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Welded Continuous Frames And Their Components

BEHAVIOR OF HAUNCHED CORNER CONNECTIONS

by

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ABSTRACT

Haunched connections are widely used in rigid frame structures at the present time. Their use makes it possible to achieve a pleasing appearance from an architectural standpoint and, at the same time, reduce the size of main structural members.

When the selection of the main members of a structure is based on plastic theory, the design of the connections should also be based on plastic methods. In References 1 and 2, theories for proportioning tapered and curved haunched corner connections based on plastic analysis are presented. This report describes tests performed to check these theories experimentally. Six specimens, four tapered and two curved, were so proportioned that they would verify important theoretical findings.

TABLE OF CONTENTS

1. INTRODUCTION

There are three types of corner connections used in rigid frames: square, tapered, and curved. Elastic methods of analysis for these types of connections are available; however, they are rather tedious to use. Studies of curved knee connections are reported in Reference 3 and an approximate method of analysis which was also checked experimentally is reported in Reference 4. Tests of two frames having curved knees are described in Reference 5, and tests of six curved knees are described in Reference 6. Based on the experiments in References 5 and 6, it was concluded: (1) that the load carrying capacity of a portal frame could be increased by haunching the knees, and (2) that it would be necessary to provide lateral support for the compression flange and to stiffen the web at the knee. A study of a series of corner connections covering the three basic types is reported in Reference 7; a detailed description of inelastic behavior and rotation capacity is also included. In Reference 8, a plastic analysis was made on square rigid frame knees.

Recently a program was carried out to obtain theoretical solutions and design methods for tapered and curved haunched connections in the plastic range. A simple method for designing haunched connections plastically is presented in References 1 and 2. The purpose of this paper is to present the results of tests performed to observe the behavior of haunched corner connections designed according to the principles formulated in References 1 and 2.

2. SUMMARY OF THEORY

Before the actual test program is described the theoretical results for haunched corner connections will be presented. This section summarizes the important theoretical findings for both the tapered and curved connections. The interested reader can find a detailed presentation in References 1 and 2.

2.1 Tapered Haunched Connections

Theoretical findings reported in Reference 1 which were to be investigated by the test program are briefly stated in the following paragraphs. The findings apply to tapered haunches of the type shown in Fig. 1a.

(a) The effect of shear upon the full plastic moment can be neglected, and the effect due to axial thrust can be treated in the same manner for haunched connections as it is for the adjoining rolled sections.

(b) There is a critical angle for the sloping flange for which the change of the resisting moment along the haunch nearly equals the change of applied moment along the length of the haunch. At this critical slope angle which is about 12 deg., the haunch will yield along its full length at ultimate load if adequate bracing is provided. When the angle is less than the critical angle, full plasticity will only occur at the haunch intersection. When the angle is greater than the critical angle, the plastic hinge forms only at the intersection of beam and haunch.

(c) The thickness of a haunch flange at an angle with the layout line should be greater than that of a flange parallel to the layout line. The relationship between thickness should be:

$$t_c = \frac{t_t}{\cos\beta}$$

where

t_c = thickness of sloping flange (usually compression)

t_t = thickness of parallel flange (usually tension)

β = angle of sloping flange with layout line

(d) To protect against lateral buckling when the compression flange is fully yielded, the maximum unsupported length of the compression flange within the haunch should not be greater than 4.8b, where b is the width of flange. This assumes that the thickness of flange within the haunch is equal to that of the rolled section.

(e) The critical buckling length of 4.8b can be increased for a particular design by limiting the extent of yielding along the flange, that is, by confining the yielding to one end of the flange. This can be accomplished in the following two ways:

(1) The angle of taper β can be increased above the critical value of 12 deg.

(2) If it is undesirable to increase the angle of taper, the thickness of both flanges can be increased to limit the extent of yielding. The increase required depends on the desired unsupported length of compression flange. In Reference 1 it was shown that the thickness of both flanges (originally assumed to be equalto the flange thickness of the rolled section) must be increased an amount Δt where

$$\Delta t = 0.11 \left(\frac{s}{b} - 4.8 \right) t$$

s - unsupported length of compression flange

b - width of compression flange

t - thickness of compression flange of rolled section

provided $\frac{s}{b} \leq 14.8$

Connection specimens No. T-44 through T-47 (Fig. 2a) were designed to verify the theory for tapered haunched connections. The specimens and their individual purposes are described in Art. 3.

2.2 Curved Haunched Connections

The procedure of analyzing a curved connection is essentially the same as that used for analyzing tapered connections. The theoretical results given in Reference 2 are similar to those described earlier for tapered connections. The results apply to curved haunches of the type shown in Fig. 1b. They are summarized as follows:

(a) The effects of shear and axial thrust on the plastic hinge moment are small provided the web and flange thicknesses of the haunch are as large as those of the adjacent rolled section and provided these effects are small in the rolled section.

(b) The plastic modulus furnished in the haunch must be adequate to resist the applied moment at any distance along the haunch. The critical sections occur at the point of tangency of the haunch and rolled beam and at a point located at an angle about 12 deg. from the point of tangency (depending on the moment gradient). Plastic hinges will have a tendency to form at these two points.

(c) To protect against lateral buckling, the maximum unsupported length of compression flange should not exceed 4.8 times the width of flange. For a right angle connection with lateral support at the diagonal stiffener and at the points of tangency, this statement implies that the radius of the flange may not exceed 6b.

(d) If an unsupported length of compression flange greater than 4.8b is desired, it is possible to provide for stability by increasing the thickness of the compression flanges by an amount

$$\Delta t = 0.11 \left(\frac{R}{4b} - 4.8 \right) t$$

where Δt = increase in thickness of compression flange

R = radius of curved haunch

b = width of compression flange

t = thickness of compression flange of rolled section

For detailed derivations, the reader is referred to Reference 2.

Connections No. T-48 and T-49 shown in Fig. 2b were designed to study the theoretical findings for curves haunches. These specimens and their individual purpose are described in Art. 3.

3. TEST PROGRAM

Six haunched connections, four tapered and two curved, were included in the program to test the theories of References 1 and 2 which are summarized in Art. 2. Each connection joined two legs of 10B19 rolled shape having equal lengths of about three times the section depth. The web thickness in all haunches was equal to the nominal web thickness of a 10B19 section and the flange widths were equal to the flange width of a 10B19 throughout. Sketches of the connections are given in Figs. 2a and 2b.

Of the four tapered haunched connections, two specimens, numbers 44 and 45, were designed for critical angle of taper (12 deg.) and critical length of compression flange (4.8b). The other two tapered connections were designed to study the effects of modifications necessary to prevent failure due to lateral instability of compression flanges having unsupported lengths approximately twice the theoretical critical length. Specimen 46 had its angle of taper increased in order to confine yielding to the region near the junction with the rolled section, thereby decreasing the yielded length and increasing the critical length. Specimen 47 had its flange thicknesses increased to reduce yielding and thus increase the critical length even though the angle of taper remained at the critical angle of 12 deg.

Curved haunch specimen 49 was designed as a 90 deg connection with the critical radius of inner flange curvature equalto six times the flange width. Specimen 48 had one and a half times as much unsupported compression flange, but this was offset by increasing the flange thickness according to the modification described in Art. 2 and Reference 2.

3.1 Description of Specimens

Specimen 44 as sketched in Fig. 2a was designed to permit yielding along the full length of a 20 inch long compression flange. This length was equivalent to 5 times the width of flange, just slightly more than the theoretical critical value of 4.8b. To bring about the desired full yielding, the angle of taper was made equal to 12 deg while the inflection point was located 32-3/4 in. out along the length of rolled section. Diagonal stiffeners were fitted inside the flanges at the outer corners of the knee. Welding details for all tapered knees were similar to those shown for specimen 46 in Fig. 3a.

Test 44A was conducted on the same specimen as Test 44 but had slight differences in lateral bracing which will be described later.

Specimen 45 had its basic design identical to specimen 44. A different fabricating detail was used at the outer corner however. The diagonal stiffener was extended past the outer flanges and was welded to the outside of the flanges as indicated in Fig. 3a, detail C'. A more positive bracing system was used to restrain the compression flange at the reentrant corner. Also, the lengths of the rolled sections were adjusted to compensate for a difference in the yield strengths of the rolled sections used in Specimens 44 and 45.

The compression flange of Specimen 46 was 40 inches long, slightly more than twice the critical unsupported length if fully yielded. However, this length would be stable according to theory if the yielding began at one end of the flange and extended along approximately 20 percent of the flange length. The angle of taper of the haunch was increased to 21 deg. With this angle and the same moment gradient as the previous specimens, the tapered flange would have a tendency to yield along approximately 20 percent of its length.

Specimen 47 also had a 40 inch unsupported length of compression flange. The angle of taper of the haunch was 12 deg which would tend to cause yielding along the full length of the flange and, consequently, premature lateral buckling. To compensate for this, the flange thickness was increased to reduce the stress and thereby increase the critical buckling length to 40 inches.

Specimens 48 and 49 were curved haunches as shown in Fig. 2b. The radius of curvature of the flange on specimen 48 was 36 in. or 9b, 1-1/2 times the theoretical critical length. To compensate for the extra unsupported length, the flanges were increased in thickness to reduce the stress and increase the critical length to the actual length used. Welding details of specimen 48 are shown in Fig. 3b.

Specimen 49 was fabricated with a 24 in. radius of curvature of the inner flange. With bracing at the diagonal line of symmetry in the corner and at the points of tangency, the unsupported length would be 4.7b or approximately the same as the theoretical critical length.

Design calculations for all specimens were based on weighted coupon test results shown in Table 1 and measured cross section dimensions shown in Table 2.

The thicknesses of all plate members were suitable for welding with ordinary E60 electrodes; however, careful attention was given to welding sequence and welding positions, so that distortion could be minimized. The downhand position was used as much as possible and an alternating sequence was adopted when necessary.

3.2 Test Set-Up

The connections were tested in an inverted position relative to that which they would have in a building as shown in Figs. 4 and 5. The column represented the vertical leg and the beam represented the horizontal leg of a letter "L". The connection was tested in this position to facilitate the loading and supporting of the specimen. Load was applied along a diagonal line joining the two free ends of the connection by means of manually-operated hydraulic jacks. This diagonal load system provided shear and thrust components at points representing the inflection points in the beam and column. Thus, shear, axial force, and moment were provided at the corner. A dynamometer consisting of a rod with strain gages previously calibrated for load was placed in series with the hydraulic jacks to indicate the load.

Light rolled beam sections simulating purlins and girts were fastened to the outer (tension) flange of the connection at the corner, at the intersection of the haunch and rolled section, and at the load points as shown in Fig. 4. These beams provided lateral support to the connection (see Section 3.3 following for a detailed description of the lateral bracing system). In addition, two of these light beams served as the bearing supports for the dead weight of the connection as shown in Fig. 4. The bearing support at the load end of the specimen was placed on a short length of wide-flange section which served as a flexible support, and the bearing support at the corner rested on a spherical seat.

3.3 Lateral Bracing System

Light weight beams simulating purlins and girts were used for lateral bracing in order to make the system equivalent to that used in building construction. As shown in Fig. 2, 3I7.5 and 6B12 sections were used for lateral support. The purlins were fastened to the tension flanges of the connection by means of bolted clamps to allow their re-use. Lateral motion of this outer flange of the haunch was resisted by axial force in the purlins, and lateral twist of the connection was resisted by the bending stiffness of the purlins. These reactions were transmitted to the compression (inner) flange of the haunch by the action of the web stiffeners at each support point. It was of interest to determine if the stiffeners and purlins could provide enough restraint to prevent the lateral deflection of the compression flange of the connection.

The far ends of the purlins were fastened to a supporting framework by means of a flex bar as shown in Fig. 4. Provisions were made to permit horizontal and vertical movement of the far end of the purlin in order to keep these purlins approximately horizontal as the test specimen deflected under load. The frame supporting the lateral bracing was constructed by erecting two 14WF30 columns on the heavy base beams and placing 6B12 beams horizontally between these columns. The lateral support framework can be seen in Fig. 5.

In Test 44 lateral support was provided by 4 ft lengths of 3I7.5 sections. Dynamometers were attached to the ends of these purlins in order to determine the magnitude of the axial thrust in the purlin, that is, the lateral bracing force. However, this arrangement was found to be unsatisfactory since the lateral deformation of the connection tended to bend the dynamometers. Consequently, the dynamometers were not used on any other test. Connection 44a had a similar type of bracing detail. Only the length of the bracing was increased. Test 45 had the same general purlin-type bracing system that was used for Test 44a. However, in addition a diagonal brace was placed between the corner purlin and the reentrant corner of the diagonal stiffener. This bracing system was used for all subsequent tests except test 46 which had additional knee braces at the intersection of the haunch and beam.

3.4 Instrumentation

In addition to the dynamometer which measured the load applied to the connection as explained previously, deformation measuring devices were used to determine the following: flexural deflection, rotation, and lateral deflections. The flexural deflection was determined by measuring the movement between the ends of the specimen along the line of action of the applied load. This displacement was measured by means of a taut wire and pulley arrangement which displaced the plunger of a dial indicator as shown in Fig. 6.

Measurements of rotation within the haunch and along parts of each rolled beam adjacent to the haunch were made by a system of rigid rods and dial gages. For example, to measure the rotation between two sections along a beam, the relative movements between points near the top and bottom flanges at each section were measured. From these measurements the rotation between these two sections was evaluated. The total rotation of the specimen was obtained by summing the rotation of sections taken around the entire connection. The rotation indicators are shown in Fig. 6.

Lateral deflections were measured by means of a transit which was set in a fixed position and its telescope allowed to move in a vertical plane only. A 0.01 in. graduated scale was held perpendicular to the plane of the web at certain discrete positions on both flanges of the connection as shown in Fig. 6. Lateral movement of the connection was determined from transit readings on the scale.

3.5 Test Procedure

Prior to actual testing, an overall check of the testing apparatus and instruments was made and zero readings were taken. In the elastic range, load increments of approximately 10 percent of the predicted yield load were used. After each load was applied, all rotation and deflection readings were taken, and the specimen was checked for any signs of yielding. Yielding was detected by flaking of the mill scale under the Whitewash coat on the specimen.

In the inelastic range, the load and deflection no longer have a linear relationship; therefore the load increments were determined by a deflection criterion. Deflection increments were arbitrarily chosen, and straining was halted after each increment was applied. Since the load would not be stable until the plastic flow stopped, readings were not recorded until static equilibrium was obtained.

After the maximum load was reached, the test was continued in order to find the rotation capacity of the connection. When the load fell below the predicted yield level, the test was terminated.

4. TEST RESULTS

The flexural deflection, rotation, and lateral deflection data recorded for each test are presented in Figs. 7, 8, and 9. These curves are discussed in separate articles in this section. The general yielding, formation of plastic hinges, and plastic buckling of each specimen were also observed. Figures 10 and 11 show the spreading of yielding and the plastic hinge of T-46 as a typical example. Lateral buckling occurred in most of the specimens with a single curvature between lateral supports. Figure 12 shows a view of the compression flange of a curved connection after the test was terminated. It represents, in general, the buckled shape of the specimens tested in this program.

4.1 Moment - Deflection Relationships

The load and flexural deflection data are presented in non-dimensional form as moment-deflection curves. These $\frac{M}{M_p}$ vs $\frac{\delta}{\delta_y}$ curves are shown in Fig. 7 where

M = applied moment at the intersection of the haunch and the rolled section

M_p = plastic moment of the rolled section

δ = measured deflection between the two ends of the specimen

δ_y = theoretical deflection between the two ends of the specimen at first yield in the rolled section. Reference 8 outlines the method used for computing δ_y.

The M_p and δ_y values were computed using the tension coupon data and measured cross section dimensions given in Tables 1 and 2 respectively.

4.2 Moment - Rotation Relationships

In Fig. 8 the non-dimensionalized curves for $\frac{M}{M_p}$ vs $\frac{\theta}{\theta_y}$ are shown. $\frac{M}{M_p}$ was defined earlier. The angle θ is the total rotation of the haunch including 12 in. of the rolled beams at each end, and θ_y is the theoretical rotation over the same total length of haunch and beam corresponding to the first yield in the rolled beam. Some of the connections rotated more than implied in Fig. 8. Lateral buckling caused distorsion of the web which caused misalignment of the rotation indicator dials shown in Fig. 6. This caused errors in the rotation.

4.3 Moment - Lateral Deflection Relationships

The relationships between moments and lateral deflections at three points along the compression flange are shown in Fig. 9. The $\frac{M}{M_p}$ ratio shown in the figure was defined in Section 4.1. The curves show the moment at which lateral buckling took place and the effect of lateral buckling on the load-carrying capabilities of the specimen. Since the connections were braced at points (a) and (c) in Fig. 9, the curves also show the effectiveness of the different bracing details. A positive brace would permit only a small amount of lateral movement.

5. DISCUSSION OF RESULTS

5.1 Tapered Connections with Critical Angle and Critical Flange Length (44 and 45)

Connections 44 and 45 represented the critical case for tapered haunched connections; that is, they were designed with both the critical angle (β = 12 deg) and the critical flange length (s = 4.8b). Connection 44 was tested twice, and the results obtained from the second test (44a) were very similar to the results of the first test (44). Test 45 was different from Test 44 only in having a truss-type brace at the reentrant corner as explained earlier. Figure 7 shows that Connection 44 never reached its theoretical bending capacity ($\frac{M}{M_p}$ max = 0.91) whereas Connection 45 reached a maximum $\frac{M}{M_p}$ of 1.06 or 16 percent greater than that of connection 44. In connection 45, yielding occurred along the entire haunch, and the plastic hinge formed at the reentrant corner. Also, connection 45 had a much greater rotation capacity than connection 44. This is shown in Fig. 7 since deflection is an integrated measure of rotation. (Fig. 8 shows that the rotation of Connections 44 and 45 are essentially equal; however, web distortion caused misalignment of the rotation indicators as explained previously). Thus, the bracing detail of connection 45 permitted larger load-carrying and rotation capacities as compared to connection 44. However, it can be seen from Fig. 9 that positive support was not provided in either case because of the large lateral movement recorded at point (a).

5.2 Tapered Connections with Flange Length Greater than Critical (46 and 47)

In order to permit a flange length greater than the critical length, Connection 46 had the angle of flange taper increased, and Connection 47 had an increased flange thickness. Both connections had truss-type bracing at their reentrant corners. The maximum observed loads were higher than those predicted by approximately 20 percent as can be seen from Fig. 7. It can also be deduced from Fig. 7 that the specimens were able to sustain large deformations and rotations. In both tests the plastic hinge formed in the rolled section. Figures 10 and 11 show the extent of yielding along the haunch and the formation of the plastic hinge for Connection 46. Figure 9 shows that in each case the compression flange buckled and that the bracing at points (a) and (c) was effective.

5.3 Curved Connections (48 and 49)

Connection 48 had an increased flange thickness to compensate for its radius of curvature which was greater than the critical value. This would force the plastic hinge to form at the point of tangency. Figure 13 shows that the plastic hinge did form in the rolled section for Connection 48. Connection 49 was proportioned using the critical radius of curvature (R = 6b). Consequently the plastic hinge should form in the haunch at an angle of approximately 12 deg from the point of tangency according to the theory. It can be seen in Fig. 14, which shows Connection 49 after testing, that the hinge did form in the haunch at approximately 12 deg from the intersection of the haunch and rolled section. It can also be seen from Fig. 13 that yielding occurred in the web of the haunch of Connection 48 (not in the flange because of the increased thickness) at an angle of 12 deg which further verifies the theory.

Both connections were more than adequate for the requirements of plastic design. The predicted load was exceeded in both cases as shown in Fig. 7. Considerable rotation capacity was also observed.

5.4 General Discussion

Connections 45, 46, 47, 48 and 49 would all be considered satisfactory for plastic design. Connection 44 had inadequate bracing as mentioned earlier. The fact that connections 45 and 49 allowed a major part of their plastic hinge action to occur within the haunch in no way reduced their effectiveness because they were adequately protected against lateral instability.

As illustrated in Fig. 7, the maximum loads for all tests except Tests 44 and 44a exceeded the theoretical predictions by amounts which vary from 6 percent to 21 percent. The excess capacity was probably due to the stiffener at the intersection of the haunch and rolled beam. The stiffener produced two effects. First, it provided added strength at this point merely on the basis of added area of steel. Second, the stiffener produced a stress concentration which caused the rolled section to go into strain-hardening quickly. Restraint offered by the purlins used as lateral bracing could also increase the carrying capacity of the connections, but this effect would only amount to a maximum of 4 percent because of the sections used.

No significant difference could be detected in the behavior of the fabrication details used at the outside corner. Whether the diagonal stiffener was fitted inside the flanges or extended past the outer flanges and then welded made little difference.

6. SUMMARY AND CONCLUSIONS

Tests of six haunched connections are described in this report. The primary objective of these tests was to verify the theoretical results presented in References 1 and 2. Following is a summary of the theoretical results which were confirmed by the tests:

1. In tapered haunched connections with an angle of taper of 12 deg, yielding occurred along the entire compression flange.
2. The critical buckling length was increased by increasing the angle of compression flange taper.
3. The critical buckling length was increased by increasing the haunch flange thickness.
4. In the curved connections, plastic hinges formed at points in the haunch 12 deg from the point of tangency when critical proportions were used.
5. Yielding in the haunch did not reduce the effectiveness of the connection.

The tests also showed that the diagonal web stiffener did not transmit enough restraint to brace the compression flange at the reentrant corner against lateral buckling. A positive brace must be provided at this point. All specimens which were braced adequately were able to sustain a moment exceeding the plastic moment and to rotate satisfactorily.

Specimens which were braced adequately did not buckle until M_p was exceeded. Thus, it can be concluded that haunched connections proportioned by the methods of References 1 and 2 will satisfy the requirements for plastic design. However, the load-carrying capacity as well as the rotation capacity depends greatly on the bracing provided. The compression flange of a haunched connection must be supported by positive lateral bracing.

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8. NOMENCLATURE

A	= Area of cross section
b	= Width of flange
d	= Depth of rolled section
E	= Modulus of elasticity
E_{st}	= Strain-hardening modulus
f	= Shape factor = $\frac{Z}{S}$
I	= Moment of inertia
M	= Applied moment at the intersection of the haunch and rolled section
M_p	= Plastic moment of the rolled section
R	= Radius of curved haunch
s	= Unsupported length of compression flange
S	= Section modulus
t	= Thickness of the flanges of the rolled section
t_c	= Thickness of the compression flange in a haunch
t_h	= Thickness of the flanges of a haunch
t_t	= Thickness of the tension flange in a haunch
w	= Thickness of the web of the rolled section
Z	= Plastic modulus
β	= Angle between the inside and the outside flanges in a tapered haunch
δ	= Measured deflection between the two ends of a specimen
δ_y	= Calculated deflection between the two ends of a specimen corresponding to the first yield at the haunch-beam junction

Δt = Increase in thickness of the compression flange

θ = Total angle of rotation of the connection

θ_y = Angle of rotation of the connection corresponding to the first yield occurring at the haunch-beam junction

σ_{ult} = Stress corresponding to the ultimate strength of the material

σ_{ys} = Static yield strength of the material

TABLE 1 SUMMARY OF TENSILE COUPON TEST RESULTS

Material	Location of Coupon	Static Yield Stress σ_{ys} (ksi)	Ultimate Strength σ_{ult} (ksi)	Young's Modulus E	Strain-Hardening Modulus E_{st} (ksi)
10 B 19	Flange Tip (4)*	35.0	56.0	29,200	542
	Web Center (2)	41.2	63.1	30,600	456
	Average**	37.9	59.4	29,900	501
$\frac{1}{4}$ in. Plate (A)	Webs of Tapered Haunches (44-47) (4)	35.5	61.3	30,200	455
$\frac{1}{4}$ in. Plate (B)	Webs of Curved Haunches (48,49) (4)	41.3	68.7	29,600	533
$4 \times \frac{7}{16}$	Flanges, Stiffeners (44-46) (16)	31.7	59.6	29,900	Not Recorded
$4 \times \frac{1}{2}$ Bar	Flanges, Stiffeners (49) (4)	33.6	60.9	30,100	429
$4 \times \frac{5}{8}$ Bar	Flanges, Stiffeners (47,48) (4)	31.3	59.1	29,200	568

* Number of specimens

** Weighted average in proportion to flange and web areas

TABLE 2 MEASURED DIMENSIONS OF SPECIMEN MATERIALS

1. Cross Sectional Properties of 10B19 Beams

	A in^2	d in	b in	t in	w in	I in^4	S in^3	Z in^3	f
Handbook	5.61	10.25	4.020	0.394	0.250	96.2	18.8	21.6	1.15
Measured	5.54	10.28	4.047	0.377	0.263	93.4	18.2	21.0	1.15

2. Dimensions of Plates and Bars

Nominal Size	Average Measured Size	
	Thickness in	Width in
1/2" Plate	0.261	-
1/2 x 4" Bar	0.506	3.989
5/8 x 4" Bar	0.630	4.007
7/16 x 4" Bar	0.433	4.005

10. FIGURES

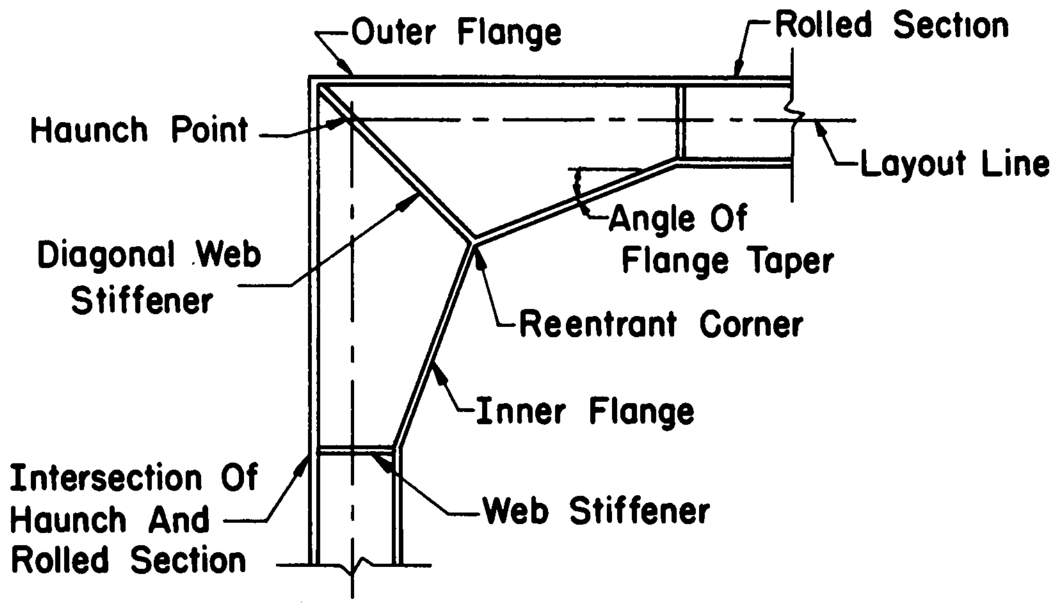


FIG. 1a Typical Tapered Haunched Connection

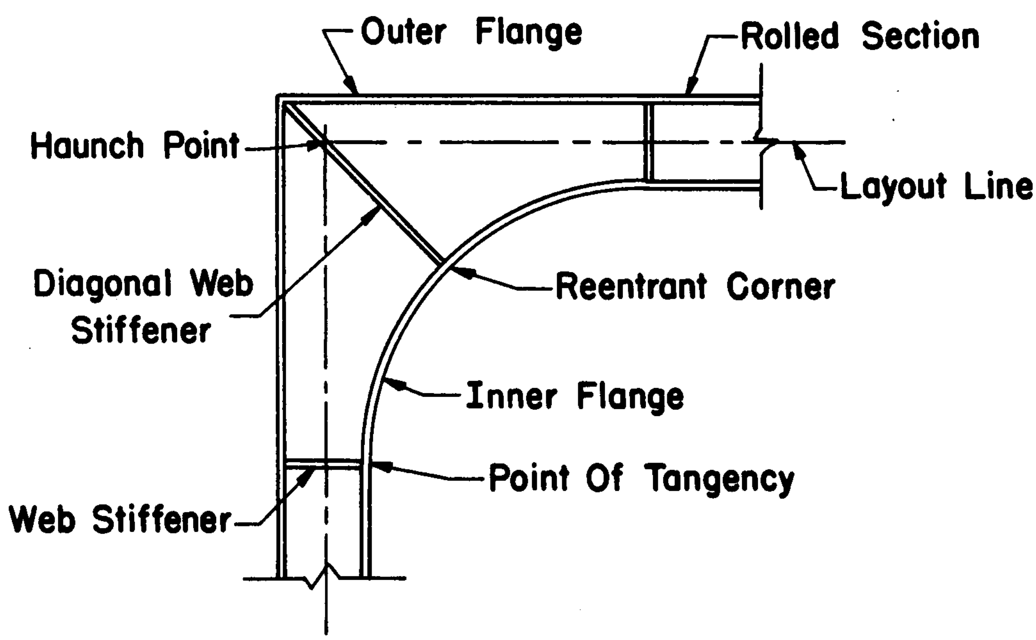


FIG. 1b Typical Curved Haunched Connection

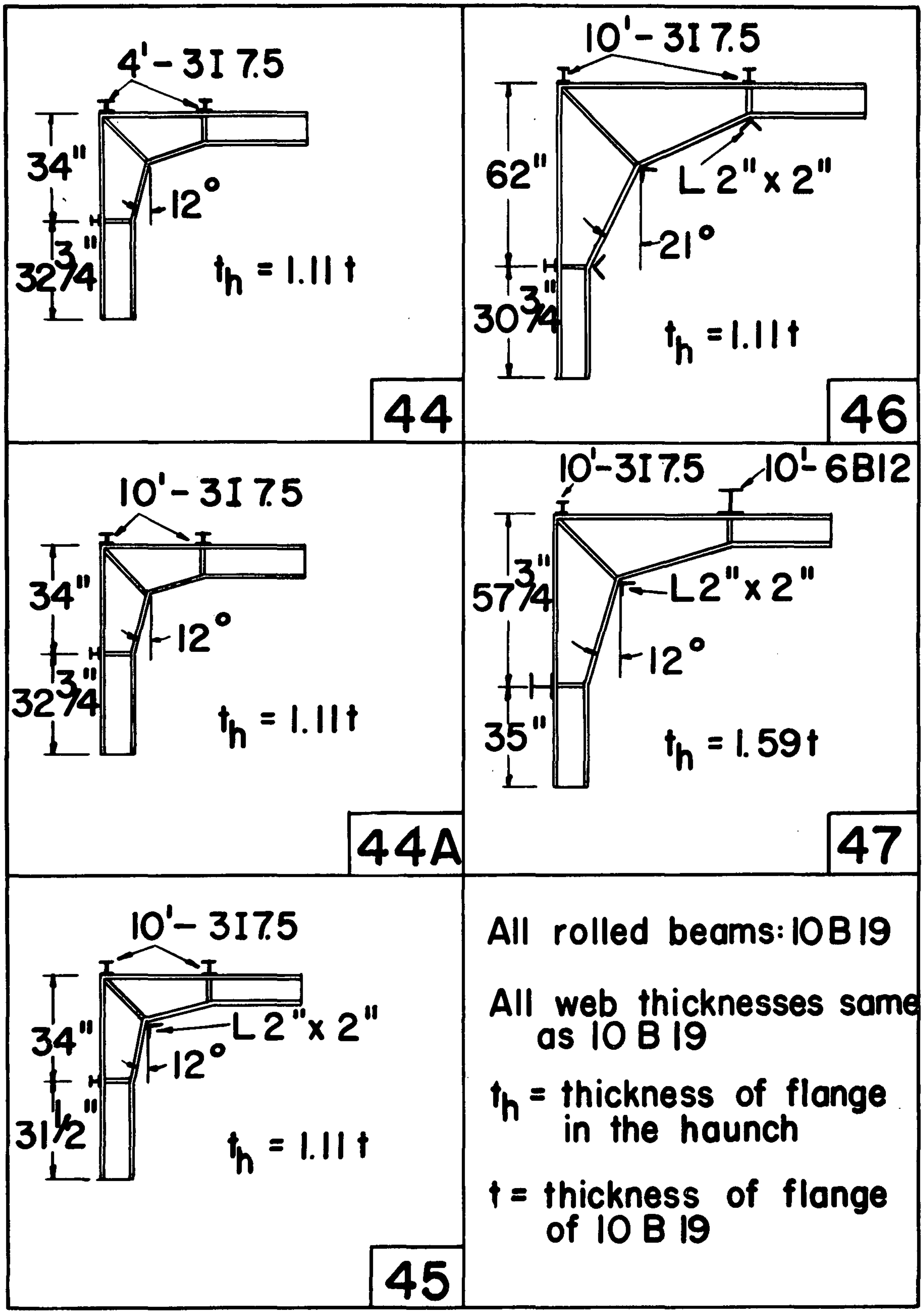
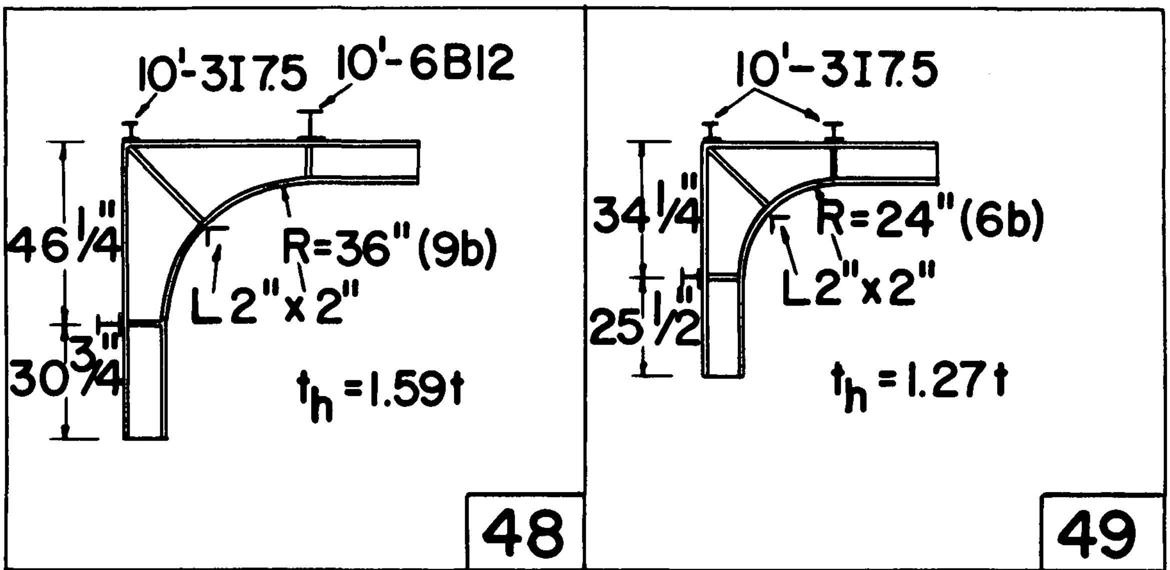


FIG. 2a Tapered Test Specimens



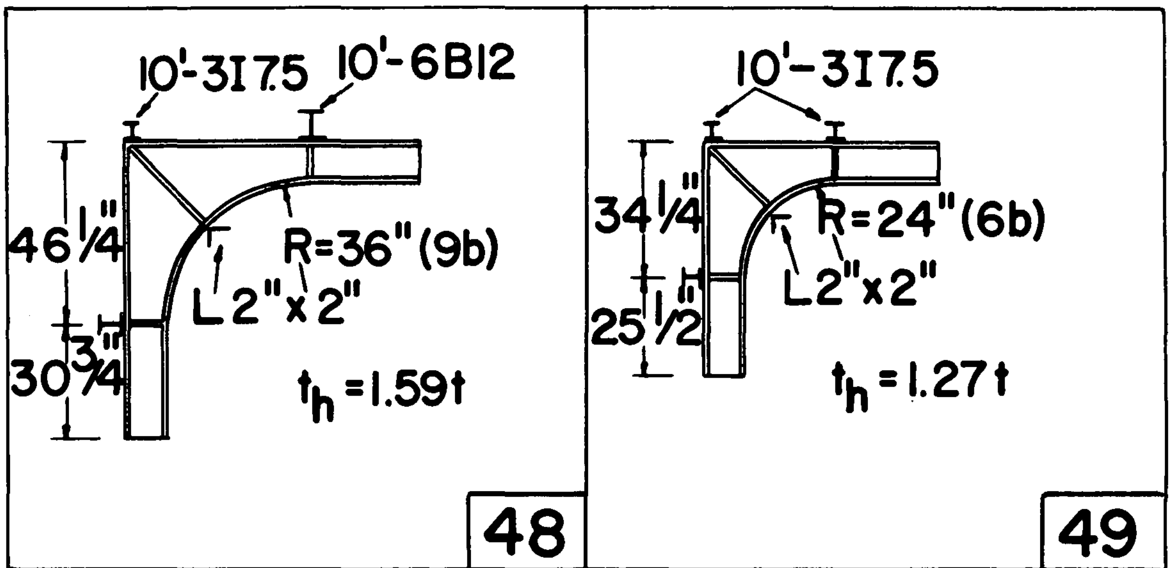
All rolled beams: 10 B 19

All web thicknesses same as 10 B 19

t_h = thickness of flange in the haunch

t = thickness of flange of 10 B 19

FIG. 2b Curved Test Specimens



All rolled beams: 10 B 19

All web thicknesses same as 10 B 19

t_h = thickness of flange in the haunch

t = thickness of flange of 10 B 19

FIG. 2b Curved Test Specimens

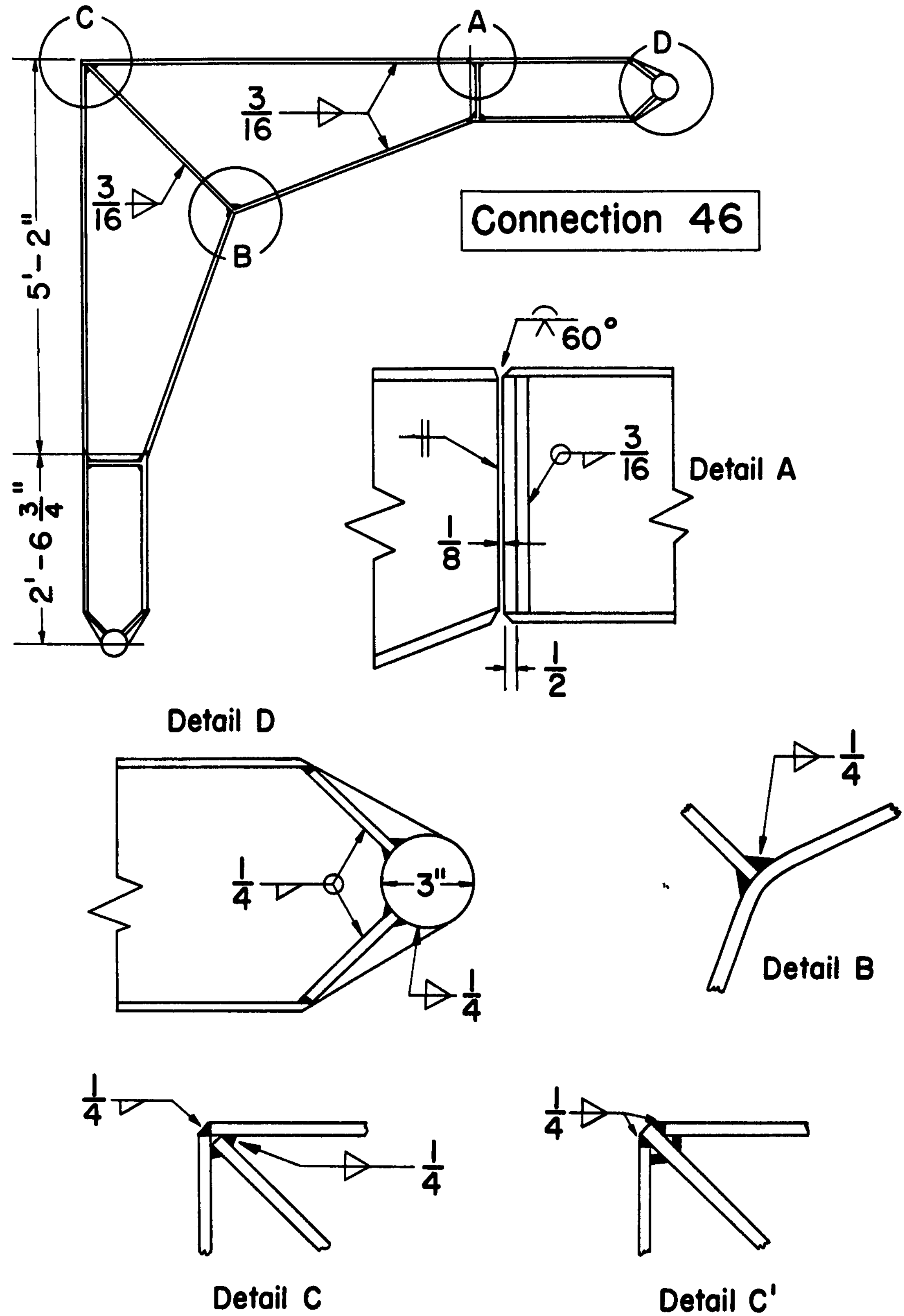


FIG. 3a WELDING DETAILS FOR TAPERED CONNECTIONS

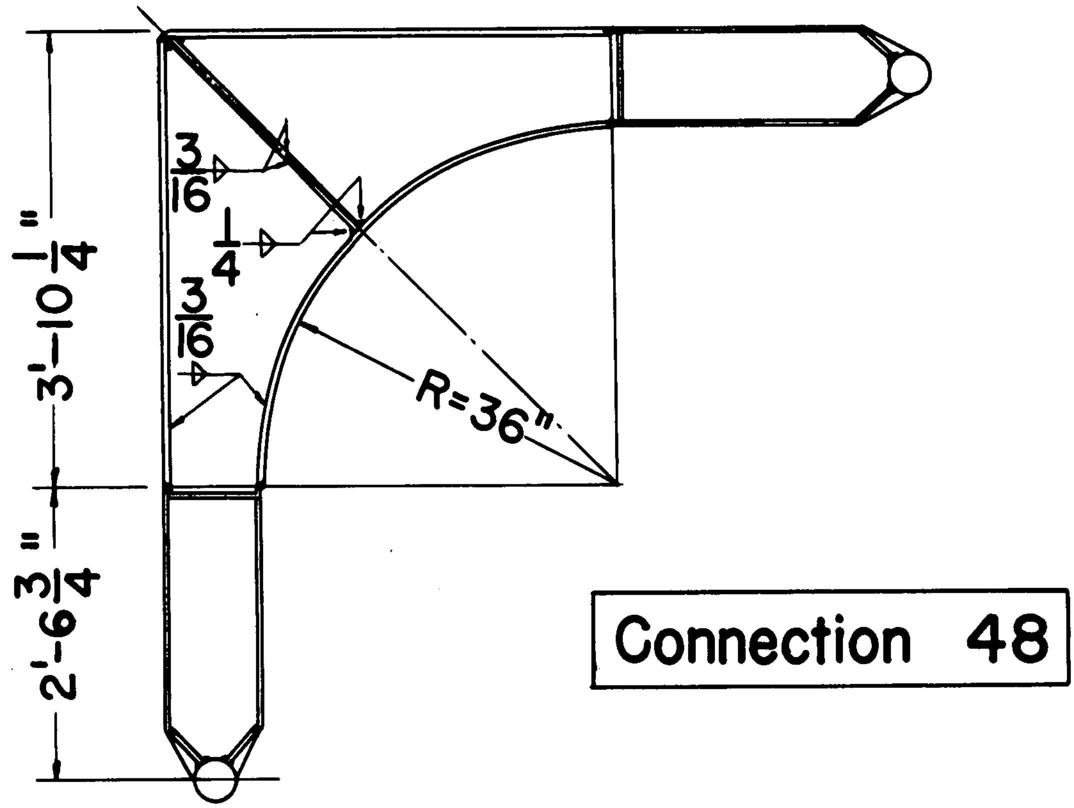


FIG. 3b Welding Details for Curved Connections

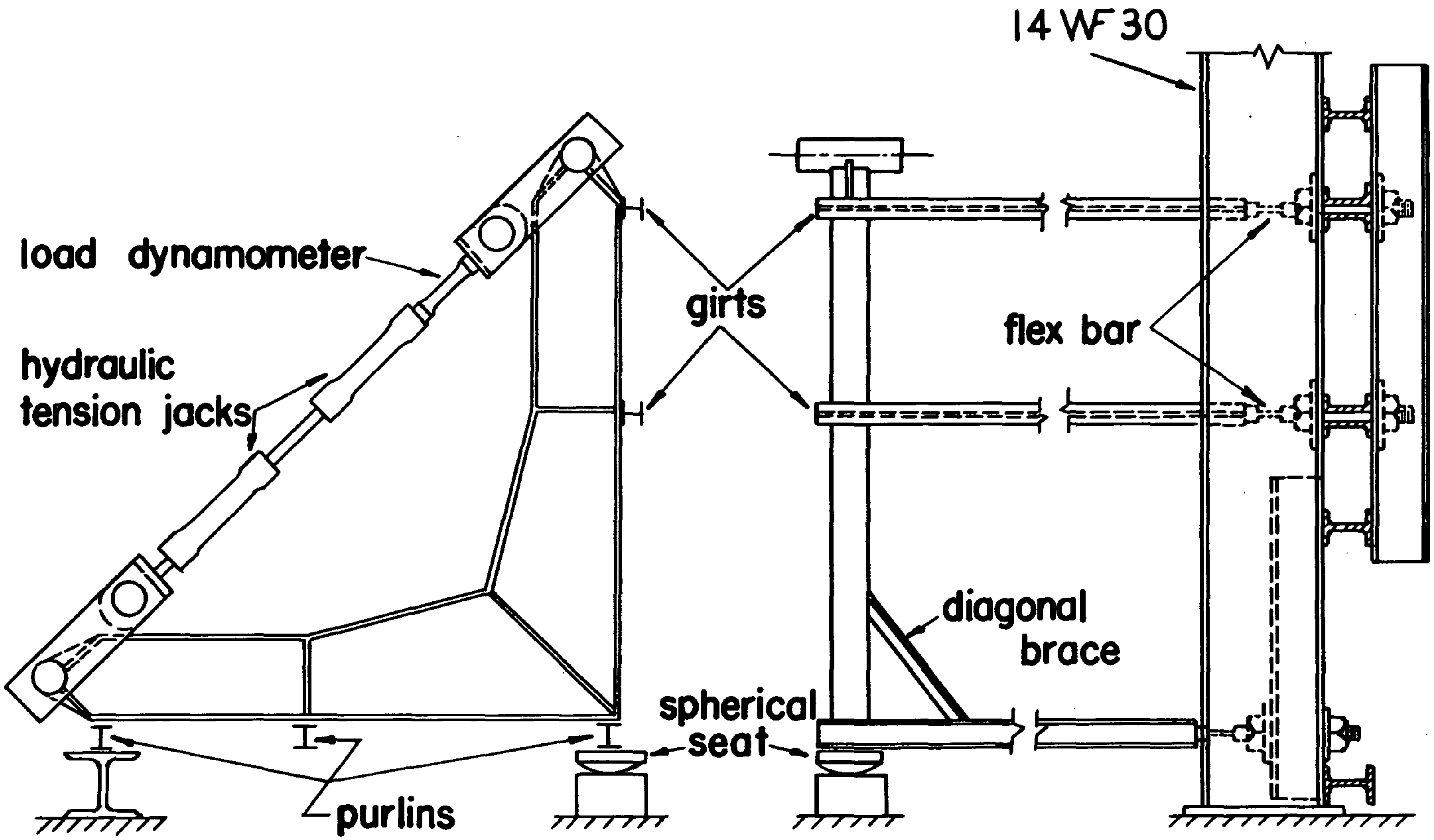


FIG. 4 Test Setup

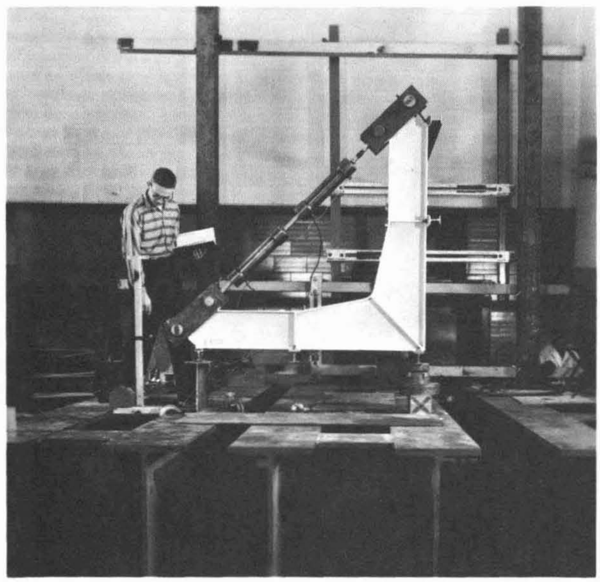


FIG. 5 Overall view of test setup. The lateral support framework can be seen in the background.

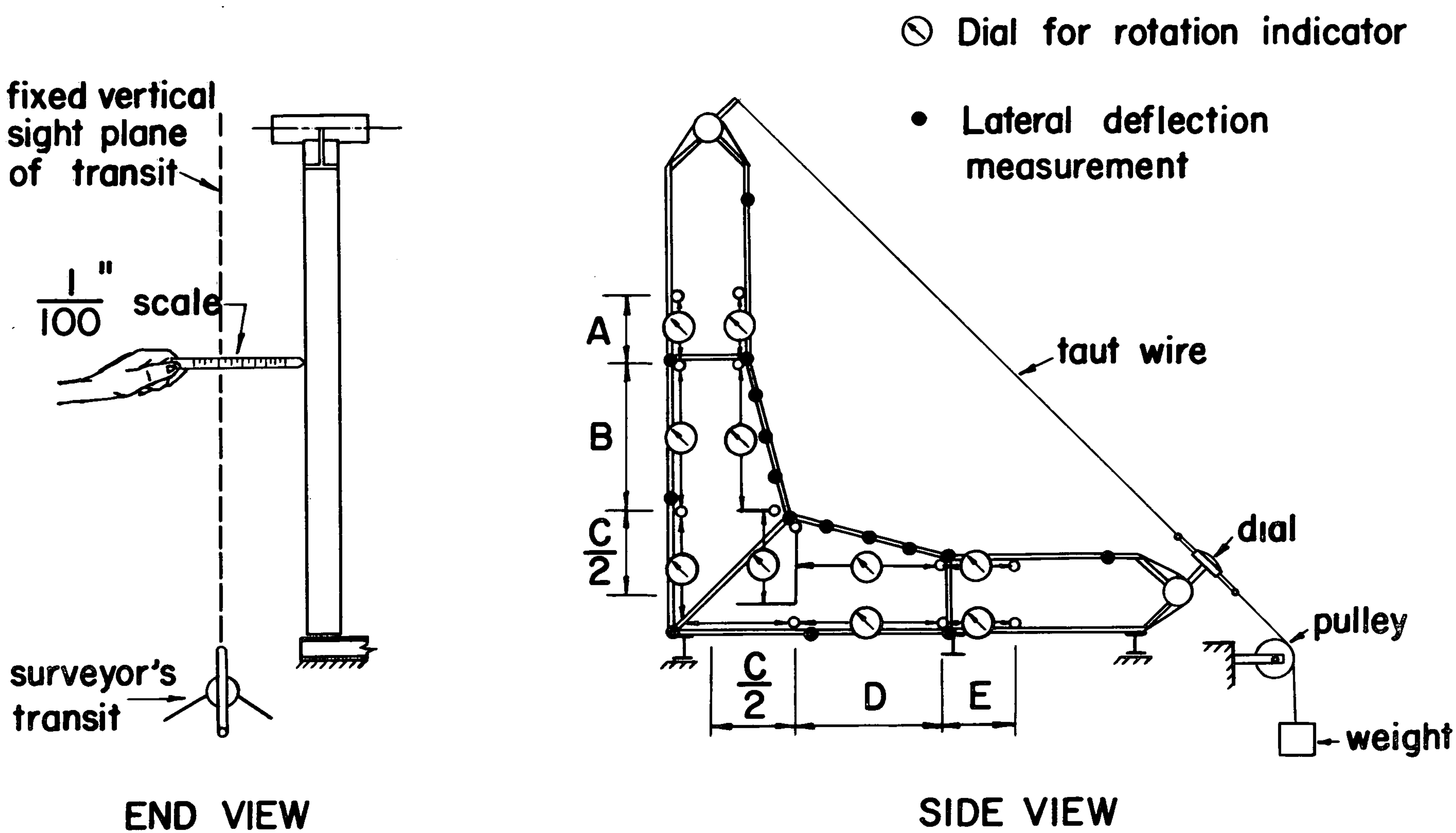


FIG. 6 Instrumentation

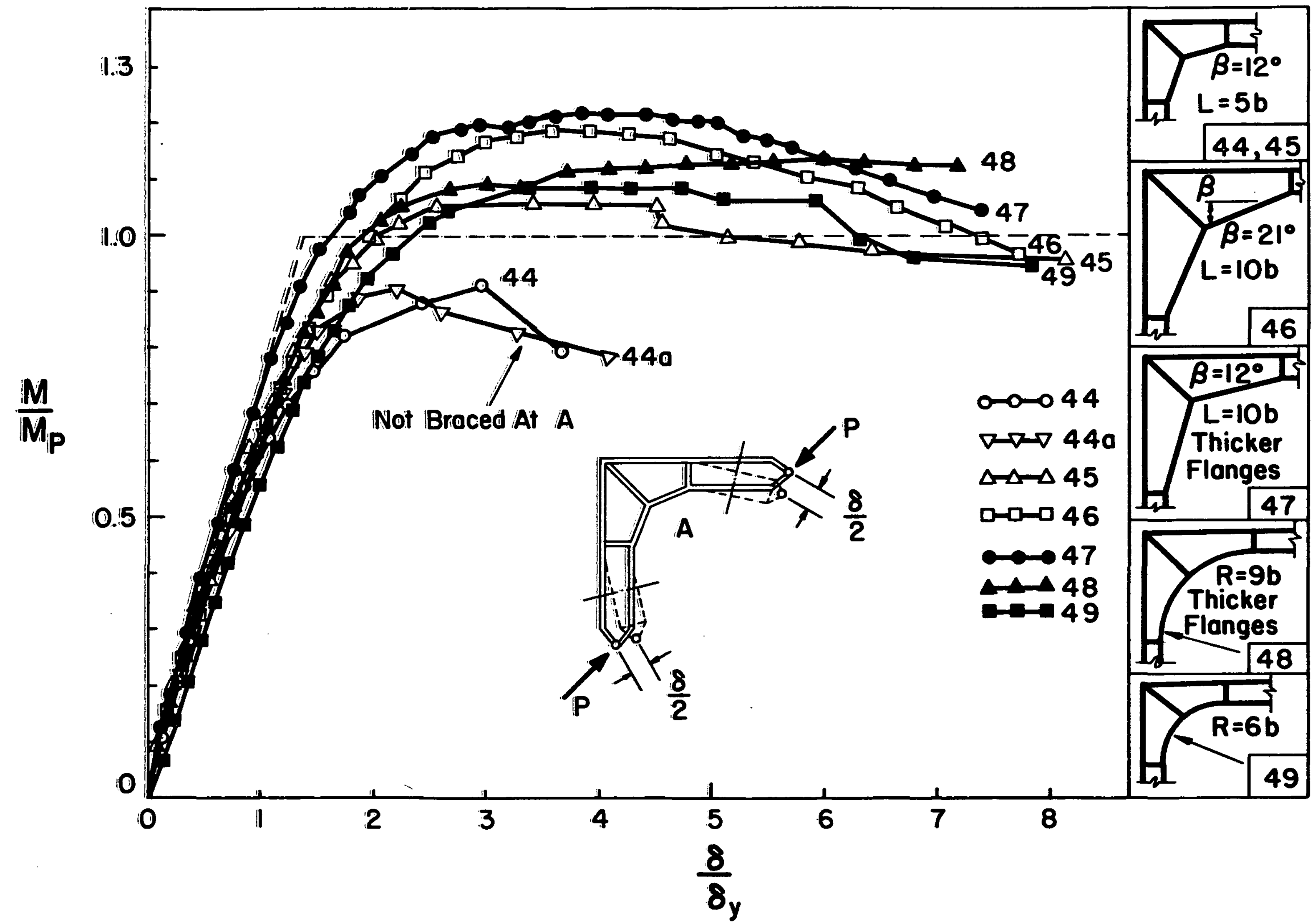


FIG. 7 Moment - Deflection Relationships

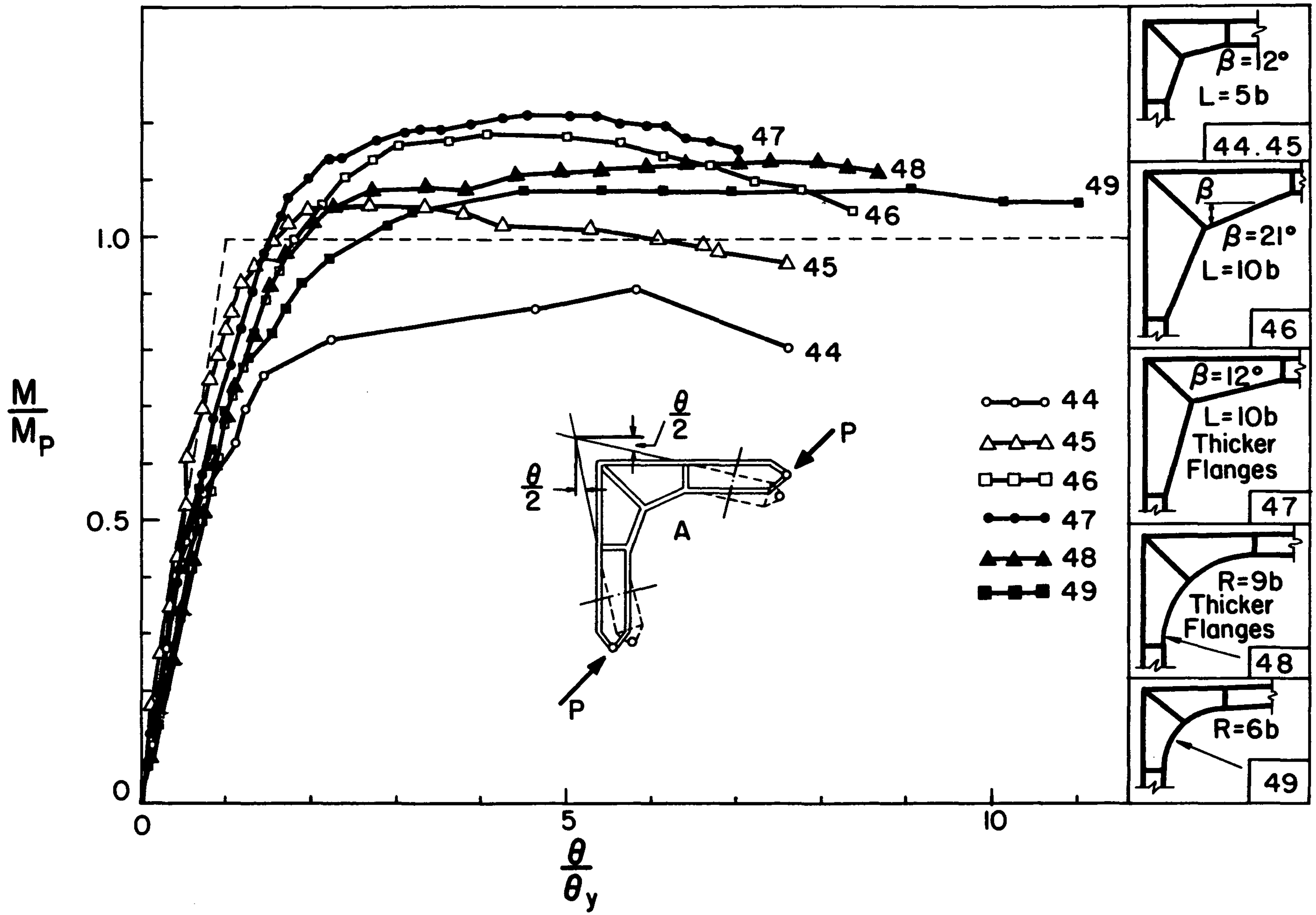


FIG. 8 Moment - Rotation Relationships

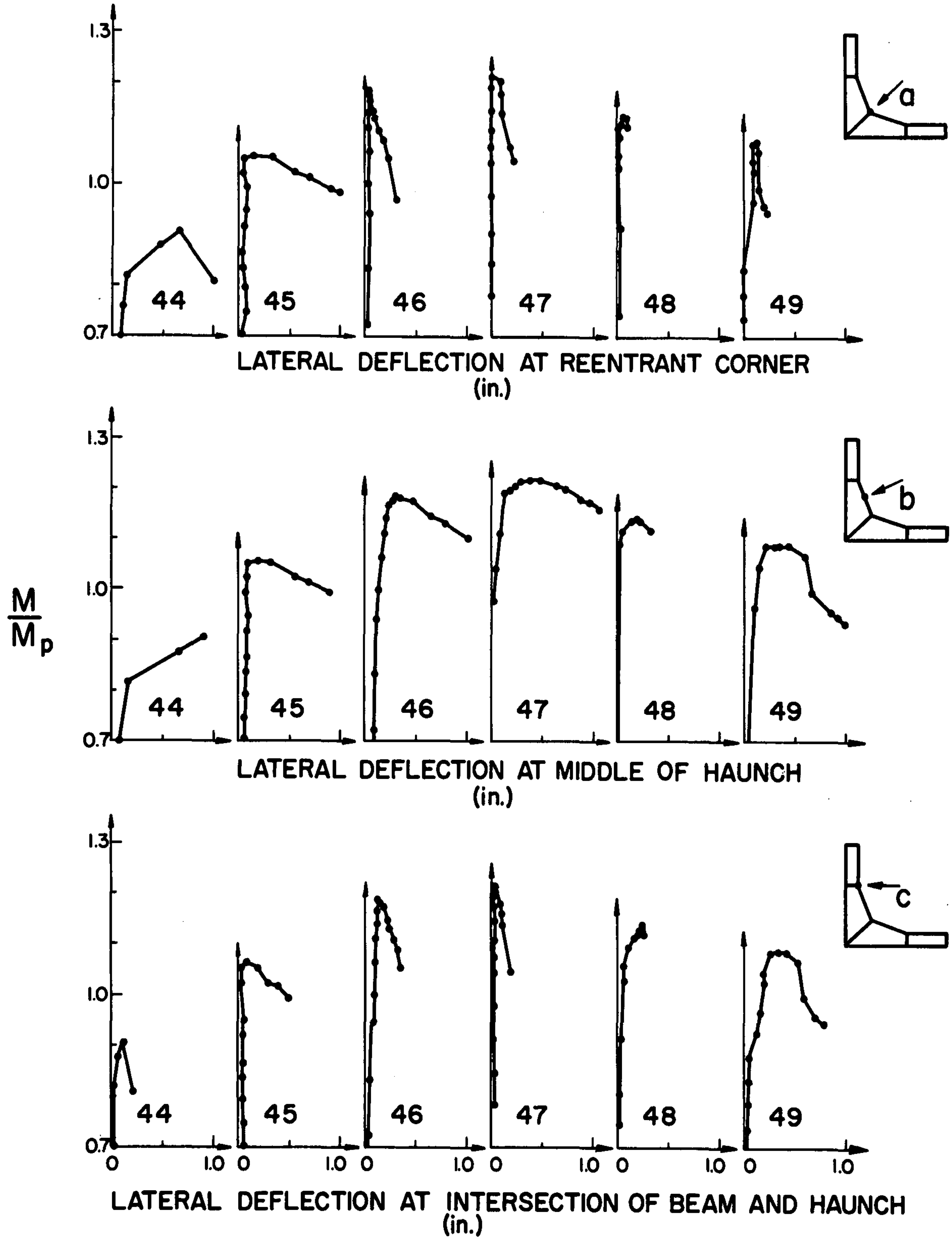


FIG. 9 Lateral Deflection of Compression Flange

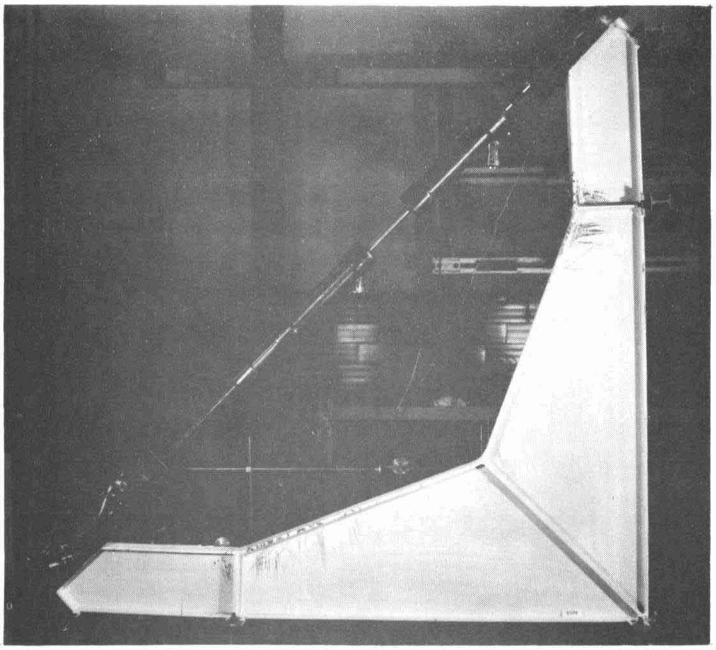


FIG. 10 Yielding in the haunch of tapered connection 46 after lateral buckling of the compression flange.

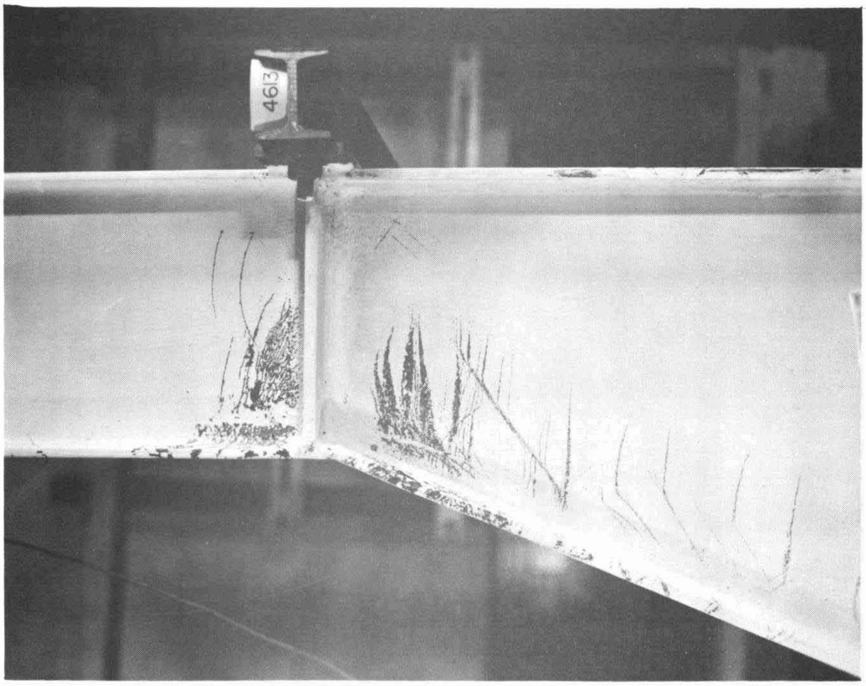


FIG. 11 The formation of a plastic hinge at the intersection of the haunch and rolled section in connection 46.

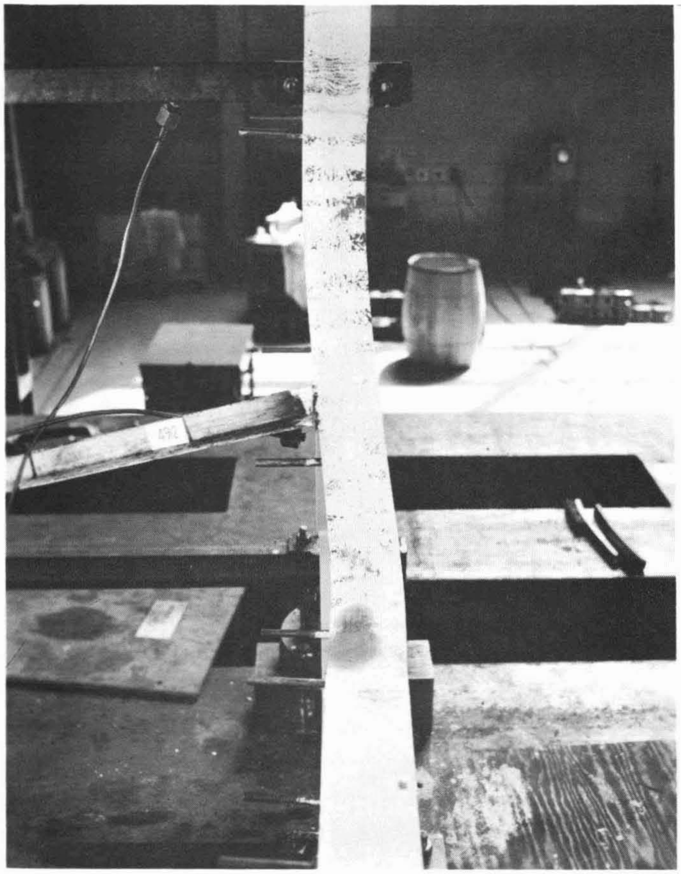


FIG. 12 In general lateral buckling of the compression flange formed a single wave between the reentrant corner and the intersection of the haunch and rolled section as shown for connection 49.

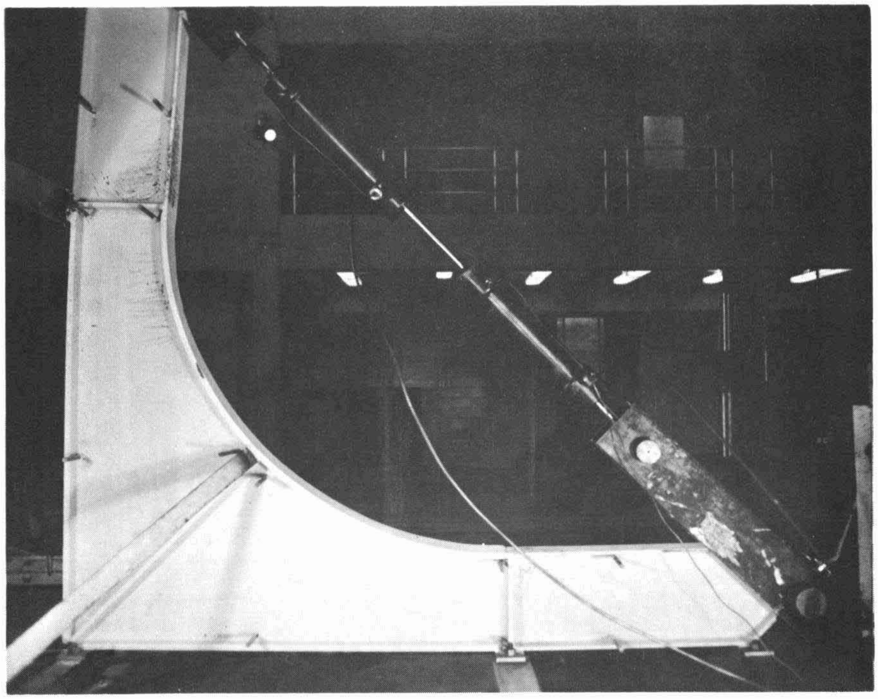


FIG. 13 In connection 48 a plastic hinge formed in the rolled section. Also, note the yielding in the web of the haunch approximately 12 deg from the point of tangency.

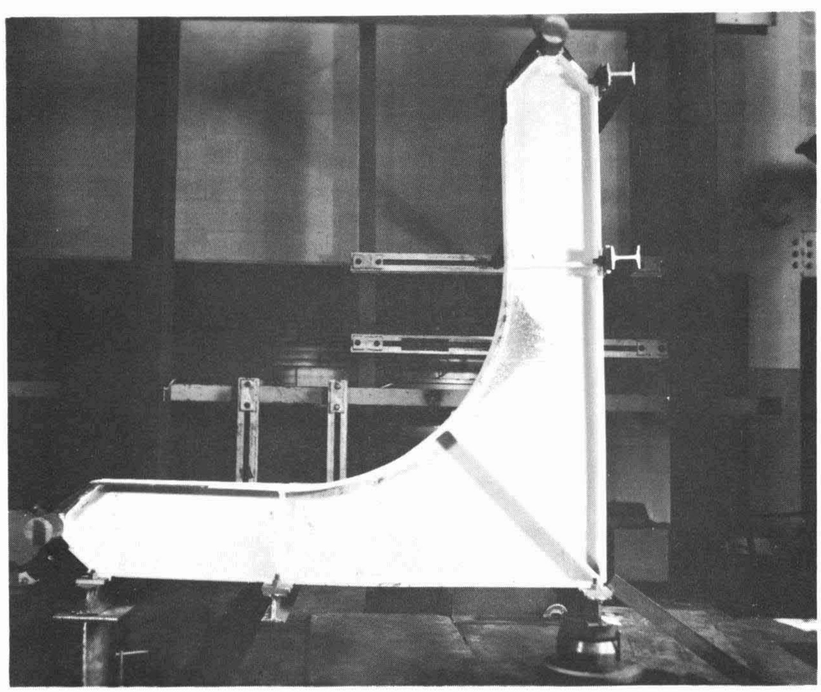


FIG. 14 In connection 49 (critical dimensions) a plastic hinge formed inside the haunch approximately 12 deg from the point of tangency.

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