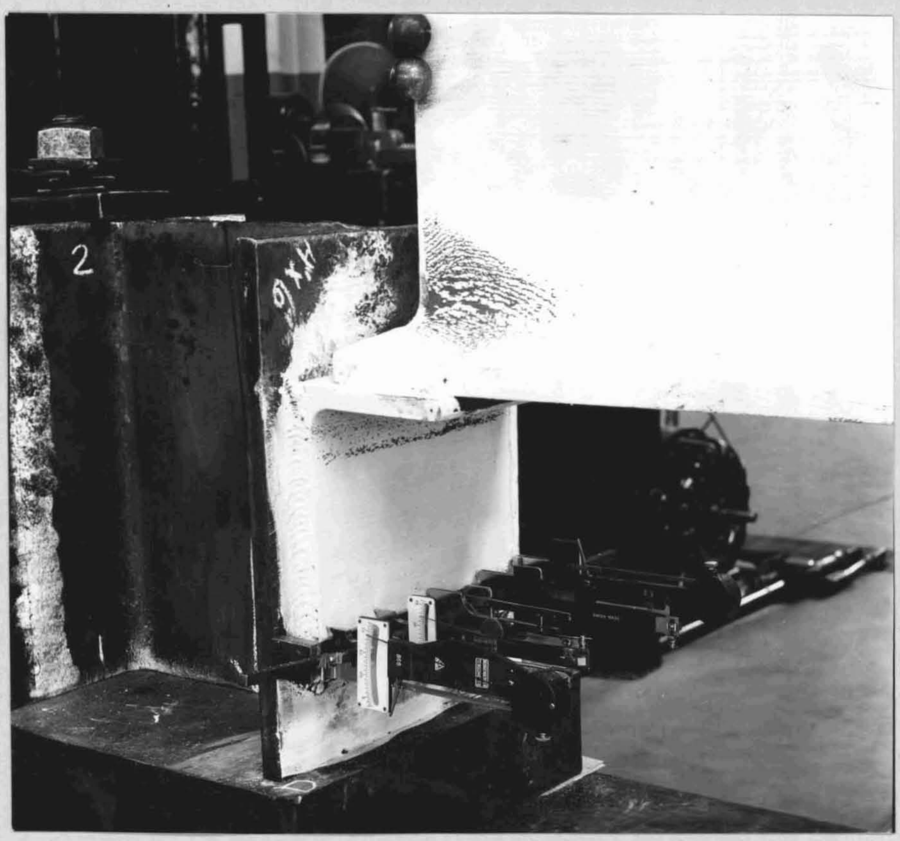


Fig.19 - Series B Specimen Showing Strain Lines and Typical Failure

Figure 10a shows the strains set up in the lower flange of the loading beam as determined by the Whittemore gage. The strains measured in this manner are greatly in excess of those which would be expected at the center of the gage length by the common beam theory. A possible explanation is that the yielding of the beam web referred to above had the same effect as a slit in the web of the beam, thus causing this section to act independently of the main body of the beam and increasing the stress in the lower flange.

Figure 10b shows the relative motion between the flange and the outstanding leg of the angle. The end of the beam pulled away from the heel of the angle thus inducing considerable stress in the tack welds between the flange and the outstanding leg. The restraint offered by these welds may also account for the high measured strains in the beam flange. This pull towards the center also accounts for much of the tipping of the columns in this direction. ~~This tipping undoubtedly relieved some of the strains on the welds at the ends of the angles and may account for the slightly higher values that were obtained~~ when comparison is made ~~with similar specimens of Series A.~~

If B 444 is compared with A 444-1, its companion, we note the following: Yielding of the angle in the Series B test occurred at 45,300 lb. as compared to approximately 30,000 lb. in the test of Series A at 1.2" lever arm. This is due to the fact that the resultant reaction of the beam acted closer to the heel of the angle than 1.2 inches. From Fig. 11 we conclude that load carrying capacity increases rapidly as the lever arm is decreased, hence this resultant reaction probably acts somewhere between 1 and 1.2 inches from the heel of the angle. Similar reasoning will account for the high strength of the welds.

Specimens B 643 and A 643-1 may also be compared. Yielding of the angles occurred at a load of 28,000 lbs. in Series B test and at approximately 29,000 lbs. at the 1.2" lever arm in Series A test. Scaling of the whitewash on the top end of the welds first occurred at a load of 33,500 lbs. in Series B tests corresponding to a like phenomenon on the companion specimen at 33,800 lbs. in Series A. ~~a remarkable coincidence~~. From the above comparisons it seems safe to assume that the position of the resultant reaction was quite close to 1.2 inches from the heel of the angle. Insert later

The end of the beam was set 7/8 inch from the face of the column in order to get the worst condition probable in practice. This figure was arrived at in the following manner. Specifications permit beams to be cut to the detailed length plus or minus 3/8 inch. Design practice allows for a clearance of 1/2 inch between each end of the beam and the column. Any deviation from detailed length should be taken up symmetrically in laying out the beam; thus a maximum gap of 11/16" is possible. However, the layout is often made from one end which gives a possible gap of 7/8" at the other end.

VI. ~~CONCLUSIONS~~ Summary of Results.

From these tests, the following ~~general conclusions~~ summary may be made:

1. The strength of a seat angle connection with welds at the ends of the vertical leg of the angles ~~varies~~ varied roughly as the square of the thickness of the angle, directly as the effective lever arm of the resultant reaction, and ~~is~~ was influenced by the length of the vertical leg of the angle, and the size of the weld. ~~Any design method should take these factors into consideration.~~

2. Vertical shear ~~has~~ had only a slight effect on the strength of the weld unless the angle ~~is~~ was thick enough so that the bending deflection of the vertical leg ~~is~~ was reduced to a minimum, in which case the vertical shear is a criterion. However, even in this case the tops of the welds were found to be most highly stressed and failed first.

3. The ~~centers~~ center of rotation for the calculation of the ~~resistance~~ strength of the weld ~~were~~ was not ~~located~~ determined in these tests, but it was evident ~~that they are~~ it was not at the midheight of the weld. ~~They probably~~ It seemed to vary with the effective lever arm of the applied load and with the load itself.

4. No effect on the strength of the connection ~~is~~ was noted with respect to concentration of load longitudinally over varying lengths of the outstanding leg, except a local yielding directly under the point of application of the load. The outstanding leg ~~seems~~ seemed to distribute the concentrated load so that the resultant moment ~~has~~ had the same effect on the welds as if the load were spread over the full length of the angle.

5. The outstanding leg acts as a cantilever beam so long as the load is applied near the toe. The weakest section is therefore at the junction of the fillet of the angle and the outstanding leg. As the load moves in toward the heel of the angle, true cantilever action is replaced by a combination of bending and vertical shearing stress giving a point of maximum principle stress on the fillet of the angle.

6. Increase in size of weld increases the strength of the connection but not in proportion to the gain in weld strength, furthermore, the added strength of the connection is far less than the increase in welding costs. Economically then it would be desirable to keep the weld as small as possible.

7. The strength of the connection does not increase markedly with the length of weld. It ~~is probable~~ that the weld need only be slightly longer than is necessary to prevent shear failure, figured simply as the total load divided by length of weld. ~~It appears evident that the bending moments set up add no appreciable stresses to the lower portion of the welds.~~

8. The failure of ~~this type of~~ connection is gradual unless the lever arm is so small that shear and not bending predominates. The weld gradually pulls away from the top allowing the angle to bend outward and downward at a rapid rate.

9. The principle lever arm for Series A was 1.2 inches, which was estimated to be a proper value from considerations of the maximum possible gap between the beam and the column face and the probable position of the resultant reaction.

between the loading beam and seat angle. This assumption of a lever arm was rather closely substantiated in the ~~two~~ tests of Series B.

10.— The position of the resultant reaction ~~is~~ was found to be dependent upon the relative stiffness of the beam flange and the angle. If the flange is heavy compared with the outstanding leg of the angle the resultant reaction will be near the end of the beam and will move ~~towards the center of the beam~~ outwards as the web yields. If on the other hand, the flange is light as compared to the angle, the reaction will be concentrated near the toe of the angle setting up high stresses in the outstanding leg and in the weld in comparison to the applied load. ~~Assuming both the beam and the angle to yield, the effective lever arm of the resultant reaction would tend to be decreased and the stresses in the angle and in the welds would not increase in proportion to the loads.~~

VIII - Design Recommendations.

AN INVESTIGATION OF

WELDED SEAT ANGLE CONNECTIONS

by

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December 1934