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EXPERIMENTAL VERIFICATION OF A PROCEDURE FOR SMF CONTINUITY PLATE WELD DESIGN

by

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Draft Final Report Submitted to American Institute of Steel Construction

February 2017

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ABSTRACT

When required in the moment connection design for Special Moment Frames, AISC 341 provides a prescriptive requirement for the continuity plate thickness and specifies complete-joint-penetration (CJP) groove welds to connect the continuity plates to the column flanges. Recently, Tran et al. (2013) proposed a procedure that gives the designer freedom in sizing the continuity plate thickness and using alternate (i.e., economical) weld joints. In this research, full-scale testing of two one-sided moment connection specimens with a Reduced Beam Section (RBS) was conducted to verify the adequacy of this design procedure. In designing the test specimens, the original procedure was slightly modified so that the strength check of the continuity plate included not only normal and shear forces but also moment in the plane of the continuity plate. The specimen design followed AISC 341 and 358, except that the continuity plate thickness and welds were sized based on the modified procedure. The design resulted in fillet welds to connect the continuity plates to the columns. One specimen used a deep (W24) column, and the other one had a shallow (W14) column. To evaluate the effect of yielding in the continuity plates, these plates for the shallow column specimen were undersized. The specimens were also designed such that significant shear yielding in the panel zones would result in kinking of the column flanges to further “challenge” the fillet welds.

Test results showed that these two RBS connections performed as expected and met the 0.04 rad. story drift requirement of AISC 341. No sign of damage was observed in the fillet weld joints. The connection performance was still satisfactory when continuity plates were yielded. The shallow-column specimen performed better than the one with a deep column; the latter was prone to column twisting despite that additional lateral bracing was provided at the beam top flange to simulate the concrete slab restraining effect. Before the proposed design procedure can be implemented, recommendations were made to further the encouraging findings from this pilot test program.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

1.1 Statement of Problem

Steel Special Moment Frames (SMF) are one of the most popular seismic-force-resisting systems due to their architectural versatility. The beam-to-column moment connections play a critical role in SMF performance since they transfer bending moments. The resulting concentrated beam flange forces at column face are very high. These forces can cause column local flange bending (LFB), column web local yielding (WLY), and beam flange complete-joint-penetration (CJP) weld fracture due to stress concentration. To meet the requirements of these limit states, column transverse stiffeners (or continuity plates) at the beam flange levels are often required in accordance with AISC 341, *Seismic Provisions for Structural Steel Buildings* (AISC 2010a). Continuity plates, when required, add a significant amount of fabrication cost because a total of four continuity plates are required at each connection and CJP welds are required by AISC 341 to connect these plates to the column flanges.

The stringent welding requirements for continuity plates were established primarily to reflect how moment connection specimens tested in the past were fabricated. Another reason for having this conservative requirement is that no mechanics-based procedure that allows the designer to calculate the required forces in the continuity plate is available. Recently, Tran et al. (2013) proposed a flexibility-based procedure to fill this gap. This procedure opens the door for using non-CJP welds (i.e., fillet welds or partial-joint-penetration groove welds) to connect continuity plates to the column. In this report, an experimental verification of this design procedure (with a slight modification to it) is documented.

1.2 AISC Design Requirements for SMF Continuity Plates and Welds

Section E3.6f of AISC 341 stipulates that continuity plates are not required when the column flange thickness meets the following two requirements:

$$t_{cf} \geq 0.4\sqrt{1.8 b_{bf} t_{bf} \frac{R_{yb} F_{yb}}{R_{yc} F_{yc}}} \tag{1.1}$$

$$t_{cf} \geq \frac{b_{bf}}{6} \tag{1.2}$$

where

F_{yb} = specified minimum yield stress of the beam flange,

F_{yc} = specified minimum yield stress of the column flange,

R_{yb} = ratio of the expected yield stress to the specified minimum yield stress of the beam,

R_{yc} = ratio of the expected yield stress to the specified minimum yield stress of the column,

b_{bf} = beam flange width,

t_{bf} = beam flange thickness, and

t_{cf} = column flange thickness.

Equation (1.1) is obtained by equating the strength associated with the LFB limit state $\left(R_n = 6.25t_{cf}^2F_{yc}\right)$ to an approximate beam flange axial force of $P_{uf} = 1.8b_{bf}t_{bf}F_{yb}$ and solving for t_{cf}; F_{yb} and F_{yc} are replaced by the expected yield stresses $R_{yb}F_{yb}$ and $R_{yc}F_{yc}$, respectively, in the above derivation. Equation (1.2) is based on the deformation of the column flange and is related to low-cycle fatigue failure (Ricles et al. 2000). Where continuity plates are required, the thickness of the plates shall be determined as following:

(a) for one-sided connections, continuity plate thickness shall be at least one-half of the thickness of the beam flange, and

(b) for two-sided connections, the continuity plate thickness shall be at least equal to the thicker of the two beam flanges on either side of the column.

AISC 341 requires that continuity plates be welded to the column flanges using CJP groove welds. Continuity plates can be welded to the column web using either groove welds or fillet welds. The required strength of the sum of the welded joints of the continuity plates to the column web shall be the smallest of the following:

(a) the sum of the design strengths in tension of the contact areas of the continuity plates to the column flanges that have attached beam flanges,

(b) the design strength in shear of the contact area of the plate with the column web,

(c) the design strength in shear of the column panel zone, and

(d) the sum of the expected yield strengths of the beam flanges transmitting force to the continuity plates.

Note in the 2016 edition of AISC 341 that items (c) and (d) have been replaced by the design shear strength of the column web when the continuity plate is welded to the column web, or the design shear strength of the doubler plate when the continuity plate is welded to an extended doubler plate.

In this report, welds between the continuity plate and the column flanges are defined as the *flange welds*, and the weld between the continuity plate and the column web is defined as the *web weld*.

1.3 Flexibility-Based Formulation by Tran et al. (2013)

The procedure originally proposed by Tran et al. (2013) and subsequently modified slightly in this study is summarized below. Representing the beam flange force as

$$P_{uf} = C_{pf} R_{yb} b_{bf} t_{bf} F_{yb} \tag{1.3}$$

AISC 341 assumes the beam flange force adjustment factor, C_{pf}, is equal to 1.8 to establish the minimum column flange thickness requirement in Eq. (1.1) when continuity plates are not required. While this assumed value is reasonable for the pre-Northridge type welded flange-bolted web moment connections, where the bolted web is ineffective in contributing to the moment resistance, Tran et al. (2013) showed that this assumption, and hence Eq. (1.1), is conservative for some post-Northridge moment connections like the Reduced Beam Section (RBS) or Welded Unreinforced Flange-Welded Web (WUF-W) moment connections; the beam web of these connections is directly welded to the column flange with a CJP weld. Based on finite element analysis, the following C_{pf} values were recommended by Tran et al. (2013) for use in Eqs. (1.1) and (1.3):

(a) for RBS connection: $$C_{pf} = 1.25 \tag{1.4}$$

(b) for WUF-W connection: $$C_{pf} = 1.75 \tag{1.5}$$

With a significantly lower C_{pf} value for the RBS connection, continuity plates that are required per AISC 341 may be unnecessary.

When continuity plates are required, the beam flange axial force, P_{uf}, is apportioned to each continuity plate based on the following equation (Tran. et al. 2013):

$$P_{cp} = \frac{P_{uf}}{2}\left(\frac{b_{bf} - t_{pz} - 2t_{cf}}{b_{bf}}\right)\left(\frac{B_{cf}}{B_{cf} + B_{cp}}\right) \tag{1.6}$$

where

b_{bf} = beam flange width,

t_{pz} = panel zone thickness,

t_{cf} = column flange thickness,

B_{cf} = column flange out-of-plane flexibility coefficient

$$= 0.26\frac{b^2}{Et_{cf}^3} + \frac{0.4\left[1 + 0.09\ln\left(\frac{b}{t_{cf}}\right)\right]}{Gt_{cf}}$$

E = Modulus of elasticity of steel = $29{,}000$ ksi,

G = Shear modulus of elasticity of steel = $11{,}200$ ksi,

b = $b_{clip} + b_n$ (total width of continuity plate),

b_{clip} = corner clip size,

b_n = net width of continuity plate,

B_{cp} = continuity plate in-plane flexibility coefficient

$$= \frac{0.42 - C}{Gt} + \frac{b^3}{Ed^3t}$$

C = 0 for interior connections, and for exterior connections:

$$= 0.6\left(\frac{b}{d}\right) - 0.14 \geq 0$$

See Tran et al. (2013) for the derivation of Eq. (1.6). Following the procedure, one can compute the required forces along three edges of the continuity plate (Figure 1.1). To ensure that the continuity plates have a sufficient in-plane stiffness, the designer then checks the local flange bending and web local yielding limit states (AISC 2010c) of the column for the portion of the beam flange force that will be transmitted from the beam flange to the column web directly:

$$P_{uf} - 2P_{cf} \leq \phi R_n \tag{1.7}$$

Figure 1.1 shows that the edges of the continuity plate next to the loaded column flanges are subjected to both normal and shear forces; the shear force is needed to satisfy moment equilibrium. The Von-Mises yield criterion is then used by Tran et al. to check the strength of the continuity plates:

$$\left(\frac{P_{cp}}{F_{ycp}A_n}\right)^2 + \left(\frac{V_{cp}}{\frac{F_{ycp}}{\sqrt{3}}A_n}\right)^2 \leq 1.0 \tag{1.8}$$

where from moment equilibrium the shear force is

$$V_{cp} = \left(\frac{0.6b}{d}\right)\sum P_{cp} \tag{1.9}$$

F_{ycp} = yield stress of continuity plate,

d = depth of continuity plate,

t_{cp} = thickness of continuity plate, and

A_n $= b_n t_{cp}$.

When Eq. (1.8) is satisfied, either fillet welds or partial-joint-penetration groove welds can be used to connect the continuity plates to the column flanges. If not, Tran et al. suggested that complete-joint-penetration (CJP) groove welds still be used because continuity plates are expected to yield. To avoid the use of CJP welds, however, an alternative is to increase the thickness of the continuity plates such that Eq. (1.8) is satisfied.

In designing the specimens for this test program, some modifications were made to Eq. (1.8). By ignoring the corner clips in the continuity plates, Tran et al. (2013) suggested that the normal force, P_{cp}, be located at a distance 0.6*b* from the column web (Figure 1.1), and the moment produced by this force with an eccentricity with respect to the center of the net width of the continuity plate was ignored in checking the strength in Eq. (1.8). Reviewing the work of Neal (1961) and Astaneh-Asl (1998), Dowswell (2015) suggested an *M-V-P* yield criterion, which can be re-written for checking the continuity plate strength as the following:

$$\left(\frac{P_{cp}e}{Z_{xn}F_{ycp}}\right)+\left(\frac{P_{cp}}{F_{ycp}A_n}\right)^2+\left(\frac{V_{cp}}{\frac{F_{ycp}}{\sqrt{3}}A_n}\right)^4 \leq 1.0 \tag{1.10}$$

where Z_{xn} is the plastic section modulus of the net section:

$$Z_{xn}=\frac{t_{cp}b_n^2}{4} \tag{1.11}$$

Refer to Figure 1.2(a) for a continuity plate in a two-sided (i.e., interior) moment connection, where corners are clipped to clear the k-area of the column section. Freebody 3 in Figure 1.2(c) shows that the normal force P_{cp} acts at a distance $0.6b$ from the column web. Moment equilibrium requires that

$$V_{cp}=\left(\frac{0.6b}{d-2b_{clip}}\right)\sum P_{cp} \tag{1.12}$$

Next consider Freebody 1 or 2. The corner clip causes the normal force at the edge of the net width to shift by an amount e^* to satisfy moment equilibrium:

$$e^*=\frac{b_{clip}V_{cp}}{P_{cp}} \tag{1.13}$$

Therefore, the moment produced by the eccentrically loaded P_{cp} at the center of the net width equals eP_{cp}, where

$$e=0.6b+e^*-(b_{clip}+0.5b_n) \tag{1.14}$$

The same approach can be applied to the continuity plate in a one-sided (i.e., exterior) moment connection. But the shear force calculation needs to be modified. As shown in Figure 1.3, it is assumed that the normal force at the non-loaded column flange side of the continuity plate equals zero. Therefore, the shear force is

$$V_{cp}=\left(\frac{0.6b}{d-b_{clip}}\right)P_{cp} \tag{1.15}$$

Equation (1.10), not Eq. (1.8), was used to design the continuity plates in this test program.

The procedure to design the fillet welds follows.

(a) Design the flange weld for the required resultant force, R_{cp}:

$$\phi R_n \geq R_{cp} \tag{1.16}$$

where

$$R_{cp} = \sqrt{P_{cp}^2 + V_{cp}^2} \tag{1.17}$$

The design strength for 2-sided fillet welds is:

$$\phi R_n = 2(\phi)(0.6)t_e b_n F_{EXX}(1.0 + 0.5\sin^{1.5}\theta) \tag{1.18}$$

where

ϕ $= 0.75$,

t_e = effective throat of the fillet weld,

F_{EXX} = minimum specified ultimate strength of the weld,

θ = angle of the resultant force, R_{cp}, measured from the weld longitudinal axis:

$$= \tan^{-1}\frac{P_{cp}}{V_{cp}}$$

(b) Check the flange weld at the location of maximum tensile stress, q_{max}:

$$q_{max} = \frac{1.6P_{cp}}{b_n} \tag{1.19}$$

When 2-sided fillet welds are used, the value of q_{max} cannot exceed the unit-length design strength, which can be computed by using Eq. (1.18) with $b_n = 1.0$.

(c) Check maximum shear stress in the flange weld, τ_{max}:

$$\tau_{max} = \frac{2V_{cp}}{b_n} \tag{1.20}$$

(d) Design the web weld for a required shear force equal to the summation of force allocated to the continuity plate, $\sum P_{cp}$, as shown in Figure 1.1(a). For exterior moment connections [Figure 1.1(b)], the required shear force equals P_{cp}.

$$\phi R_n \geq \sum P_{cp} \tag{1.21}$$

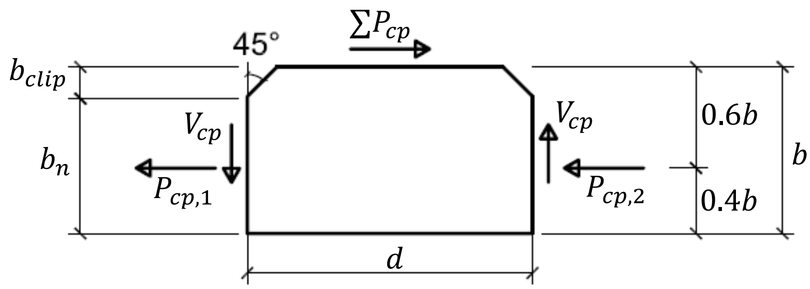
For 2-sided fillet welds, the design strength is computed as:

$$\phi R_n = 2(\phi)(0.6)t_e l_w F_{EXX} \tag{1.22}$$

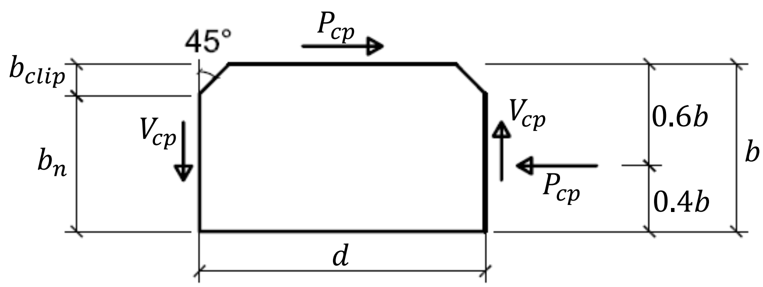
where

l_w = length of the web weld.

Tran et al. proposed that a ϕ value of 0.9 be used for designing the fillet welds. In this test program, however, it was decided to use the ϕ value (= 0.75) per AISC 360. Also, it was judged that using Eqs. (1.19) and (1.20) to check the local stresses are too stringent and conservative. Test results to be presented later showed that no damage was observed in the fillet welds even though these two equations were not used in design.



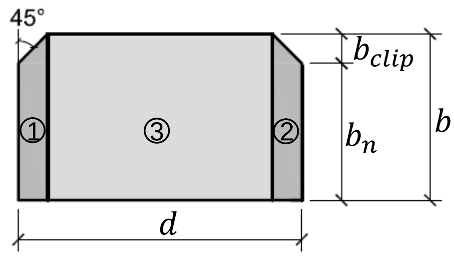
(a) Interior Connection



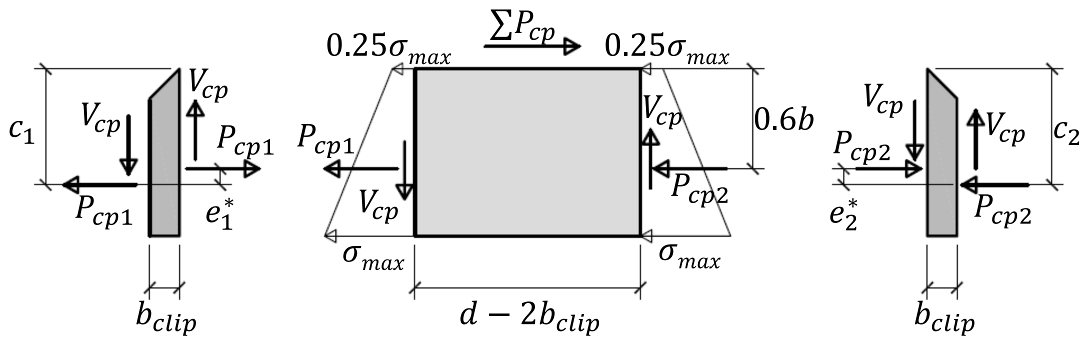
(b) Exterior Connection

Figure 1.1 Freebody Diagram of a Continuity Plate

(Adopted from Tran et al. 2013)

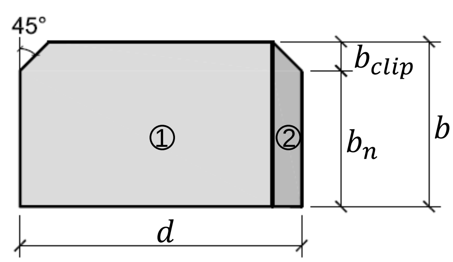


(a) Geometry of Continuiy Plate

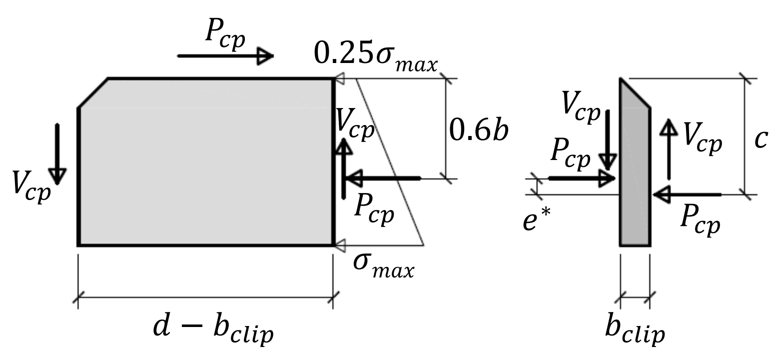


(b) Freebody 1 (c) Freebody 3 (d) Freebody 2

Figure 1.2 Continuity Plate Freebody Diagrams (Interior Connection)



(a) Geometry of Continuiy Plate



(b) Freebody 1 (c) Freebody 2

Figure 1.3 Continuity Plate Freebody Diagrams (Exterior Connection)

2 TEST PROGRAM

2.1 Design of Test Specimens

2.1.1 Specimens Sizes

A W30×116 beam connected to a W24×176 “deep” column was selected for Specimen C1, whereas a W36×150 beam connected to a W14×257 “shallow” column was chosen for Specimen C2. Column height, h, was 16 ft and the beam span, L, was 15 ft. Table 2.1 shows the cross-sectional dimensions of the beams and the columns.

2.1.2 Moment Connection Design

The reduced beam section (RBS) connection was used for both specimens. The RBS design was carried out per AISC 358 (AISC 2010b); strong-column/weak-beam condition and panel zone strength satisfied the AISC 341 requirements. But continuity plates and welds were designed per the proposed flexibility-based procedure. Figure 2.1 and Figure 2.2 show the connection detail of both specimens.

A summary of key design parameters of each specimen is listed in Table 2.2. While satisfying the panel zone strength requirement in AISC 341, note the demand-capacity ratios (DCR) were high (0.9 and 0.95 for Specimens C1 and C2, respectively) so column flange kinking due to panel zone shear yielding would “challenge” the fillet welds connecting the continuity plates to the column flanges. For Specimen C2 with a shallow (W14) column, note the required shear force, V_{cp} (= 62.8 kips), acting on the continuity plate and flange weld is significant.

A comparison of the continuity plate and weld design based on the flexibility-based procedure and AISC 341 is summarized in Table 2.3. The proposed design called for a continuity plate thickness of 7/8 in. for Specimen C2. AISC 341 implicitly assumes that continuity plates should remain essentially elastic. Since the effect of yielded continuity plates has never been reported in the literature, it was decided to use 5/8 in. thick continuity plates instead. A comparison of the welds for the continuity plates based on both procedures is also provided in the table. Although the proposed procedure called for thicker continuity plates, fillet welds, not CJP welds, were used for the flange welds.

Table 2.4 summarizes the components of Eq. (1.10) for the continuity plate design of both specimens. The continuity plates of Specimen C2 were significantly under-sized; the demand-capacity ratio was 1.31. The shear force component was minimal for the deep-column Specimen C1, mainly because the depth of the continuity plates was larger [Eq. (1.15)]. For the shallow-column Specimen C2, both shear and moment components were significant. Also, note that the moment component played a more significant role than the shear component in checking the plate strength for both specimens. Therefore, it is not appropriate to ignore the moment component and use Eq. (1.8) to check the strength of continuity plates.

2.2 Test Setup

The overall geometry of each test setup is shown in Figure 2.3. The inflection points were assumed to be at the mid-height of each story. Inflection points were simulated by mounting the column ends to two W14×257 hinge sections on its back side and a W14×342 on its bottom positioned to experience weak-axis bending (see Figure 2.4 for the hinges used in the testing of Specimen C2 which were identical for both Specimens). A corbel was bolted to the free end of the beam and attached to two 500-kip hydraulic actuators. Lateral restraint was provided on both sides of the specimens at two locations, one at corbel location and one at 10 ft-3¼ in. from the centerline of the column. For Specimen C1, which utilized a deep column, two extra lateral restraints were provided. One was a bracing provided for the beam top flange near RBS location to simulate the slab restraining effect and the second was at the top end of the column. The second lateral restraint was a 2L3×2×1/2 strut to provide lateral support against twisting at the top end of the column; a deep column without the presence of a concrete slab was shown to prone to twisting (Chi and Uang 2002). The lateral restraint assembly is illustrated in Figure 2.5 for both specimens. Figure 2.6 shows the beam bracing and column top bracing for Specimen C1.

2.3 Specimen Construction and Inspection

All the continuity plate welds were done in a commercial fabricator’s shop. The beams and the columns were delivered to UCSD. To simulate the field conditions, all specimens were erected in the upright position and then welding of the beam flanges and the web to the column flange were conducted in the test laboratory, see Appendix C for the

Welding Procedure Specifications. Ultrasonic (UT) testing of all CJP welds was conducted by a certified inspector. See Appendix D for the inspection reports.

2.4 Material Properties

ASTM A992 steel was specified for the beams and columns. The continuity plates were fabricated from ASTM A572 Gr. 50 steel. Table 2.5 summarizes the steel mechanical characteristics obtained from both tensile coupon tests conducted at UCSD (Appendix A) and the Certified Mill Test Reports (Appendix B). Table 2.6 shows the chemical composition of the materials obtained from the Certified Mill Test Reports.

2.5 Instrumentation

A combination of displacement transducers, strain gage rosettes, and uniaxial strain gages were used to measure the global and local responses. Figure 2.7 shows the location of displacement transducers. Displacement transducer L1 was used to control the stroke of the hydraulic actuators and at the same time used to monitor the beam end displacement. L2 was used to detect any slippage between the corbel and the beam end plate. L3 and L4 were used to monitor the panel zone shear deformation. L5 and L6 were used to monitor the column deformation. L7, L8, and L9 were used to monitor displacements at the column end supports, which were anticipated to be negligible.

Rosettes and uni-axial strain gages were used to measure the strains in the connection region (see Figure 2.8 and Figure 2.9).

2.6 Data Reduction

The total Inelastic Rotation (θ_p) of the specimen was calculated by dividing the inelastic component of the beam tip displacement (δ_p), measured at the actuator line of action, by the beam span length from the column centerline to the actuator line of action:

$$\theta_p = \frac{\delta_p}{L} = \frac{1}{L}(\delta_{total} - \delta_e) = \frac{1}{L}\left(\delta_{total} - \frac{P}{K}\right) \tag{2.1}$$

where δ_{total} is the total beam tip deflection measured by displacement transducer L1, P is the applied load, and K is the elastic stiffness determined from the initial low-amplitude test results. The panel zone component was determined from displacement transducers L3 and L4. Together with the measurement of transducers L5 and L6, the component of the total beam tip deflection due to the column deformation can also be established (Uang and Bondad, 1996).

2.7 AISC Acceptance Criteria

Per Section E3.6b of AISC 341, beam-to-column connections used in Special Moment Frames shall satisfy the following requirements:

(1) The connection shall be capable of accommodating a story drift angle of at least 0.04 rad.

(2) The measured flexural resistance of the connection, determined at the column face, shall equal at least $0.8M_p$ of the connected beam at a story drift angle of 0.04 rad, where M_p is the nominal plastic moment of the beam.

2.8 Loading Sequence

Testing was conducted in a displacement control mode. The loading sequence used for all specimens was the standard AISC loading sequence specified in Section K2 of AISC 341. This loading sequence specifies a series of load cycles at different Story Drift Angles (hereinafter referred to as “drift”), with the distance from the column centerline to actuator line of action being used in calculating the drift angle. The loading history begins with six cycles each at 0.00375, 0.005, and 0.0075 rad drifts. These are followed by four cycles at 0.01 rad drifts, two cycles at 0.015 rad drifts, two cycles at 0.02, 0.03, 0.04 rad drifts, etc. up until failure. It should be noted that in testing of Specimen C2, after successful completion of 0.05 rad drift cycles, it was decided to skip the 0.06 rad drift cycles before one cycle at 0.07 rad drift was applied.

Table 2.1 Member Sizes and Cross Sectional Dimensions

Spec. No.	Member	*d* (in)	t_w (in)	h/t_w	b_f (in)	t_f (in)	$b_f/2t_f$
C1	Beam (W30×116)	30.0	0.565	47.8	10.5	0.85	6.17
	Column (W24×176)	25.2	0.75	28.7	12.9	1.34	4.81
C2	Beam (W36×150)	35.9	0.625	51.9	12.0	0.94	6.37
	Column (W14×257)	16.4	1.18	9.71	16.0	1.89	4.23

Table 2.2 RBS Connection Key Design Parameters

(a) Specimen C1: W30×116 Beam Connected to a W24×176 Column

RBS Dimensions: $a = 7$ in., $b = 25$ in., $c = 2$ in.
Plastic Section Modulus of RBS Section, $Z_{RBS} = 278.9$ in^3; $\frac{Z_{RBS}}{Z_{beam}} = 0.74$
Probable maximum moment, $M_{pr} = 1470$ kip-ft
Shear force at the center of the RBS, $V_{RBS} = 119.3$ kips
Probable maximum moment at the face of the column, $M_f = 1664$ kip-ft
Plastic moment of the beam based on the expected yield stress, $M_{pe} = 1732.5$ kip-ft
$\phi_d M_{pe} = 1732.5 \geq M_f = 1664$ kip-ft (OK)
Strong-Column/Weak-Beam Check: $\frac{\sum M_{pc}^*}{\sum M_{pb}^*} = 2.38 \geq 1.0$ (OK)
Panel Zone Demand-Capacity Ratio (DCR) = $\frac{573.11}{636.5} = 0.9 \leq 1.0$ (OK)
No Doubler Plates Required
Continuity Plate Flange Weld Forces (Normal, Shear, and Resultant): $P_{cp} = 157.6$ kips, $V_{cp} = 26.7$ kips, $R_{cp} = \sqrt{P_{cp}^2 + V_{cp}^2} = 159.8$ kips
Continuity Plate Web Weld Force (Shear): $\sum P_{cp} = 157.6$ kips
Continuity plate thickness, $t_{cp} = 3/4$ in.
Continuity Plate-to-Column Flange Weld: $9/16$ in. (Fillet Welds)
Continuity Plate-to-Column Web Weld: $5/16$ in. (Fillet Welds)

Table 2.2 RBS Connection Key Design Parameters (continued)

(b) Specimen C2: W36×150 Beam Connected to a W14×257 Column

RBS Dimensions: $a = 7$ in., $b = 25$ in., $c = 2.5$ in.
Plastic Section Modulus of RBS Section, $Z_{RBS} = 416.7$ in^3; $\frac{Z_{RBS}}{Z_{beam}} = 0.72$
Probable maximum moment, $M_{pr} = 2196.3$ kip-ft
Shear force at the center of the RBS, $V_{RBS} = 173.1$ kips
Probable maximum moment at the face of the column, $M_f = 2477$ kip-ft
Plastic moment of the beam based on the expected yield stress, $M_{pe} = 2662.9$ kip-ft
$\phi_d M_{pe} = 2662.9 \geq M_f = 2477$ kip-ft (OK)
Strong-Column/Weak-Beam Ratio: $\frac{\sum M_{pc}^*}{\sum M_{pb}^*} = 1.56 \geq 1.0$ (OK)
Panel Zone Demand-Capacity Ratio (DCR) = $\frac{688.2}{723.8} = 0.95 \leq 1.0$ (OK)
No Doubler Plates Required
Continuity Plate Flange Weld Forces (Normal, Shear, and Resultant): $P_{cp} = 157$ kips, $V_{cp} = 62.8$ kips, $R_{cp} = \sqrt{P_{cp}^2 + V_{cp}^2} = 169.1$ kips
Continuity Plate Web Weld Force (Shear): $\sum P_{cp} = 157$ kips
Continuity plate thickness: t_{cp}= 5/8 in.
Continuity Plate-to-Column Flange Weld: 1/2 in. (Fillet Welds)
Continuity Plate-to-Column Web Weld: 9/16 in. (Fillet Welds)

Table 2.3 Comparison of Continuity Plate and Weld Design

	Specimen C1		Specimen C2	
	Proposed Procedure	AISC 341	Proposed Procedure	AISC 341
Required Continuity Plate Forces (kips)	$P_{cp} = 157.6$ $V_{cp} = 26.7$	N.A.	$P_{cp} = 157.0$ $V_{cp} = 62.8$	N.A.
Continuity Plate Thickness	3/4 in.	$1/2$ in. (= $t_{bf}/2$)	$5/8$ in.	$1/2$ in. (= $t_{bf}/2$)
Continuity Plate-to-Column Flange Weld	Fillet Weld ($9/16$ in.)	CJP Weld	Fillet Weld ($1/2$ in.)	CJP Weld
Continuity Plate-to-Column Web Weld	Fillet Weld ($5/16$ in.)	Fillet Weld ($3/16$ in.)	Fillet Weld ($9/16$ in.)	Fillet Weld ($3/8$ in.)

Table 2.4 Strength Check of Continuity Plates

Specimen No.	Equation (1.10)			
	Moment Component, $\left(\frac{P_{cp}e}{Z_{xn}F_{ycp}}\right)$	Normal Force Component, $\left(\frac{P_{cp}}{F_{ycp}A_n}\right)^2$	Shear Force Component, $\left(\frac{V_{cp}}{\frac{F_{ycp}}{\sqrt{3}}A_n}\right)^4$	Σ
C1	0.14	0.78	0.01	0.93
C2	0.36	0.80	0.15	1.31

Table 2.5 Base Metal Mechanical Properties

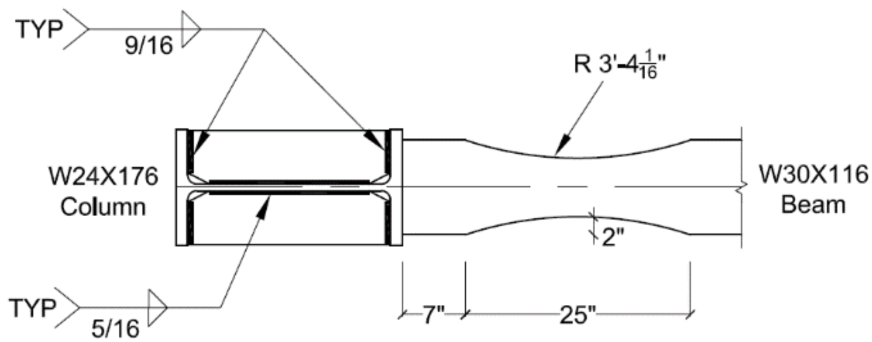
Spec. No.	Component	Steel Type/ Heat No.	Yield Stress (ksi)[a]	Tensile Strength (ksi)	Elong. (%)[b]
C1	Beam Flange (W30×116)	A992 443484	56.9 (56.5)[b]	75.6 (72.0)[b]	34.5 (28.0)[b]
	Beam Web (W30×116)		58.5	73.2	39.5
	Column Flange (W24×176)	A992 442208	57.2 (57.5)[b]	70.6 (72.5)[b]	39.1 (27.0)[b]
	Column Web (W24×176)		58.5	72.2	37.3
	Continuity Plate (3/4 in.)	A572 Gr. 50 SB15106	68.1 (58.0)[b]	85.6 (81.0)[b]	36.9 (25.0)[b]
C2	Beam Flange (W36×150)	A992 60114091/04	53.5 (57.0)[b]	74.9 (75.1)[b]	38.3 (26.4)[b]
	Beam Web (W36×150)		57.9	74.7	38.1
	Column Flange (W14×257)	A992 317275	52.3 (57.0)[b]	74.3 (75.0)[b]	37.7 (26.0)[b]
	Column Web (W14×257)		54.8	74.8	38.6
	Continuity Plate (5/8 in.)	A572 Gr. 50 813K75180	54.1 (57.6)[b]	79.8 (82.6)[b]	35.1 (22.5)[b]

[a] Yield strength determined by the 0.2% strain offset method.
[b] Values in parentheses from Certified Mill Test Reports, others from testing at UCSD.

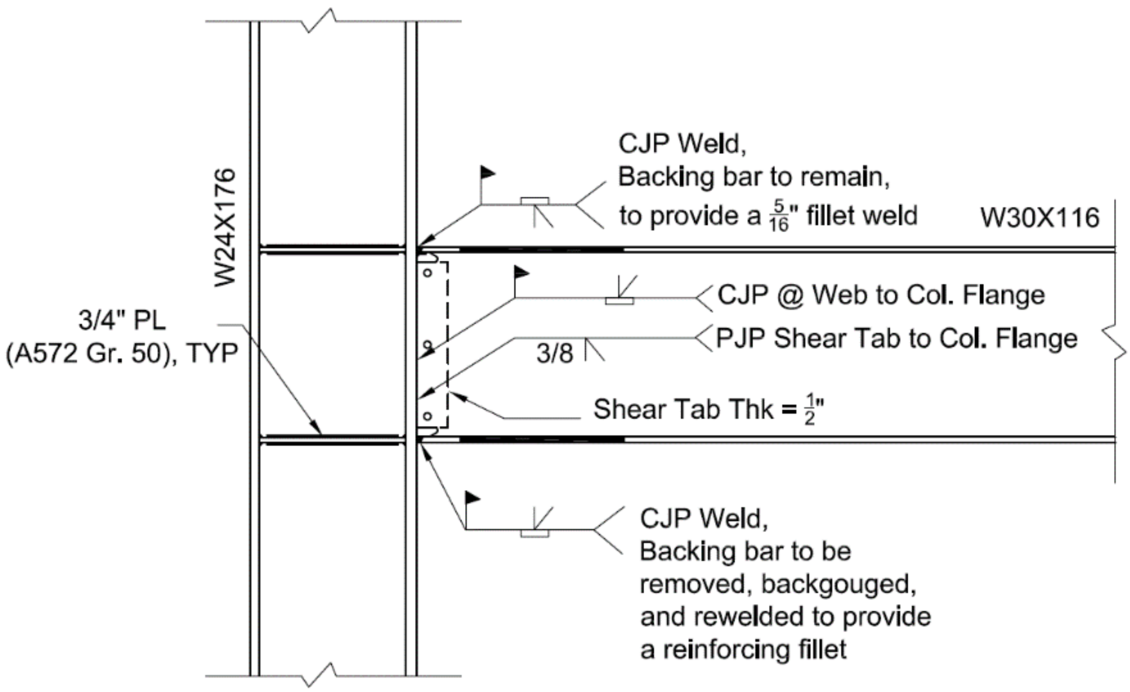
Table 2.6 Chemical Compositions for Components from Mill Certificates

Spec. No.	Member	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	CE
C1	Beam (W30×116)	0.080	1.130	0.016	0.027	0.230	0.250	0.100	0.140	0.040	0.000	0.330
	Column (W24×176)	0.080	1.360	0.018	0.018	0.210	0.220	0.100	0.140	0.030	0.060	0.370
	Continuity Plate (3/4 in.)	0.147	1.383	0.014	0.002	0.346	0.010	0.008	0.023	0.002	0.003	0.384
C2	Beam (W36×150)	0.100	1.170	0.011	0.028	0.230	0.380	0.170	0.150	0.044	0.002	0.370
	Column (W14×257)	0.070	1.360	0.018	0.023	0.320	0320	0.090	0.110	0.020	0.050	0.370
	Continuity Plate (5/8 in.)	0.180	1.220	0.013	0.004	0.279	0.024	0.010	0.040	0.005	0.056	0.406

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

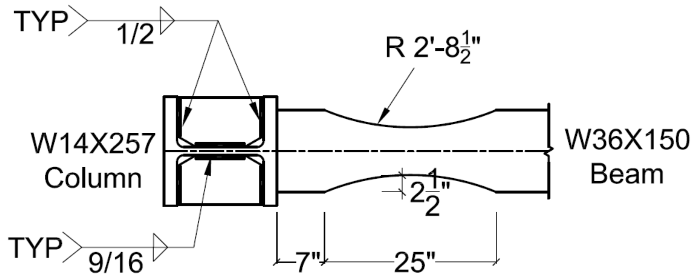


(a) Plan View

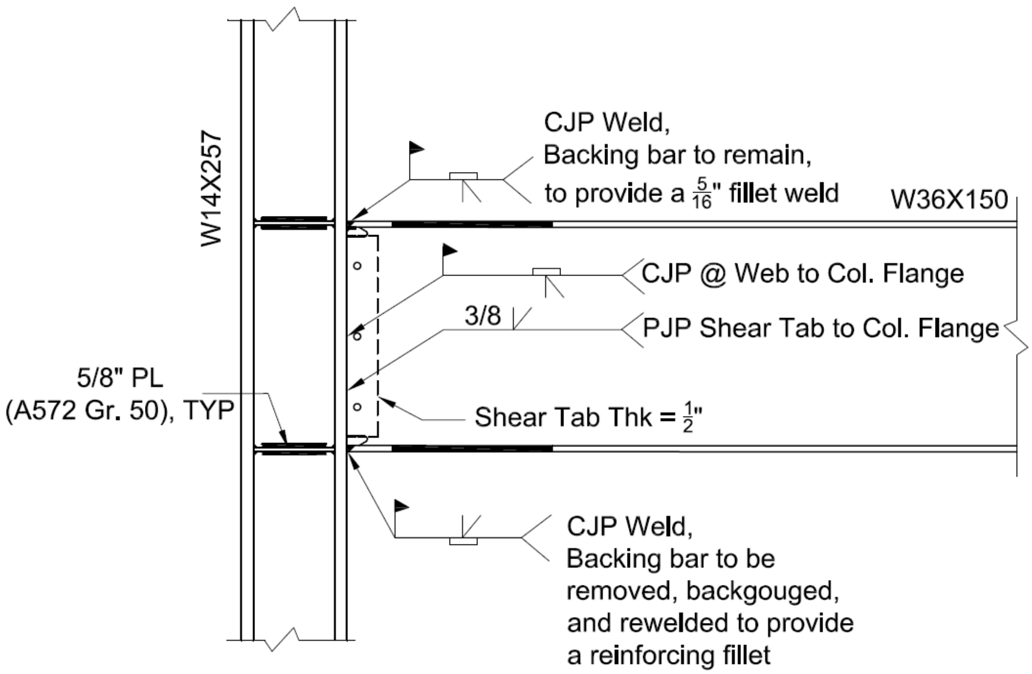


(b) Elevation View

Figure 2.1 Specimen C1 Connection Detail

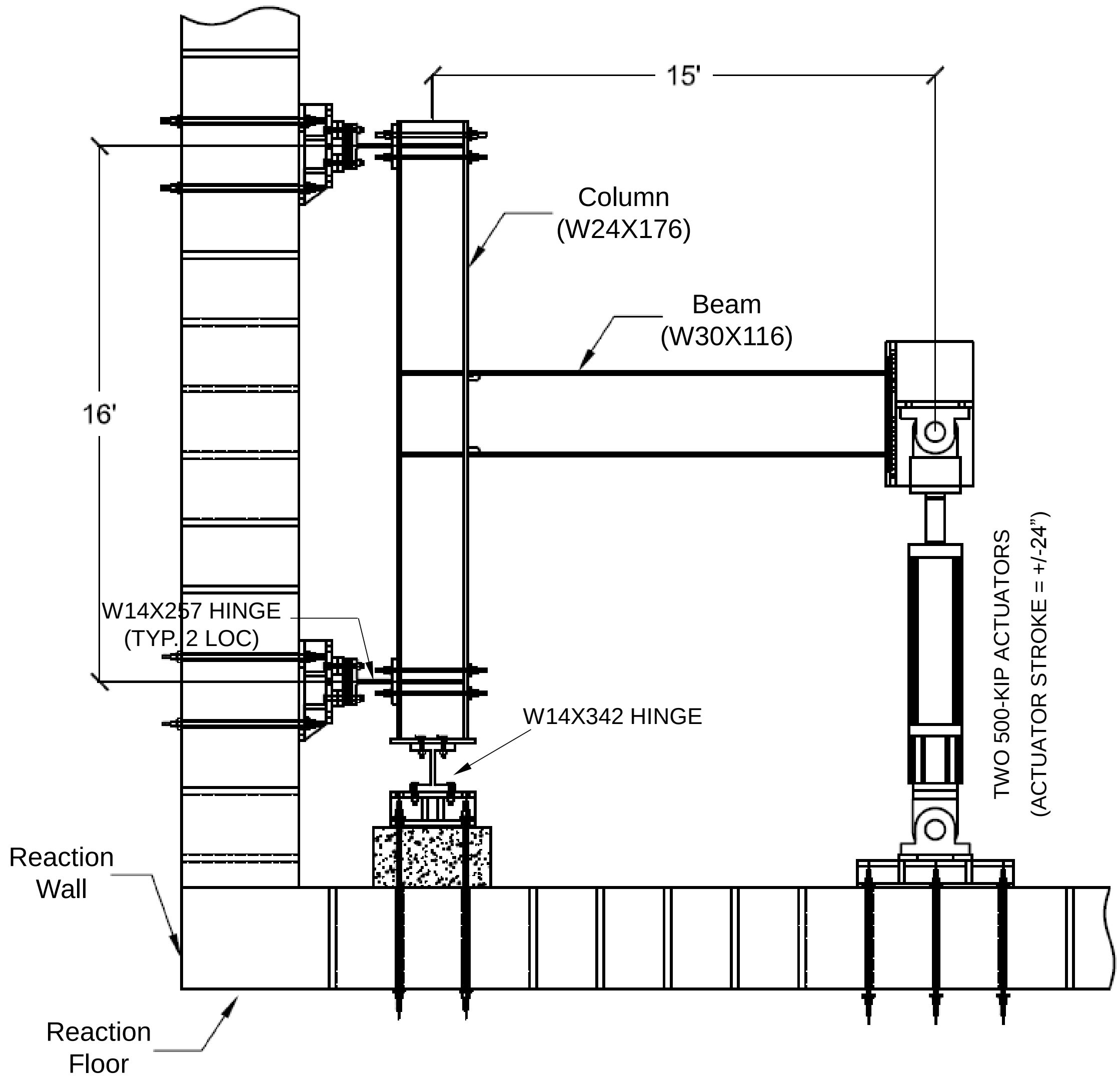


(a) Plan View



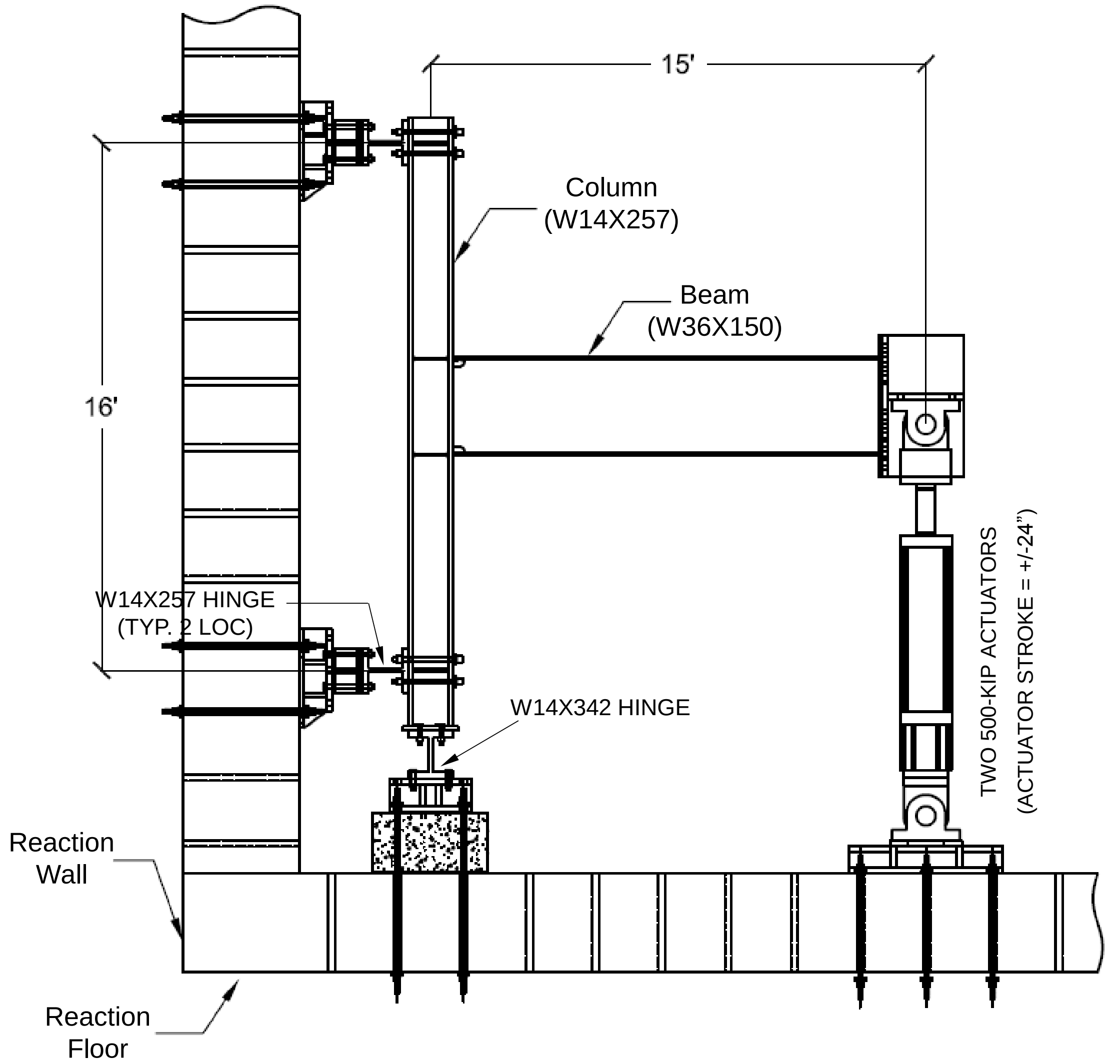
(b) Elevation View

Figure 2.2 Specimen C2 Connection Detail



(a) Specimen C1

Figure 2.3 Test Setup



Note: Lateral bracing system not shown

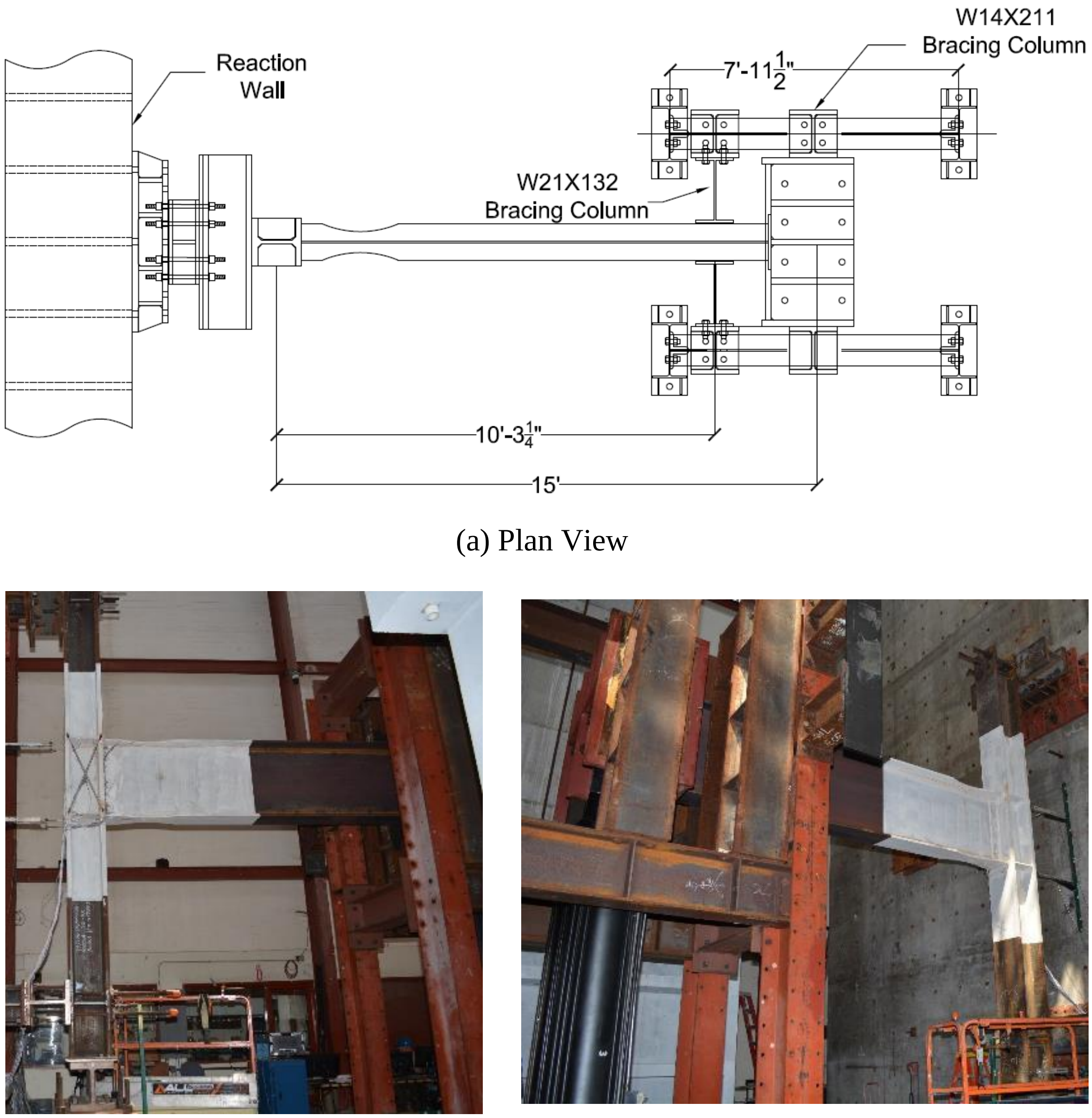
(b) Specimen C2

Figure 2.3 Test Setup (continued)

(a) Top End

(b) Bottom End

Figure 2.4 Hinge Supports

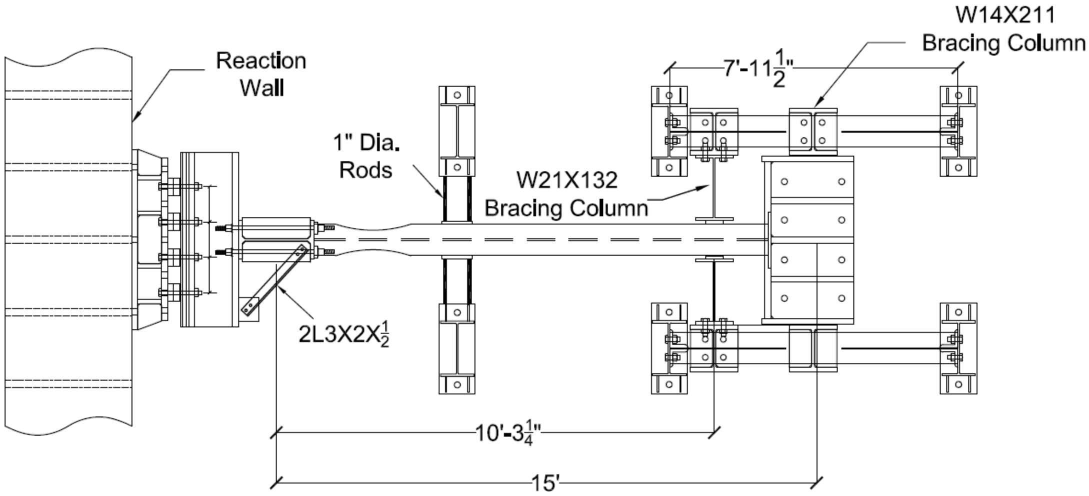


(a) Plan View

(b) View from West

(c) View from South-East

Figure 2.5 Beam Lateral Bracing System



(a) Plan View

(b) View from East

(c) View from West

(d) Column Top Bracing

Figure 2.6 RBS and Column Top Bracings (Specimen C1 with a Deep Column)

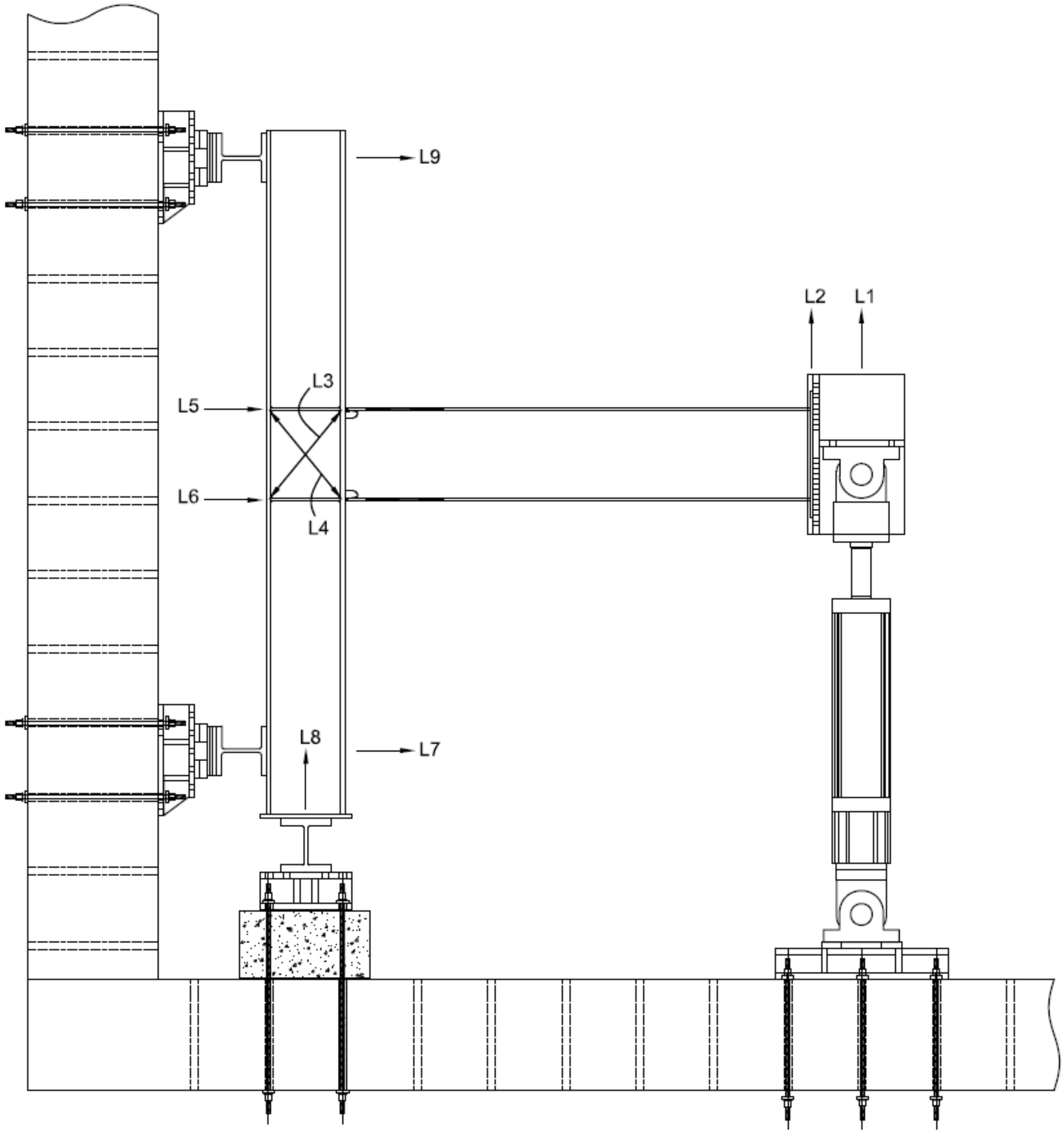
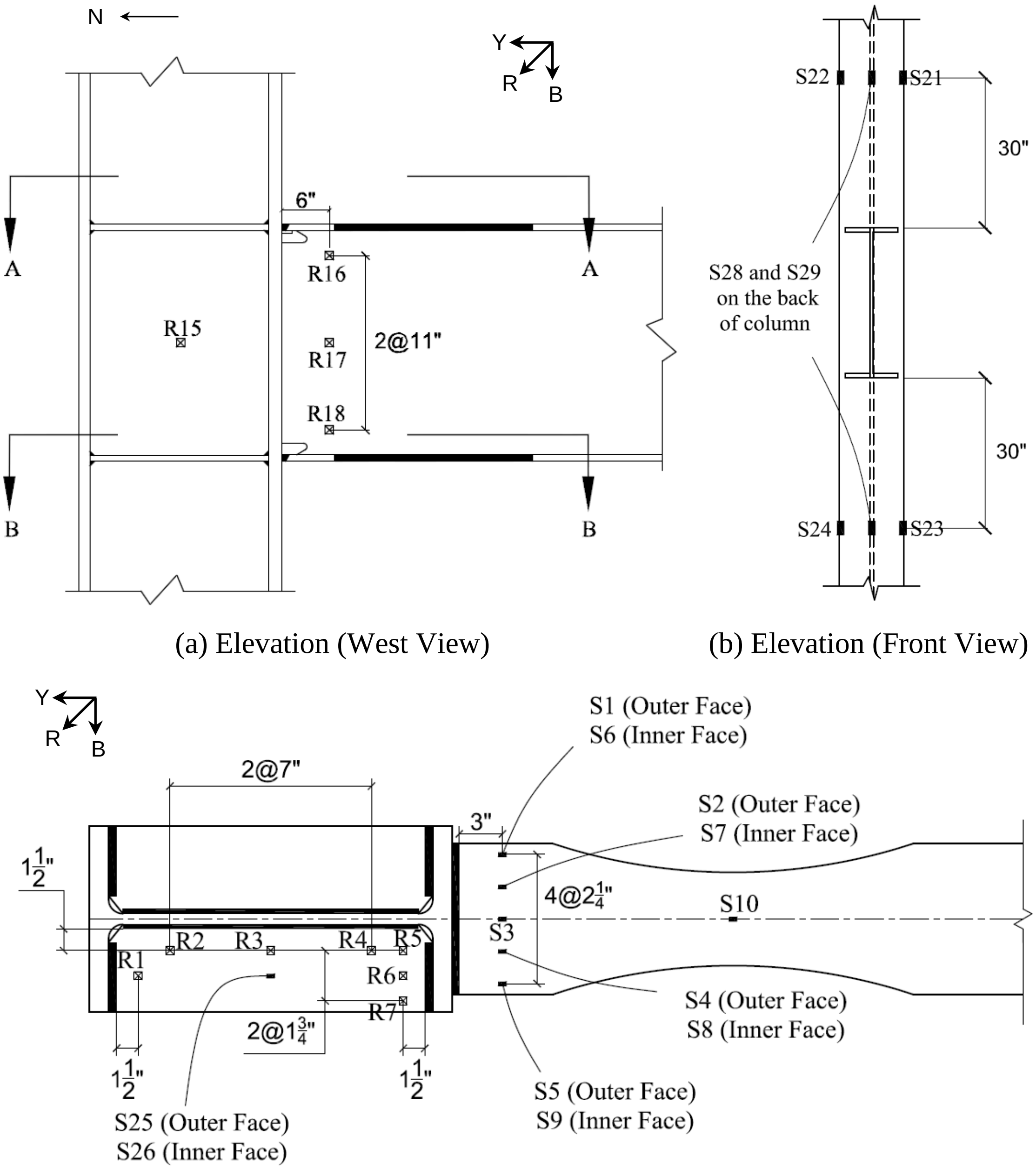


Figure 2.7 Location of Displacement Transducers

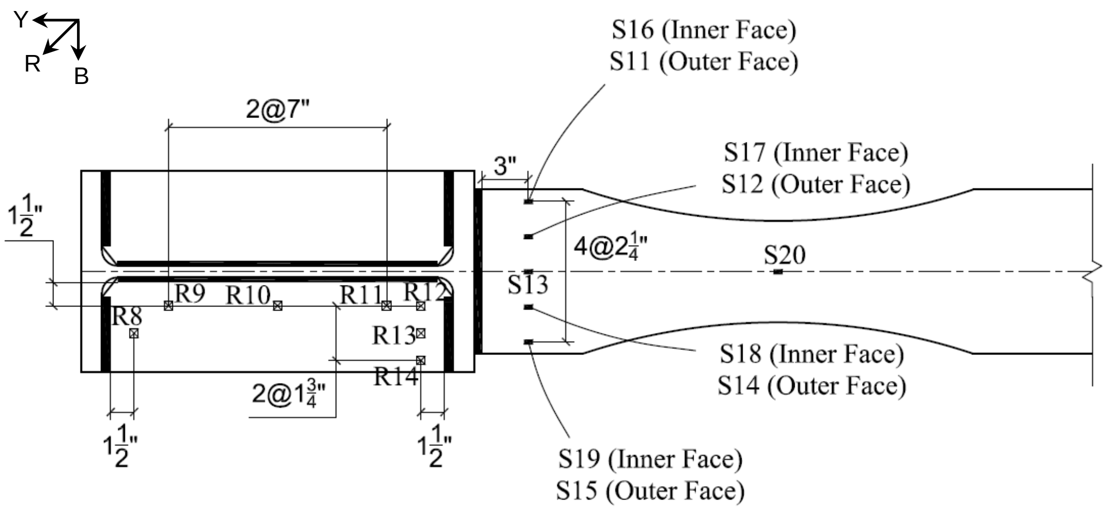


(a) Elevation (West View)

(b) Elevation (Front View)

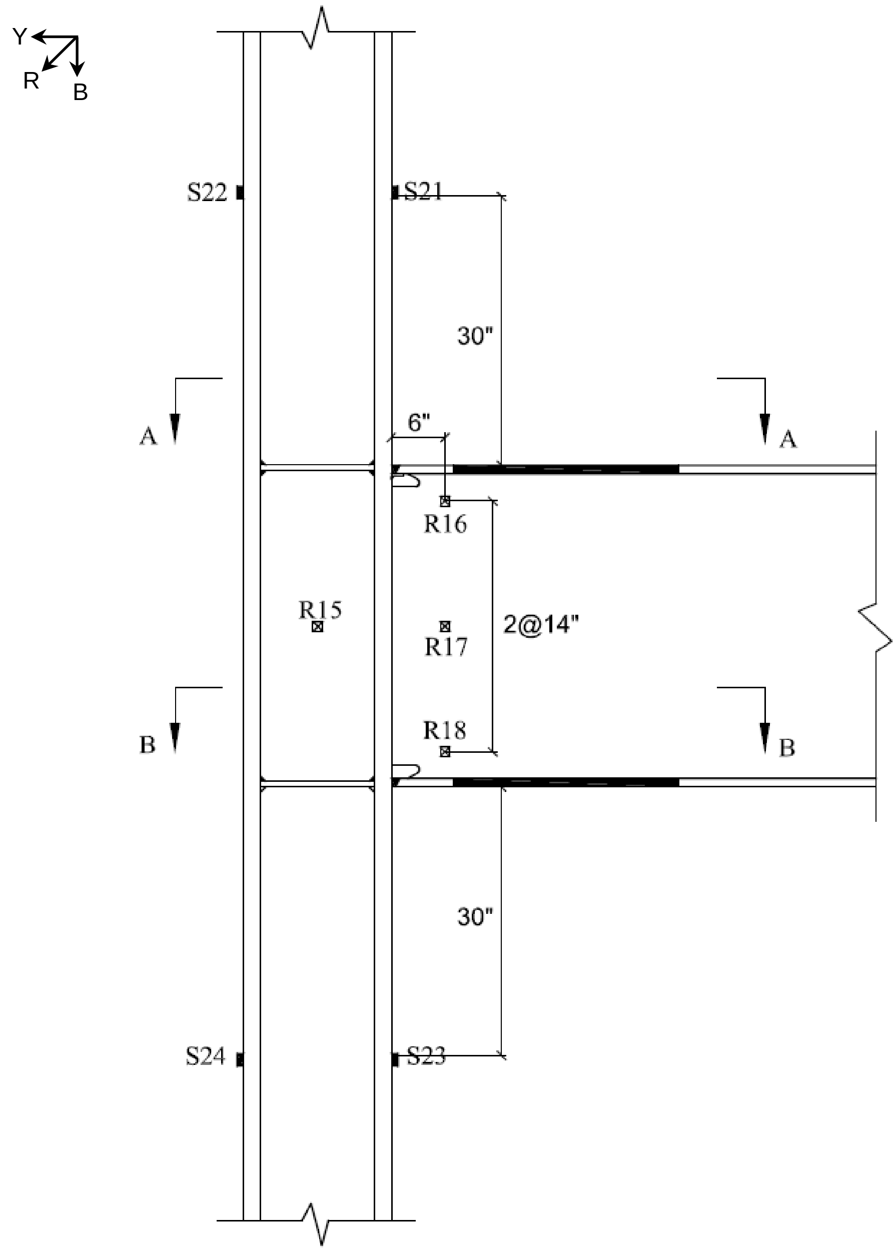
(c) View A-A

Figure 2.8 Specimen C1 Strain Gage and Rosette Locations



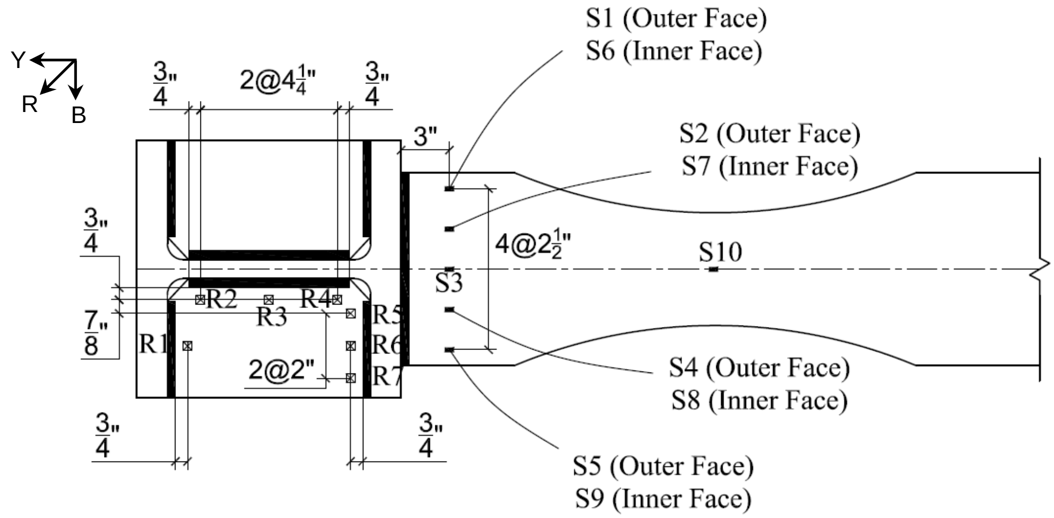
(c) View B-B

Figure 2.8 Specimen C1 Strain Gage and Rosette Locations (continued)

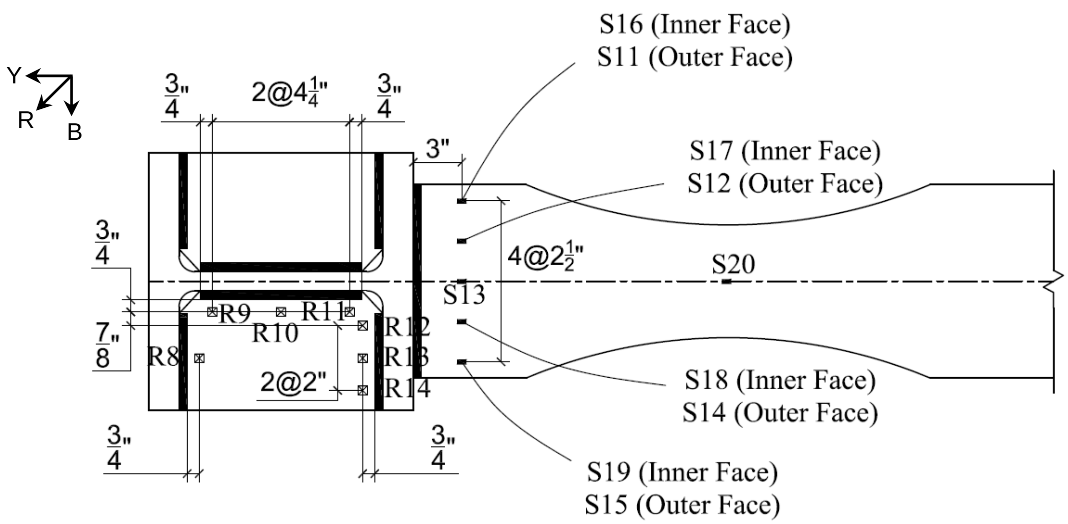


(a) Elevation (West View)

Figure 2.9 Specimen C2 Strain Gage and Rosette Locations

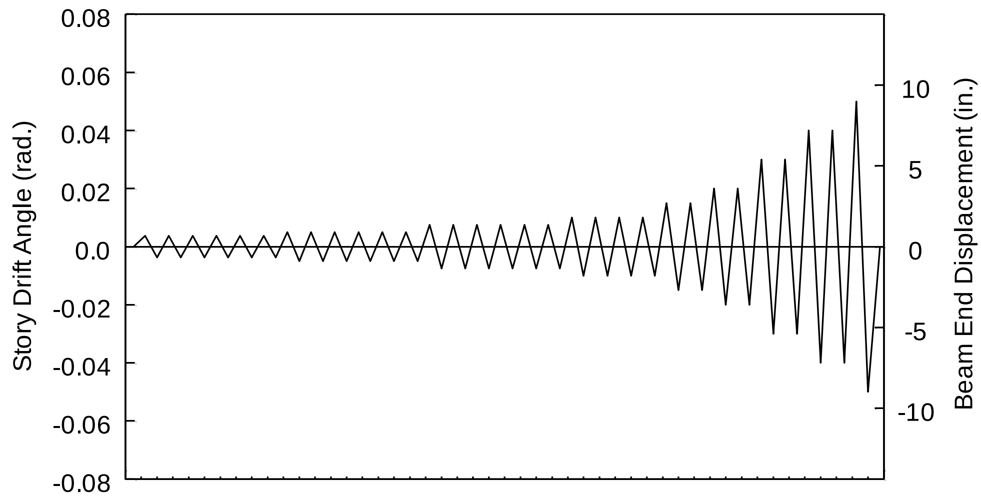


(b) View A-A

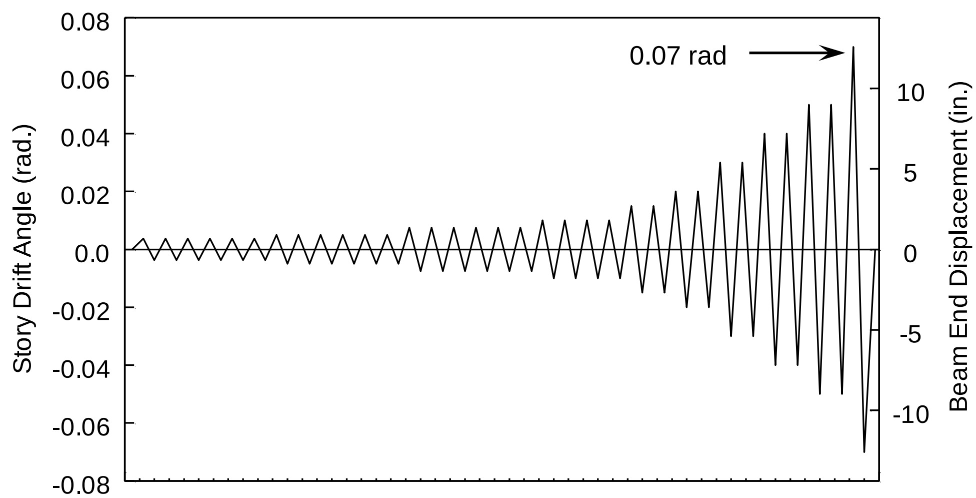


(c) View B-B

Figure 2.9 Specimen C2 Strain Gage and Rosette Locations (continued)



(a) Specimen C1



(b) Specimen C2

Figure 2.10 Loading Protocol

3 TEST RESULTS

3.1 Specimen C1

3.1.1 Observed Performance

Figure 3.1 shows the specimen prior to testing. At 0.01 rad drift, minor yielding of beam top and bottom flanges was observed (Figure 3.2). At the end of the second cycle of -0.015 rad drift, panel zone yielding was observed and yielding in the beam flanges extended into the web [Figure 3.3(b) and (c)]. However, no damage to any of the continuity plates fillet welds was observed, [Figure 3.3(d) and (e)].

Both beam flange local buckling and lateral-torsional buckling were observed at 0.03 rad drift. The specimen reached its peak strength at this drift level, but the fillet welds remained intact (Figure 3.4). At 0.04 rad drift, yielding in the beam and panel zone as well as beam buckling became more severe (Figure 3.5). Figure 3.6 shows the global view of the specimen after completing one cycle at 0.05 rad drift. The beam flexural strength at the face of the column had degraded below 80% of the beam nominal plastic moment, and the test was stopped. Figure 3.7 shows the fillet welds of the continuity plates after completing the test, showing no sign of damage. Figure 3.8 depicts lateral-torsional buckling of the beam at 0.03, 0.04, and 0.05 rad drifts.

3.1.2 Recorded Response

3.1.2.1 Global Response

A plot of the load versus beam tip displacement is shown in Figure 3.9. The relationship between the moment at the column face and the story drift angle is shown in Figure 3.10; the vertical axis on the right shows the moment normalized by the nominal plastic moment (M_{pn}) of the beam. Vertical dotted lines indicate 0.04 rad drift as required by AISC 341 for Special Moment Frame. The specimen completed two cycles at a story drift angle of 0.04 rad before the moment at the column face degraded below $0.8M_{pn}$.

Figure 3.11 shows the relationship between the moment at the column face and the total plastic rotation. Figure 3.12 shows that the panel zone yielded in shear. The "unusual" nonlinear response in the figure was due to twisting of the deep column (Chi and Uang 2002).

3.1.2.2 Local Response

Figure 3.13 shows the flexural strain profiles of the beam top and bottom flanges at a section 3 in. away from the column face. Buckling in the beam skewed the strain profiles at higher drift levels. Figure 3.14 and Figure 3.15 show the strain profiles on the top and bottom continuity plates, respectively. The continuity plates remained essentially elastic. Figure 3.16(a) and (c) show the normal strain profiles at Sections G and H, respectively. The strain near the non-loading column flange was lower than that near the loaded column flange. Figure 3.16(b) shows the normal strains on both surfaces of the top continuity plate were very similar. Figure 3.16(d) compares the normal strains of the top and bottom continuity plates at a section 1½ in. away from the non-loaded column flange.

Figure 3.17 shows the flexural strain response of two pairs of strain gages located 30 in. above and below the top and the bottom beam flanges, respectively. The response of each pair is expected to be similar such that the plot lies on a 45° line. However, warping stresses created by column twisting when the drift 1.5% caused the response to deviate from a line of 45°. Figure 3.18 shows that shear yielding occurred near the top and bottom portions of the beam web.

3.2 Specimen C2

3.2.1 Observed Performance

Significant panel zone yielding with column flange kinking was expected because Specimen C2 was designed with a demand-capacity ratio of 0.95 for the panel zone. Figure 3.19 shows the specimen prior to testing. The specimen remained essentially elastic until 0.0075 rad drift cycles. At the end of 0.0075 rad drift, yielding of the panel zone started (Figure 3.20). At the completion of 0.01 rad drift cycles, yielding at the top and the bottom beam flanges was also visible (Figure 3.21). Figure 3.22 shows the connection at the end of second cycle of -0.015 rad drift; the fillet welds connecting the continuity plates to the column flanges were intact. Yielding extended to the beam web at 0.03 rad drift [Figure 3.23(a)]. Panel zone yielding was significant, and yielding of the column flange at the column flange kink locations was observed [Figure 3.23(b) and (c)]. Figure 3.24 shows the specimen at 0.04 rad drift. All the fillet welds were intact [Figure 3.24(c) and (d)]. Although the $b_f/2t_f$ and h/t_w ratios of Specimens C2 were somewhat larger than those of Specimen C1 (Table 2.1), local buckling was less severe in C2 because the weaker panel zone accommodated more inelastic deformation at the same drift level. As can be seen in Figure 3.24(f), panel zone yielding was very significant.

Figure 3.25 shows the specimen after completing two cycles at 0.05 rad drift. It was then decided to displace the specimen to 0.07 rad drift directly. Testing was stopped after completing one cycle at 0.07 rad drift because the beam flexural strength at the face of the column had degraded below 80% of the beam nominal plastic moment. Figure 3.26 and Figure 3.27 show the connection at the end of +0.07 and -0.07 rad drifts, respectively. Figure 3.28 shows lateral-torsional buckling of the beam at -0.05 and -0.07 rad drift. At 5% drift, note that lateral-torsional buckling was much less severe in Specimen C2 than in C1 [Figure 3.8(c)] because the latter had a deep column and was more prone to column twisting. On the way to return the specimen to its zero beam tip displacement, the beam bottom flange completely fractured (Figure 3.29).

It was observed after testing that continuity plates had yielded [Figure 3.30(a)] and column flange yielding at the kink locations was more pronounced [Figure 3.30(b) and (c)]. No damage in the fillet welds was observed, which was confirmed from magnetic particle inspection conducted after the test.

3.2.2 Recorded Response

3.2.2.1 Global Response

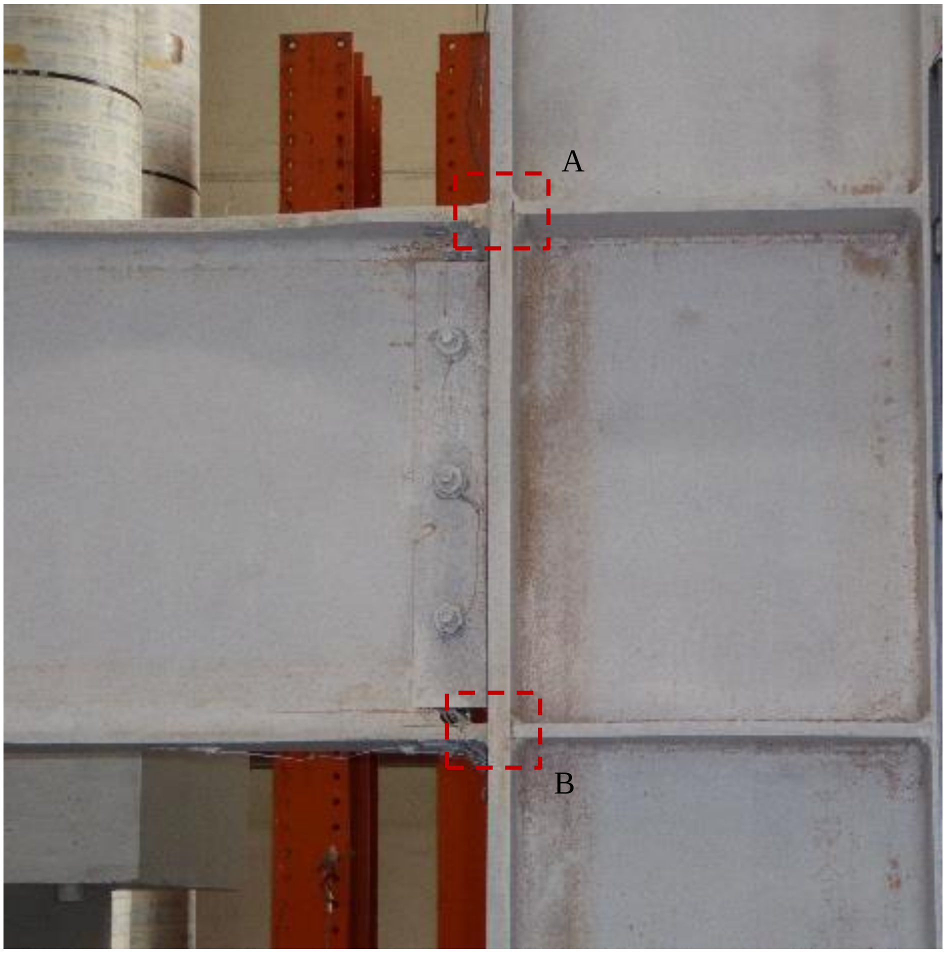
A plot of the load versus the beam tip displacement is shown in Figure 3.31 The relationship between the moment at the face of the column and story drift angle is shown in Figure 3.32. The specimen completed two cycles at a story drift angle of 0.05 rad before the moment at the column face degraded below $0.8M_{pn}$.

Figure 3.33 shows the relationship between the moment at the column face and the total plastic rotation. Figure 3.34 shows the panel zone experienced significant shear yielding and reached 8.5 times the shear yield strain. The column remained essentially elastic throughout the test.

3.2.2.2 Local Response

Figure 3.35 shows the flexural strain profiles on the beam top and bottom flanges at a distance 3 in. away from the column face. (Strain gage S14 malfunctioned.) The strain profiles were more uniform across the flange width when compared with those of Specimen C1 (Figure 3.13), mainly because a shallow (W14) column that was less prone to column twisting was used. The recorded strains in the top and bottom continuity plates (Figure 3.36 and Figure 3.37) showed that yielding had occurred. (Recall that the continuity plates were intentionally undersized by 1/4 in.) The maximum normal strain was about three times the yield strain. Despite the significant yielding in the continuity plates, the connection performance was not affected.

Figure 3.38 compares the normal strain profiles in the top and the bottom continuity plates. (The reading from rosette R01 seems unreliable since it almost read zero strains.) As comparison of Figure 3.38(d) with Figure 3.16(c) of Specimen C1 shows that more force in the continuity plate was transmitted to the unloaded column flange when a shallow column was used. Figure 3.39 indicates significant shear yielding on the beam web close to the column flange.



(a) Global View from East

(b) Detail A

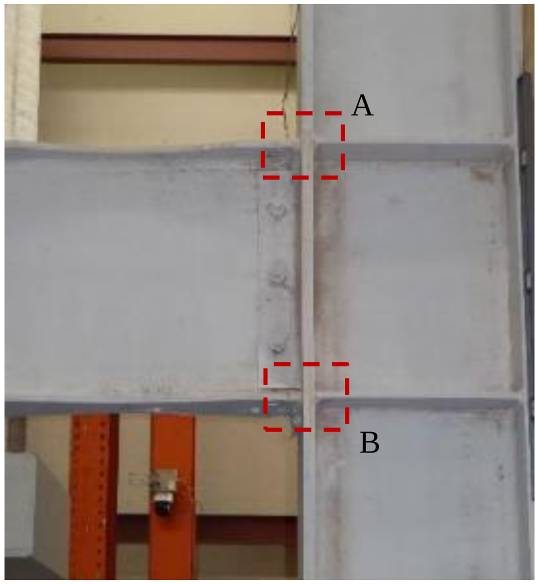
(c) Detail B

Figure 3.1 Specimen C1 Connection Prior to Testing

(a) Global View from East

(b) Yielding in Beam Top and Bottom Flanges

Figure 3.2 Specimen C1 at End of -0.01 rad Drift Cycles



(a) Global View from East

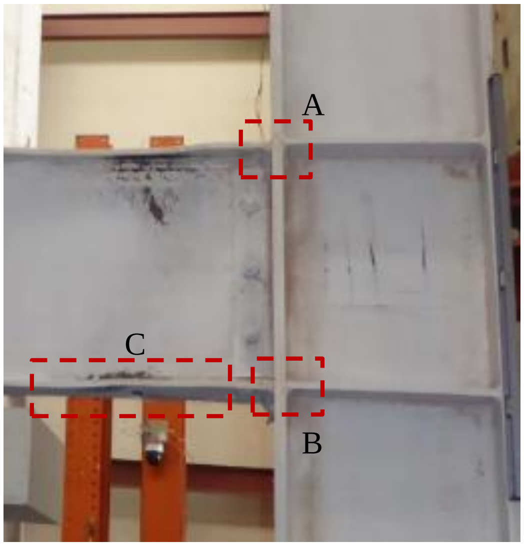
(b) Minor Panel Zone Yielding

(c) Spread of Yielding to Beam Web

(d) Detail A

(e) Detail B

Figure 3.3 Specimen C1 at -0.015 rad Drift (2nd Cycle)



(a) Global View from East

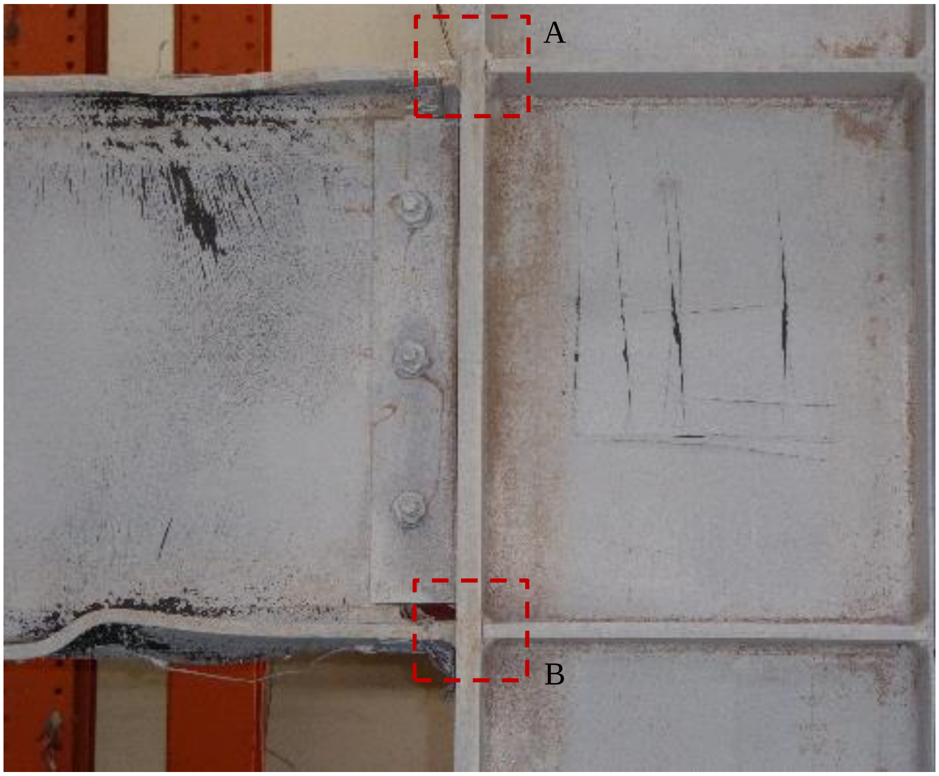
(b) Detail A

(c) Detail B

(d) Detail C (Beam Flange Local Buckling)

(e) Beam Lateral-Torsional Buckling

Figure 3.4 Specimen C1 at -0.03 rad Drift (2nd Cycle)



(a) Global View from East

(b) Detail A

(c) Detail B

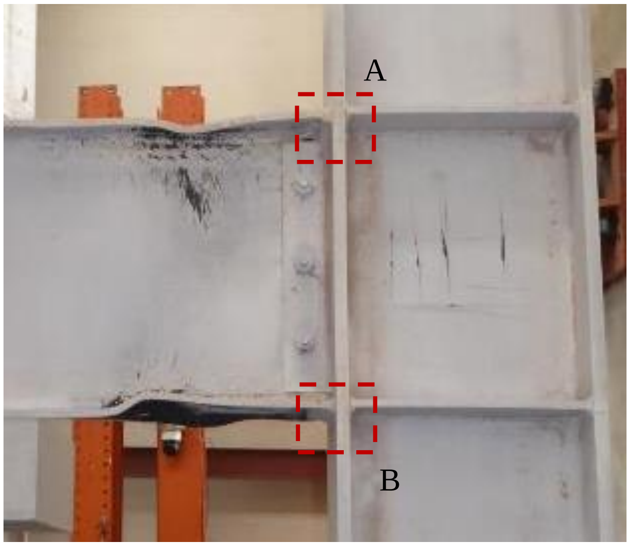
Figure 3.5 Specimen C1 at -0.04 rad Drift (2nd Cycle)

(a) at +0.05 rad Drift

(b) View from East (at -0.05 rad Drift)

(c) View from West (at -0.05 rad Drift)

Figure 3.6 Specimen C1 at 0.05 rad Drift (1st Cycle)



(a) Global View from East

(b) Detail A, View from East

(c) Detail A, view from Bottom

(d) Detail B, View from East

(e) Detail B, View from Bottom

Figure 3.7 Specimen C1 at Test Completion

(a) -0.03 rad Drift (2nd Cycle)

(b) -0.04 rad Drift (2nd Cycle)

(c) -0.05 rad Drift (1st Cycle)

Figure 3.8 Specimen C1 Beam Lateral-Torsional Buckling

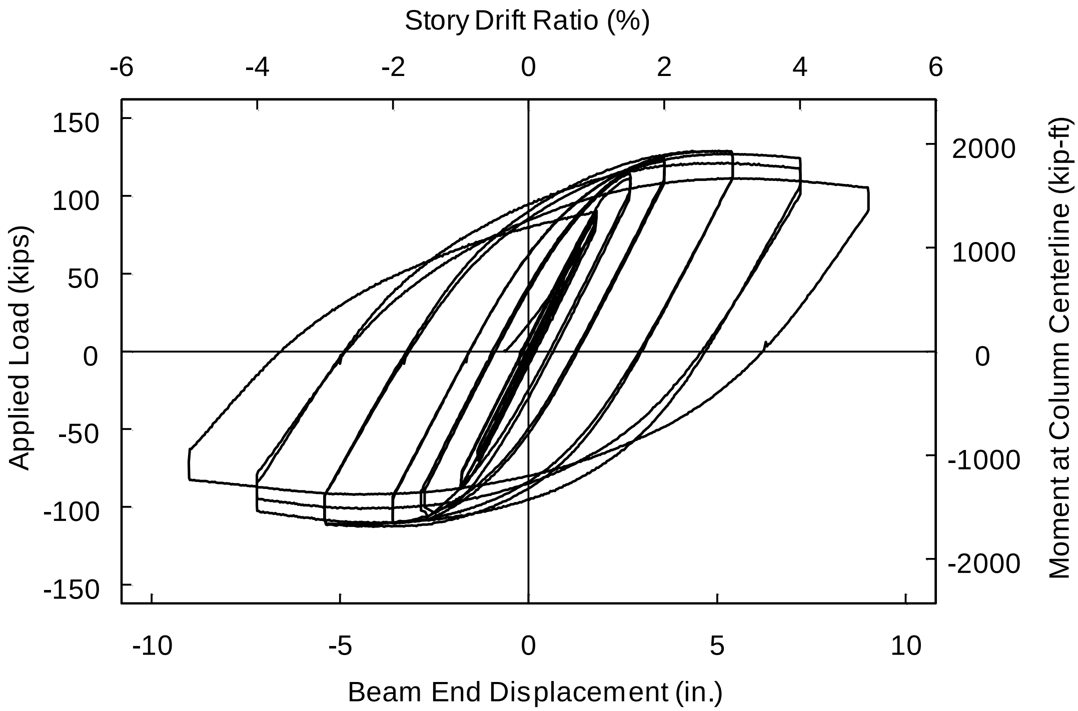


Figure 3.9 Specimen C1 Load versus Beam Tip Displacement Relationship

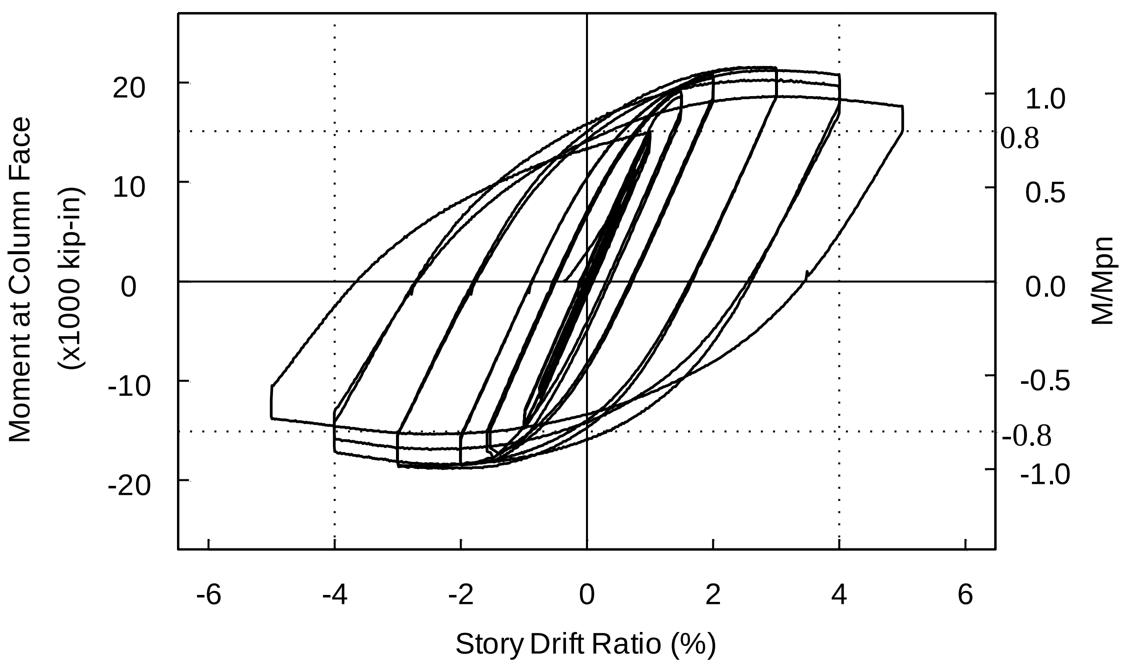


Figure 3.10 Specimen C1 Moment versus Story Drift Angle Relationship

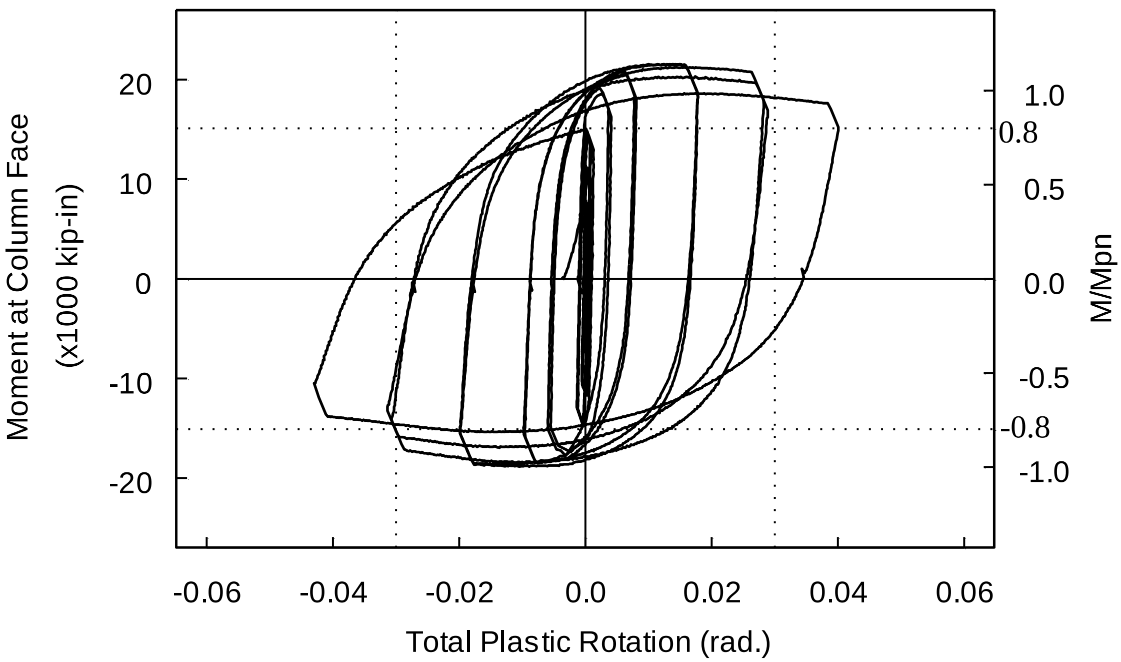


Figure 3.11 Specimen C1 Moment versus Total Plastic Rotation Relationship

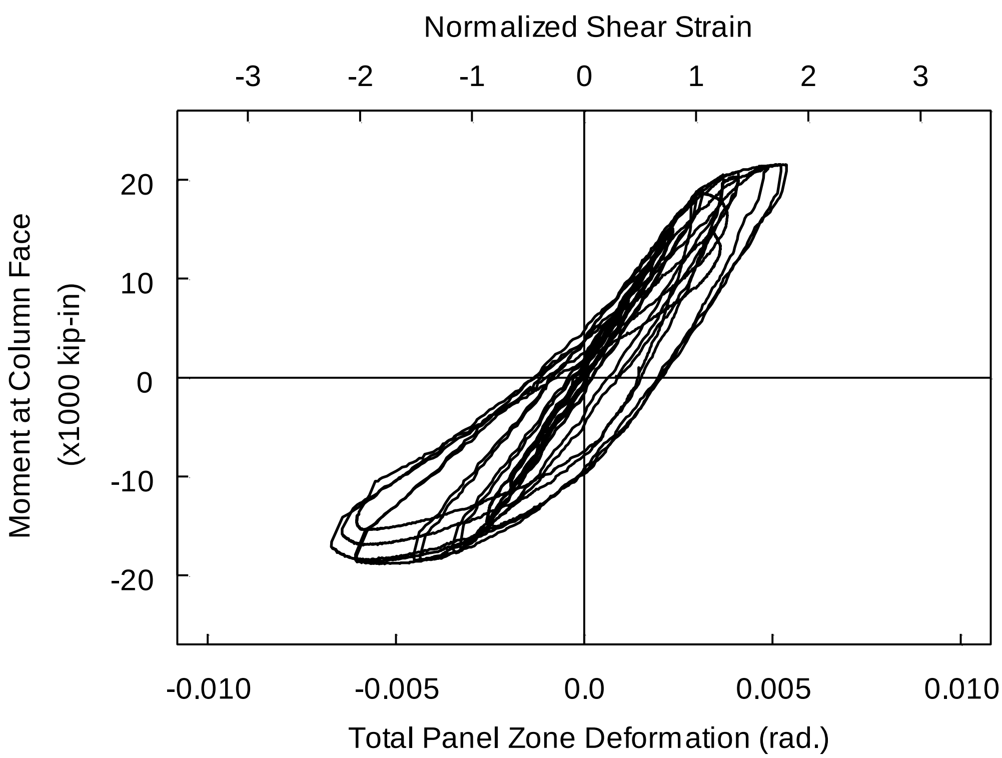


Figure 3.12 Specimen C1 Moment versus Total Panel Zone Shear Deformation Relationship

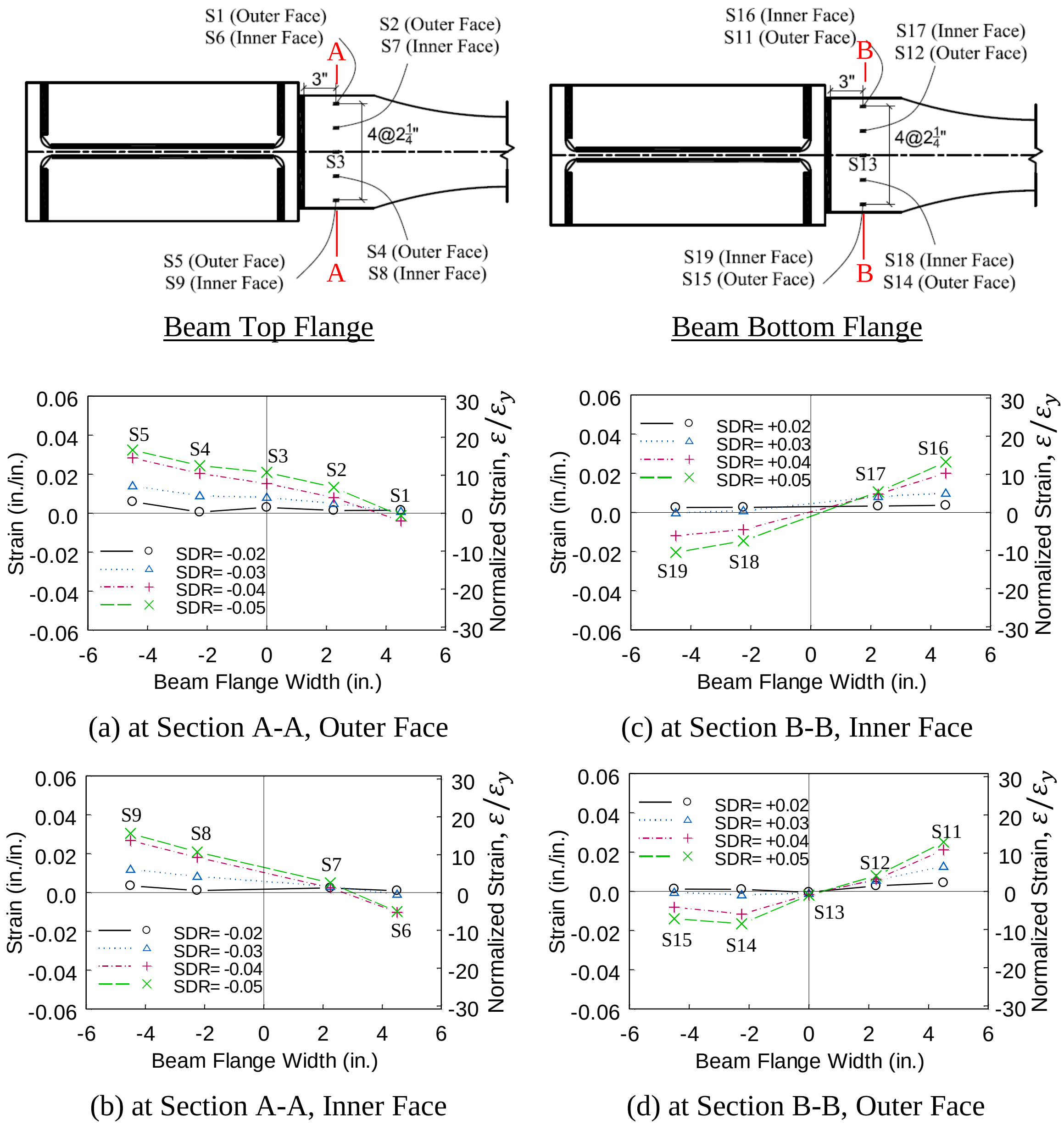
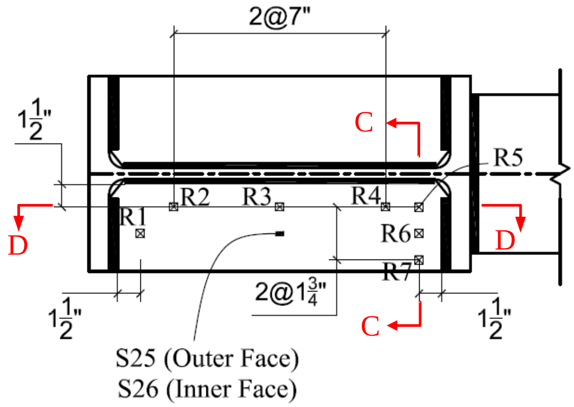
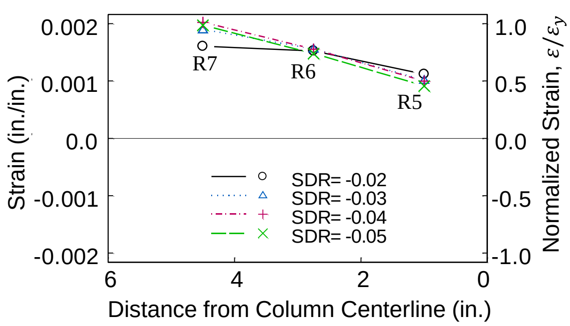


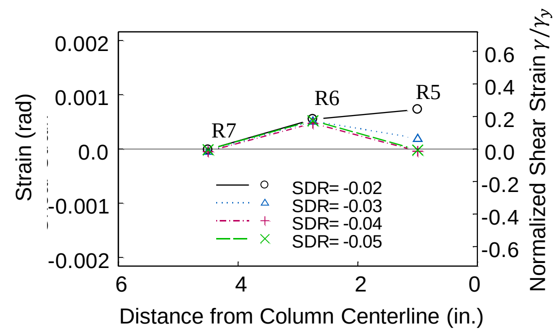
Figure 3.13 Specimen C1 Beam Flange Flexural Strain Profiles



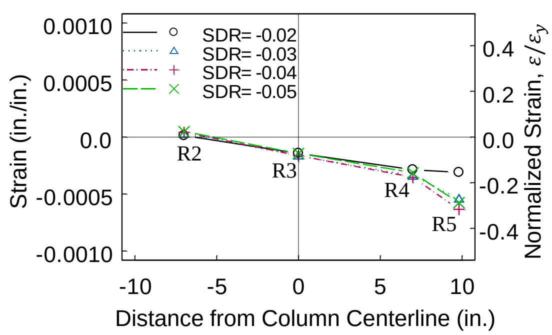
Top Continuity Plate



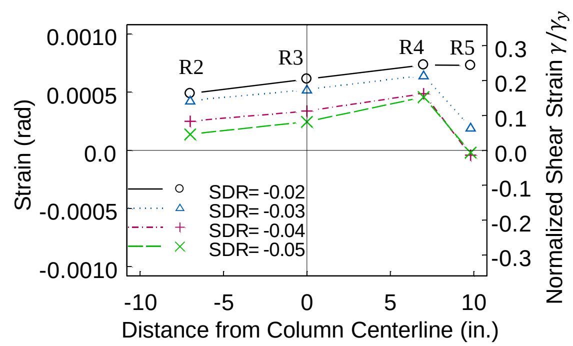
(a) Strain Normal to Flange Weld at Section C-C



(b) Shear Strain at Section C-C

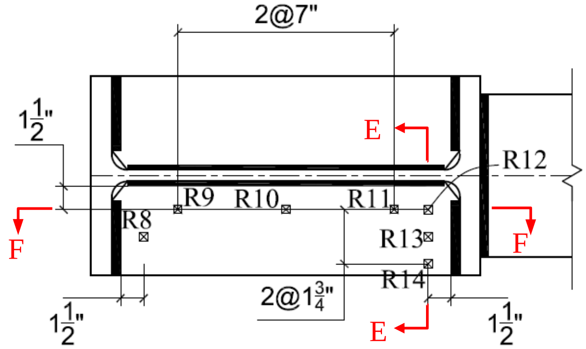


(c) Strain Normal to Web Weld at Section D-D

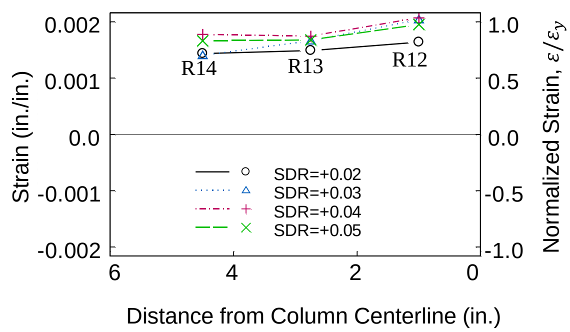


(d) Shear Strain at Section D-D

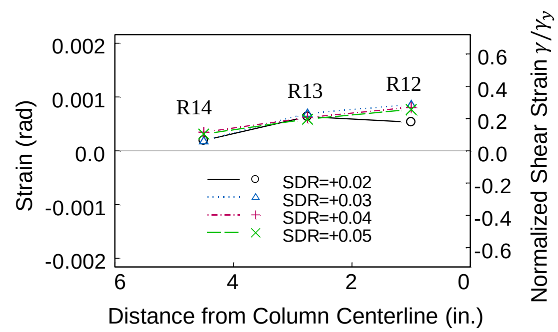
Figure 3.14 Specimen C1 Top Continuity Plate Strain Profiles



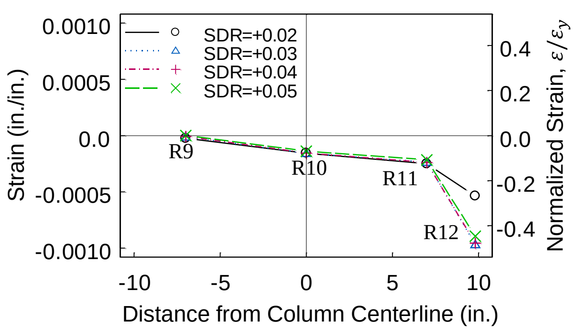
Bottom Continuity Plate



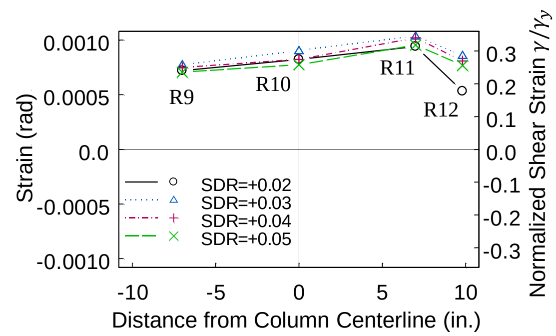
(a) Strain Normal to Flange Weld at Section E-E



(b) Shear Strain at Section E-E

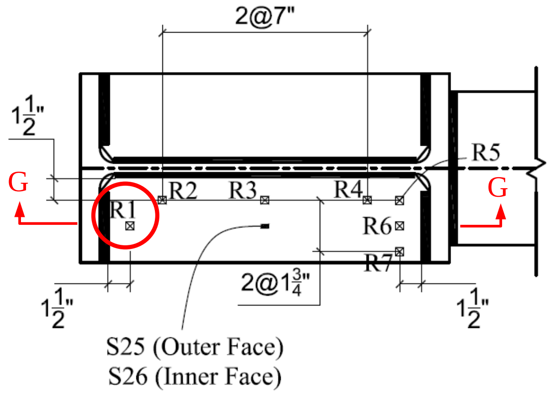


(c) Strain Normal to Web Weld at Section F-F

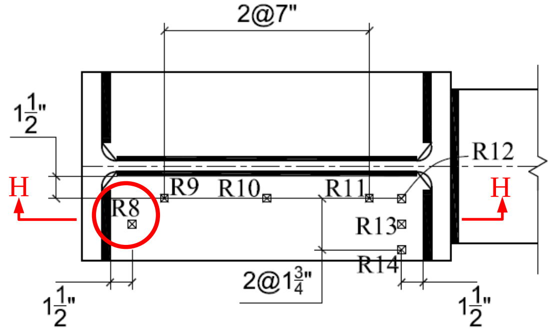


(d) Shear Strain at Section F-F

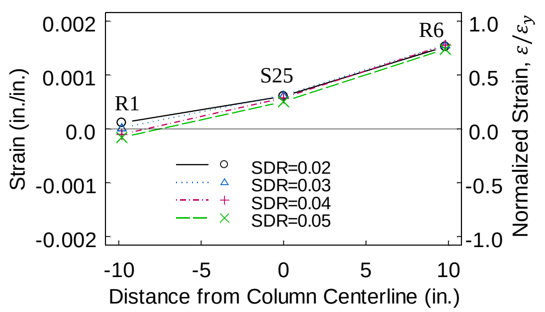
Figure 3.15 Specimen C1 Bottom Continuity Plate Strain Profiles



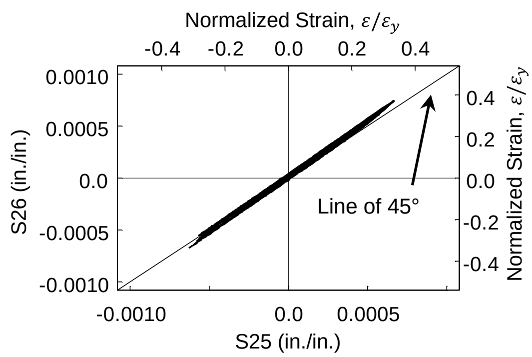
Top Continuity Plate



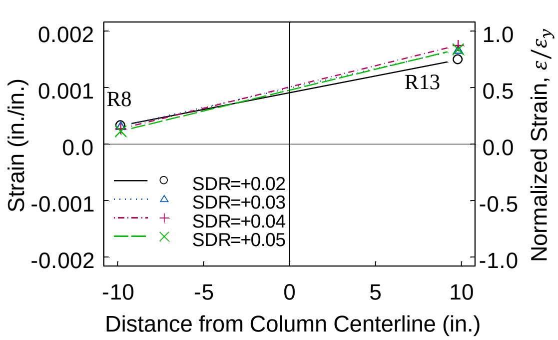
Bottom Continuity Plate



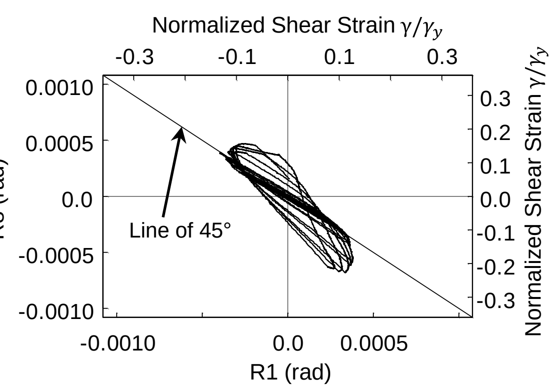
(a) Normal Strain at Section G-G



(b) Plot of S25 vs S26

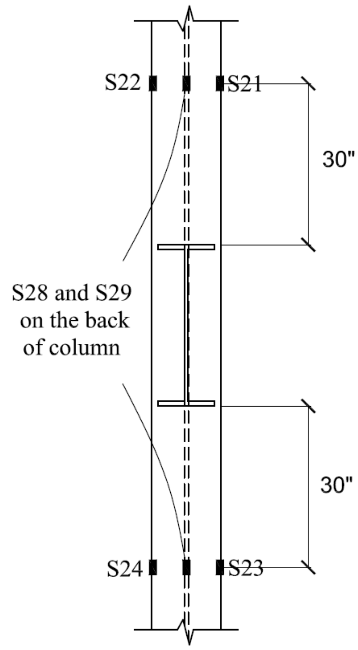


(c) Normal Strain at Section H-H

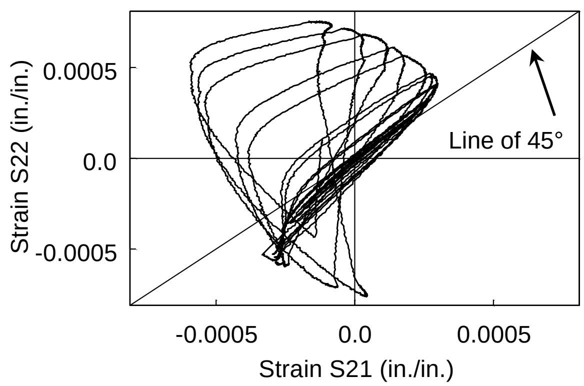


(d) Shear Strain Plot of R8 vs R1

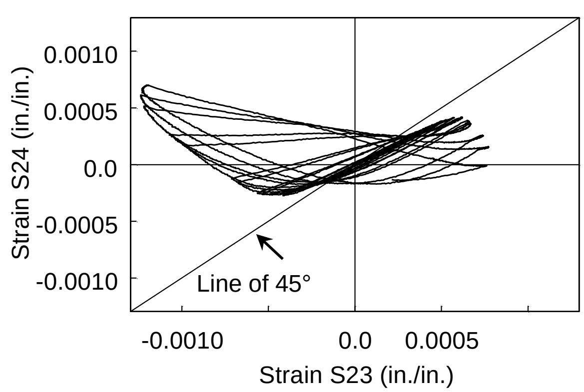
Figure 3.16 Specimen C1 Top and Bottom Continuity Plates Strain Profiles



(a) Location of Strain Gages on the South Face of the Column

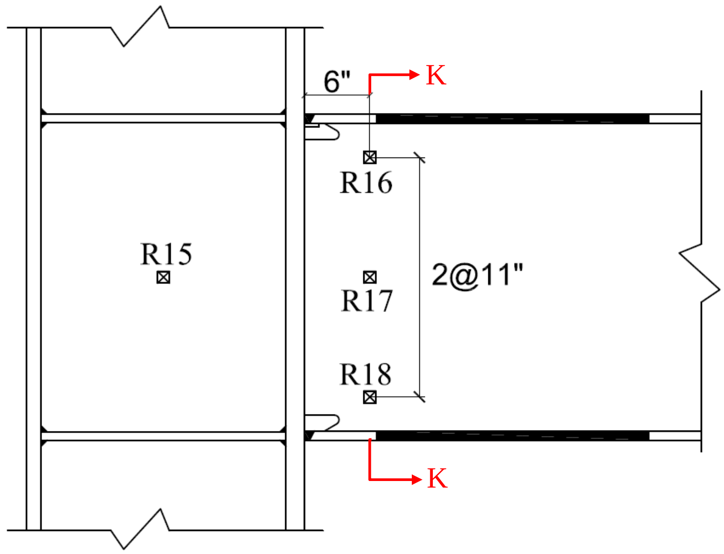


(b) Plot of S21 vs S21

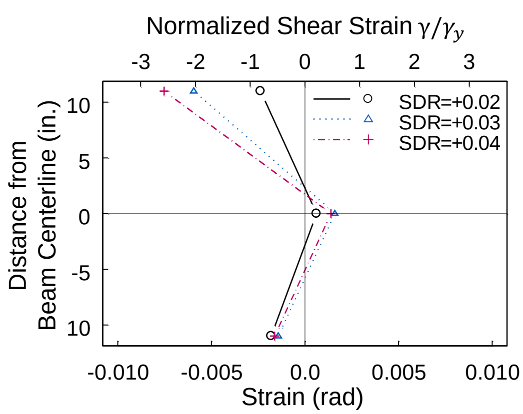


(c) Plot of S23 vs S24

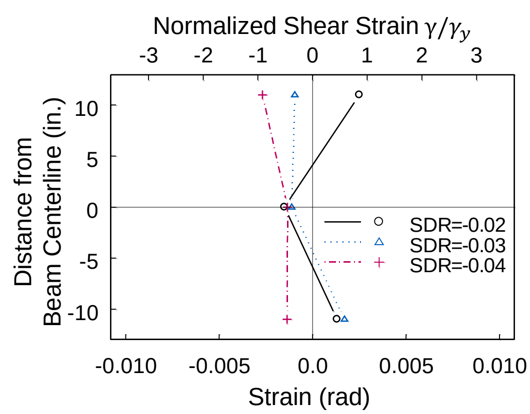
Figure 3.17 Specimen C1: Effect of Column Twisting on Column Flexural Strains



(a) Section K-K

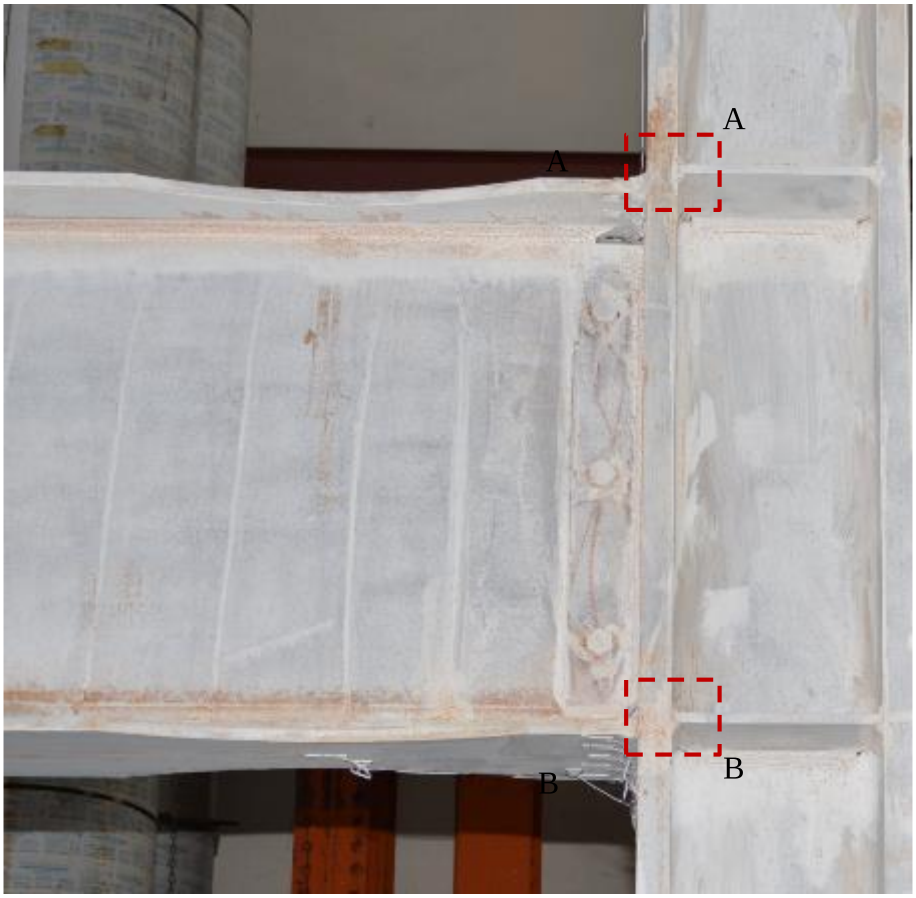


(b) Positive Excursions



(c) Negative Excursions

Figure 3.18 Specimen C1 Beam Web Shear Strain Profiles



(a) Global View from East

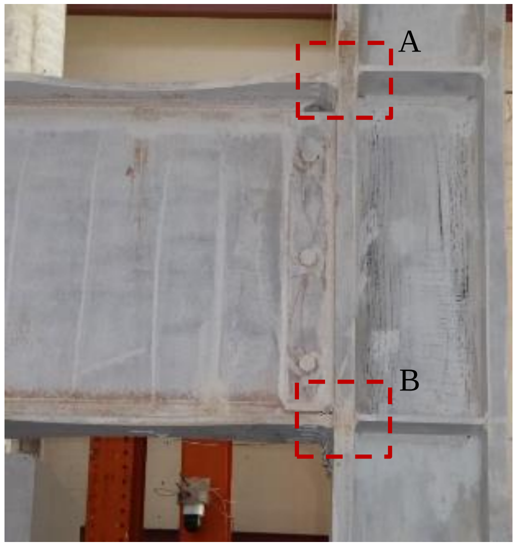
(b) Detail A

(c) Detail B

Figure 3.19 Specimen C2 Connection Region Prior to Testing

Figure 3.20 Specimen C2 Panel Zone Minor Yielding at Completion of 0.0075 rad Drift Cycles

Figure 3.21 Specimen C2 Beam Flange Yielding at Completion of 0.01 rad Drift Cycles

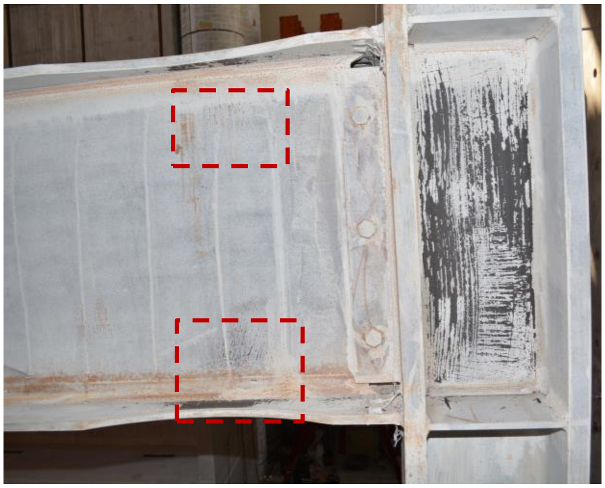


(a) Global View from East


(b) Detail A


(c) Detail B

Figure 3.22 Specimen C2 Connection at -0.015 rad Drift (2nd Cycle)

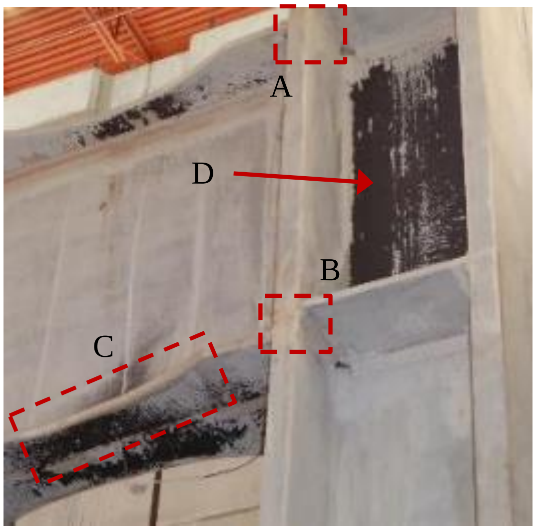


(a) Spread of Yielding to Beam Web

(b) Column Flange Yielding Due to Column Kinking (Back Side)

(c) Column Flange Yielding Due to Column Kinking (Front Side)

Figure 3.23 Specimen C2 Connection at -0.03 rad Drift (2nd Cycle)



(a) Global View from East

(b) Global View from West

(c) Detail A

(d) Detail B

(e) Detail C, Minor Flange and Web Local Buckling

(f) Detail D, Significant Panel Zone Yielding and Column Kinking

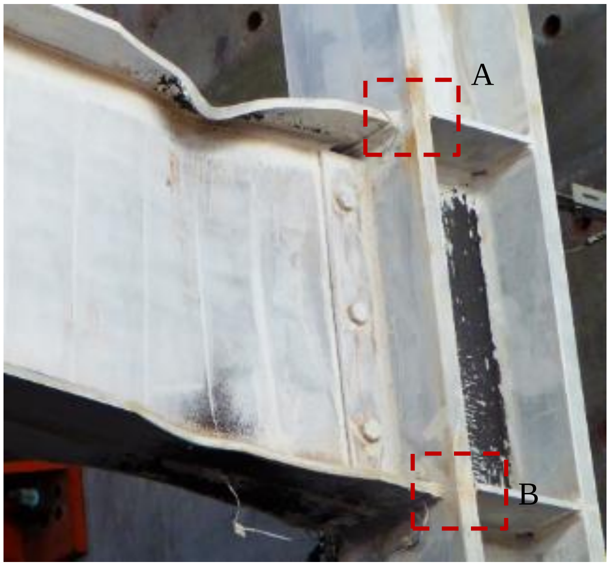
Figure 3.24 Specimen C2 Connection at -0.04 rad Drift (2nd Cycle)

(a) View from East

(b) View from West

Figure 3.25 Specimen C2 at -0.05 rad Drift (2nd Cycle)

(a) Global View from East

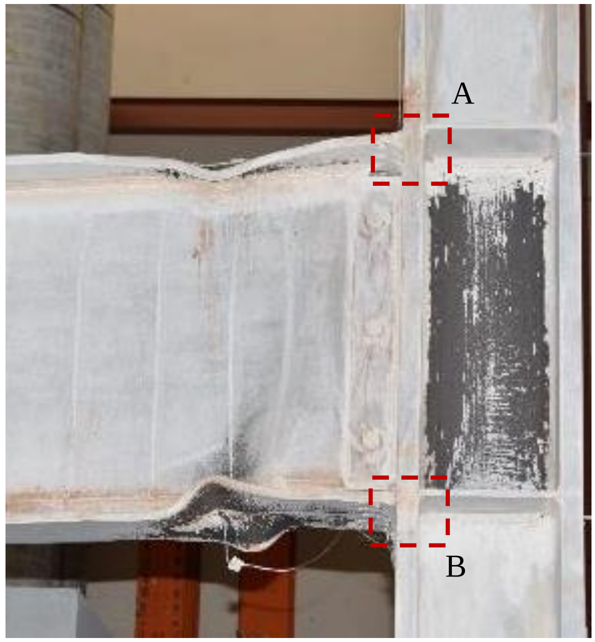


(b) Global View from South East

(c) Detail A

(d) Detail B

Figure 3.26 Specimen C2 at +0.07 rad Drift (1st Cycle)



(a) Global View from East

(b) Detail A, View from East

(c) Detail A, view from Bottom

(d) Detail B, View from East

(e) Detail B, View from Bottom

Figure 3.27 Specimen C2 Connection at -0.07 rad Drift (1^{st} Cycle)

(a) -0.05 rad Drift (2^{nd} Cycle)

(b) -0.07 rad Drift (1^{st} Cycle)

Figure 3.28 Specimen C2 Beam Lateral-Torsional Buckling

(a) View from East

(b) View from West

(c) Close-up View

Figure 3.29 Specimen C2 Complete fracture of Beam Bottom Flange at Test Completion

(a) Yielding in Bottom Continuity Plate

(b) Column Flange Yielding Due to Column Kinking (Back Side)

(c) Column Flange Yielding Due to Column Kinking (Front Side)

Figure 3.30 Specimen C2 Continuity Plate and Column Flanges Yielding at Test Completion

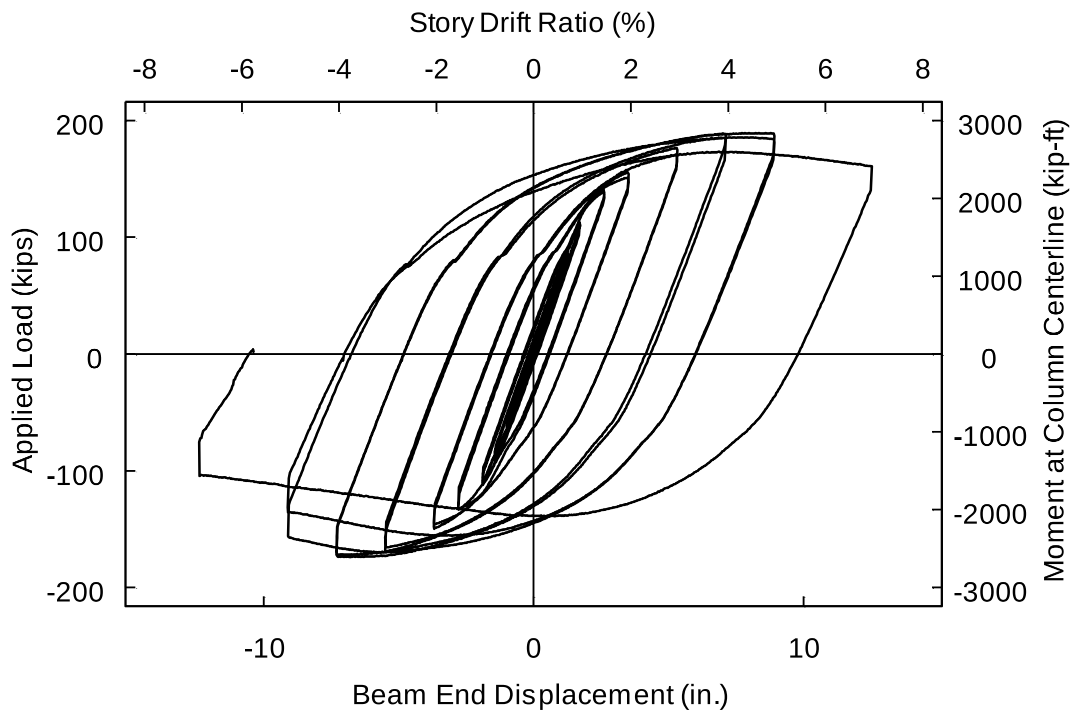


Figure 3.31 Specimen C2 Load versus Beam Tip Displacement Relationship

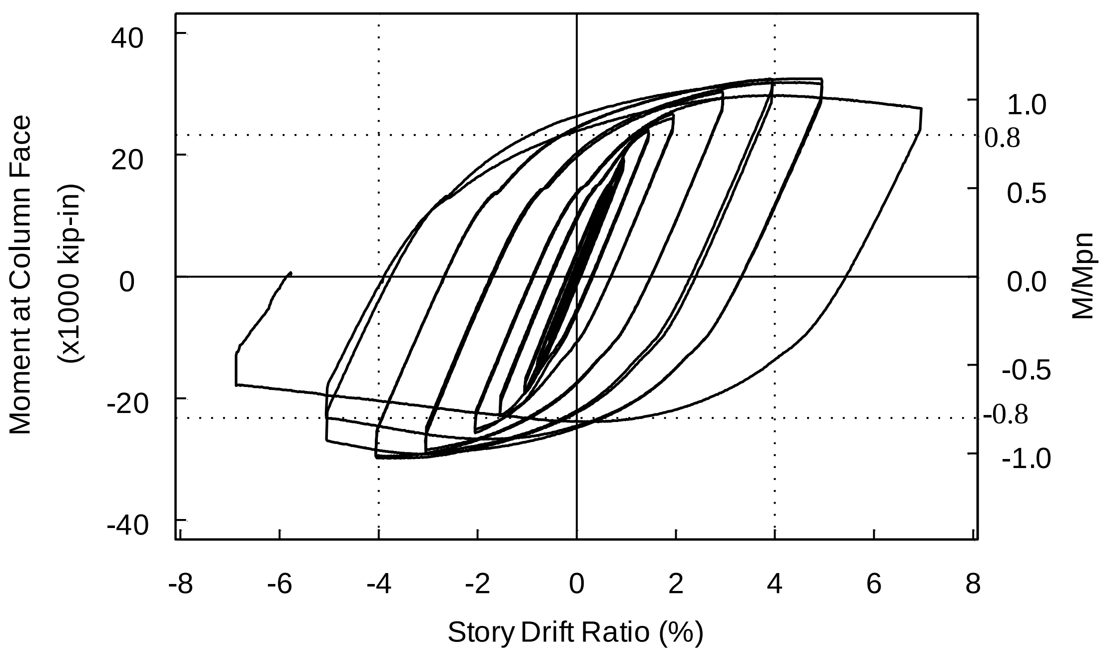


Figure 3.32 Specimen C2 Moment versus Story Drift Angle Relationship

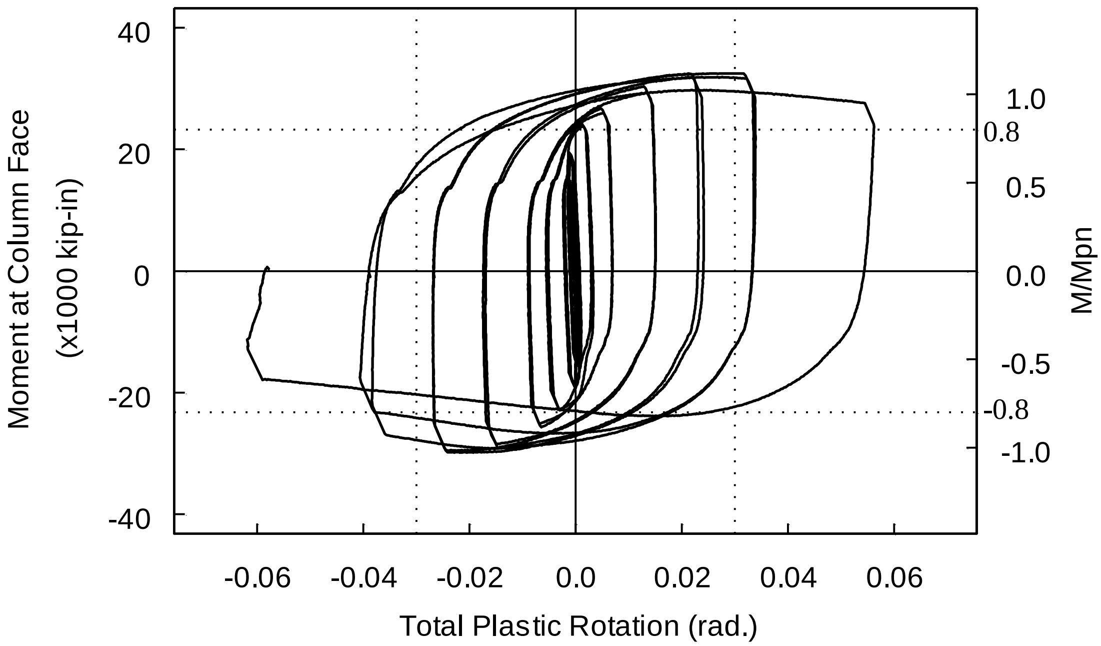


Figure 3.33 Specimen C2 Moment versus Total Plastic Rotation Relationship

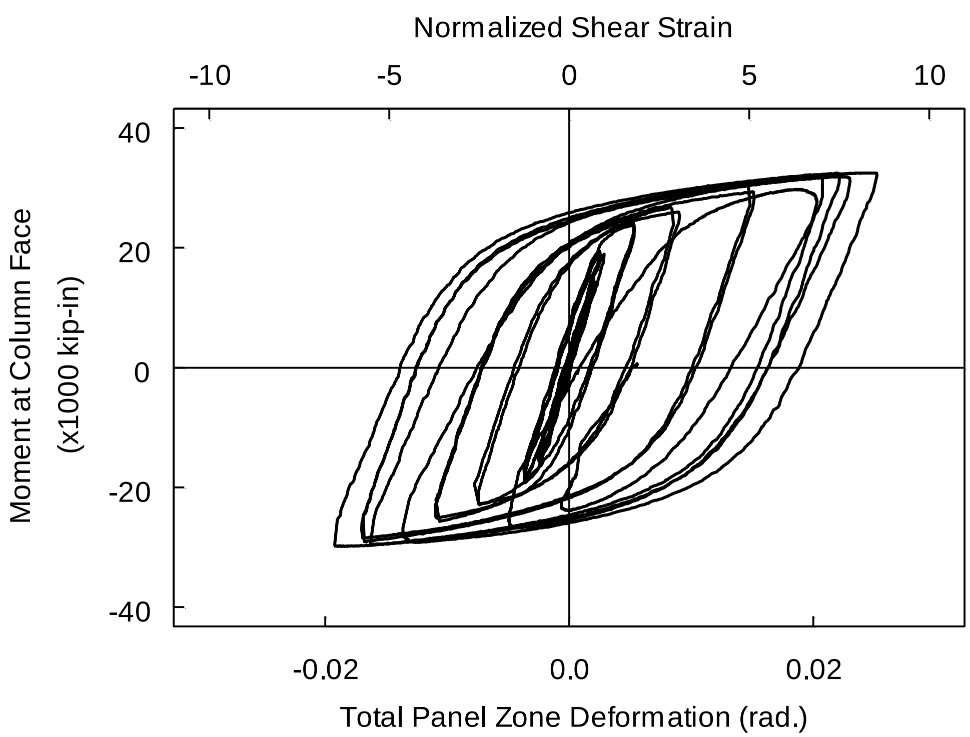
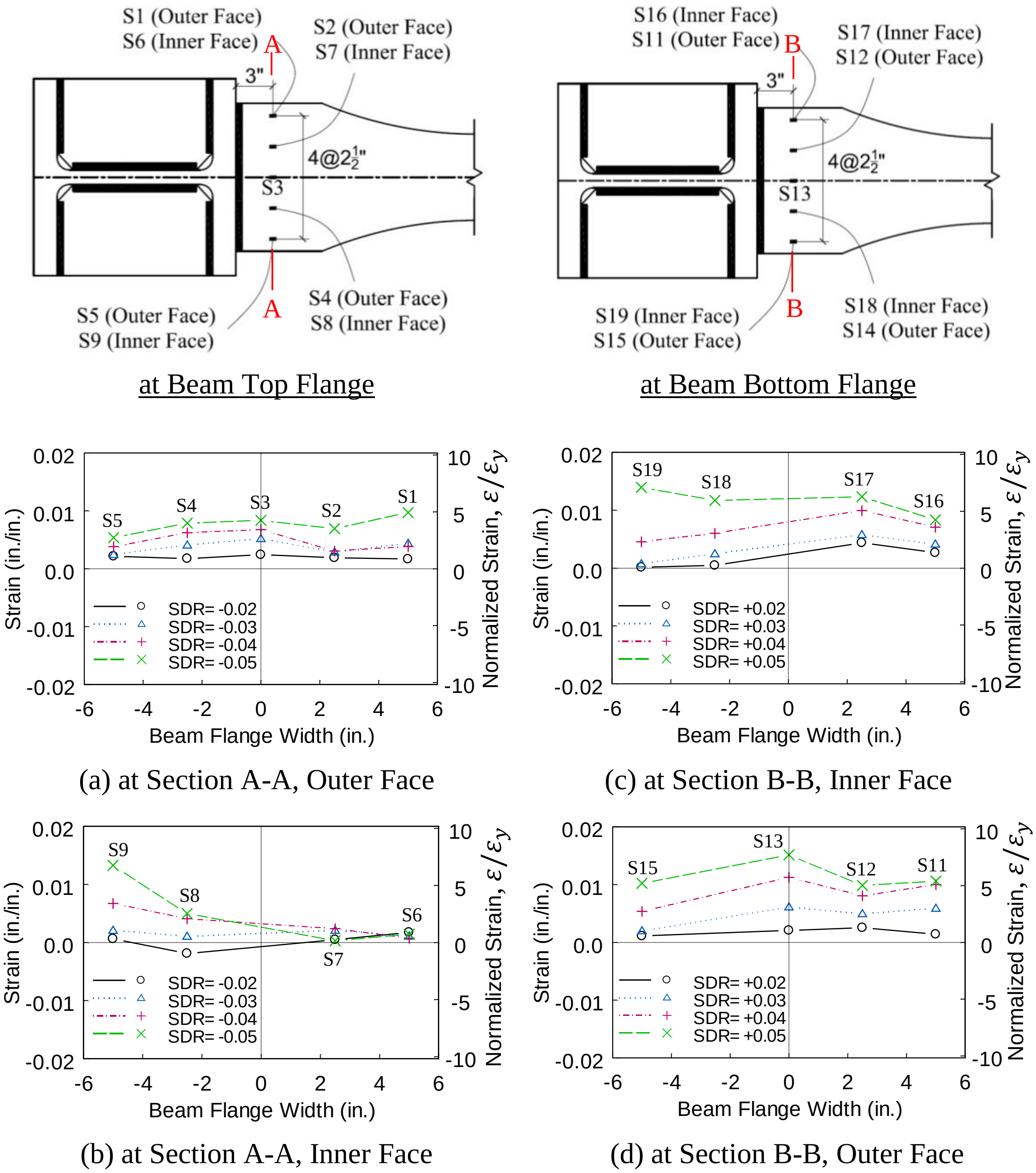


Figure 3.34 Specimen C2 Moment versus Total Panel Zone Shear Deformation Relationship



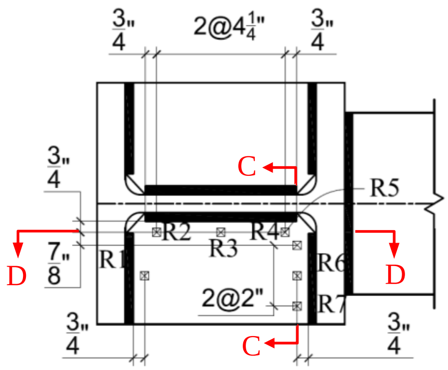
(a) at Section A-A, Outer Face

(c) at Section B-B, Inner Face

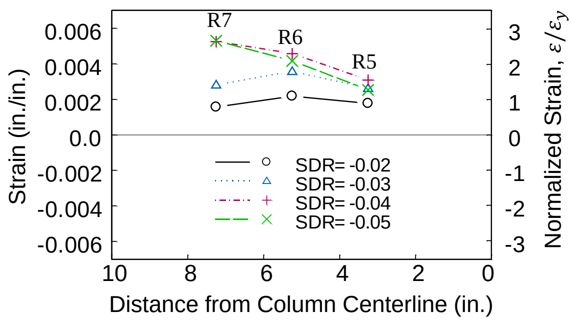
(b) at Section A-A, Inner Face

(d) at Section B-B, Outer Face

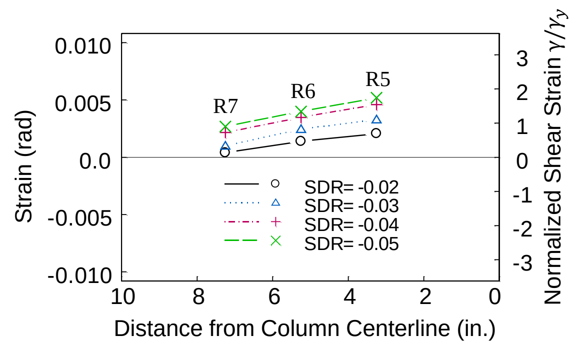
Figure 3.35 Specimen C2 Beam Flange Flexural Strain Profiles



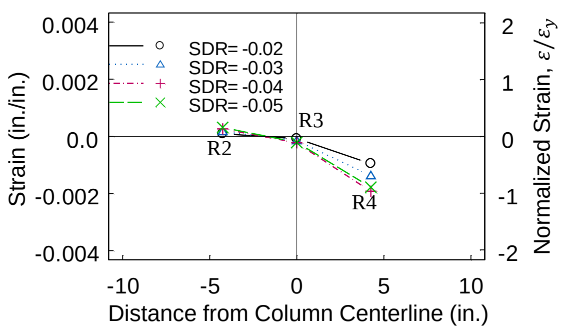
Top Continuity Plate



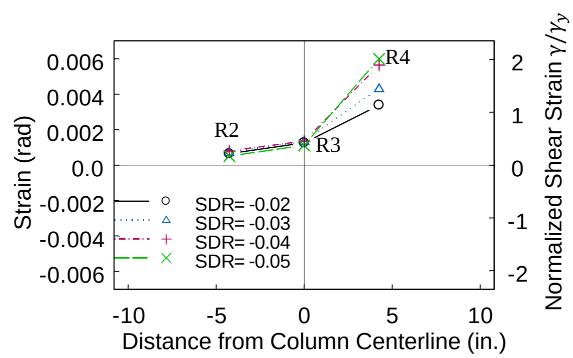
(a) Strain Normal to Flange Weld at Section C-C



(b) Shear Strain at Section C-C

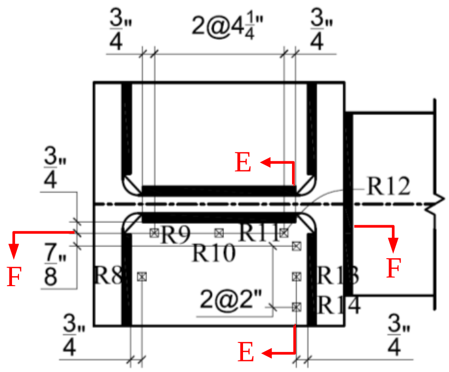


(c) Strain Normal to Web Weld at Section D-D

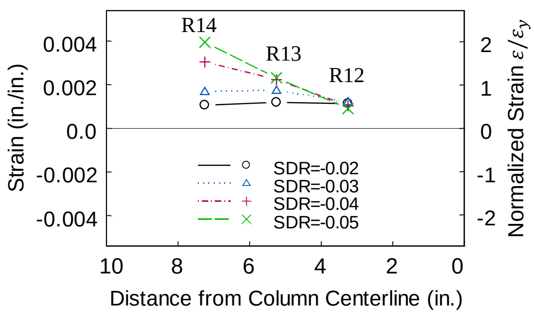


(d) Shear Strain at Section D-D

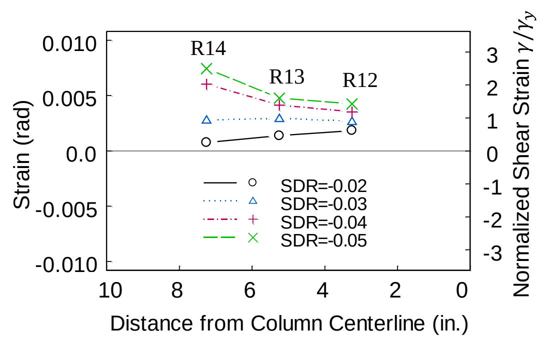
Figure 3.36 Specimen C2 Top Continuity Plate Strain Profiles



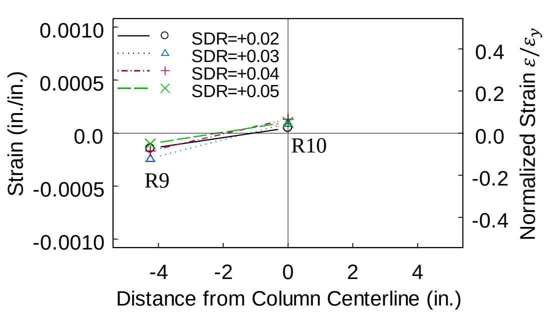
Bottom Continuity Plate



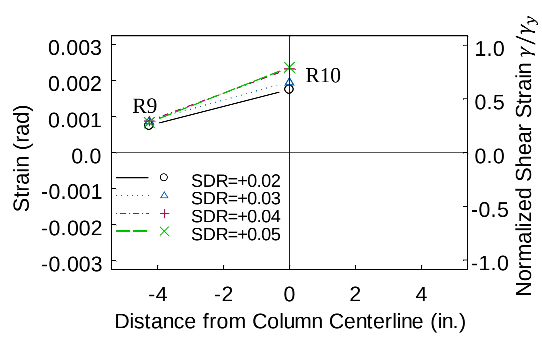
(a) Strain Normal to Flange Weld at Section E-E



(b) Shear Strain at Section E-E

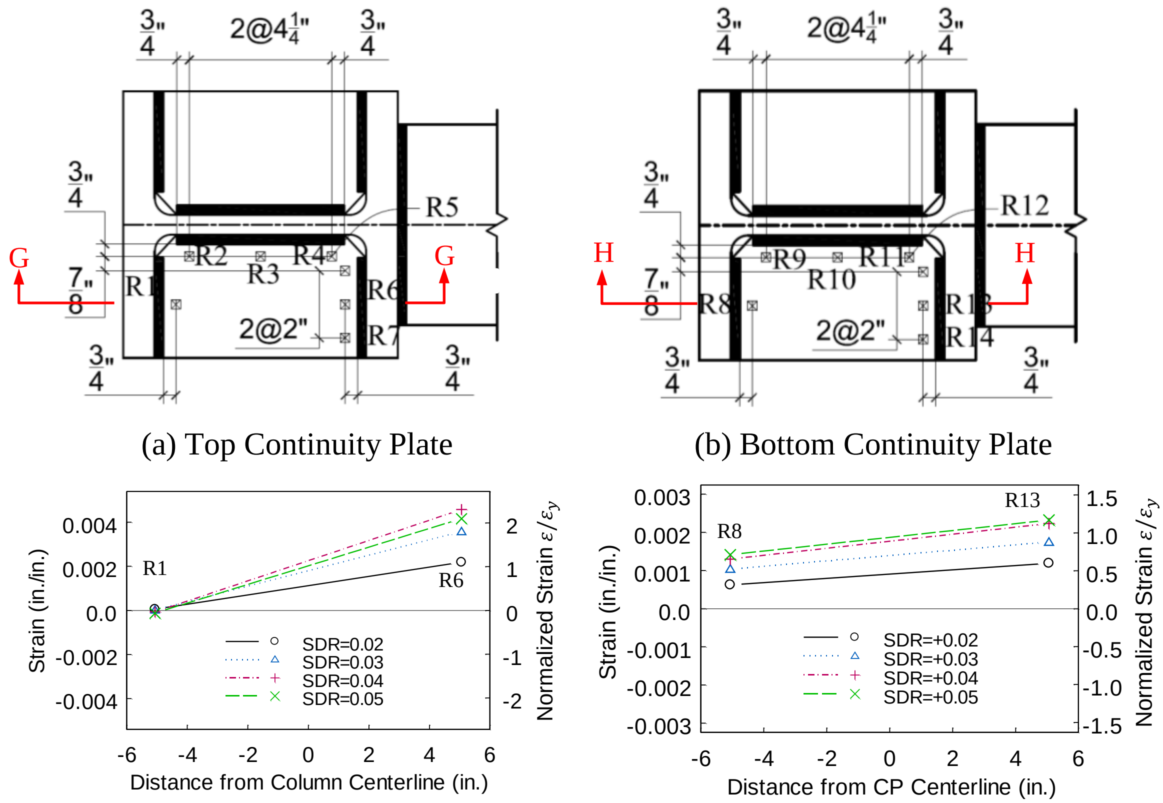


(c) Strain Normal to Web Weld at Section F-F



(d) Shear Strain at Section F-F

Figure 3.37 Specimen C2 Bottom Continuity Plate Strain Profiles



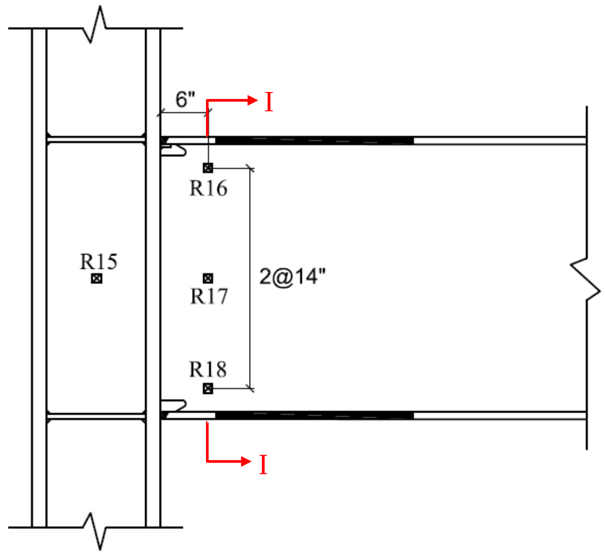
(a) Top Continuity Plate

(b) Bottom Continuity Plate

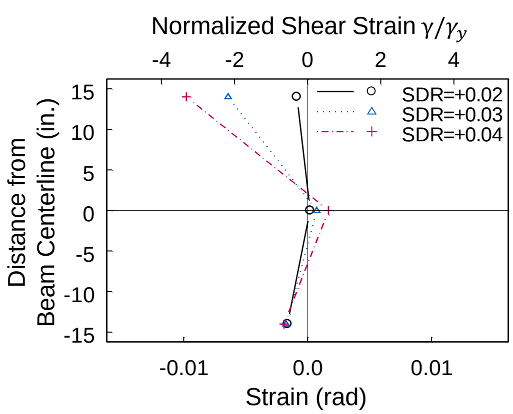
(c) Normal Strain at Section G-G

(d) Normal Strain at Section H-H

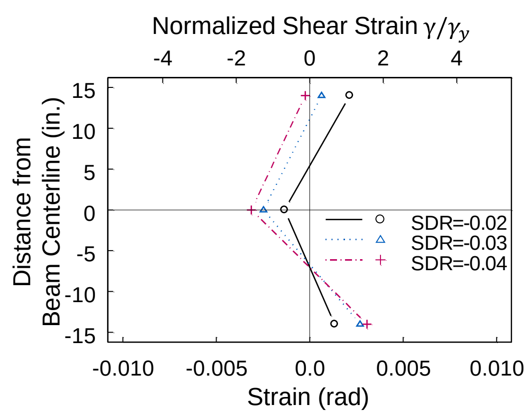
Figure 3.38 Specimen C2 Top and Bottom Continuity Plates Strain Profiles



(a) Section I-I



(b) Positive Excursions



(c) Negative Excursions

Figure 3.39 Specimen C2 Beam Web Shear Strain Profiles

4 ANALYSIS OF TEST RESULTS AND FINITE ELEMENT SIMULATION

4.1 Global Response and Failure Mode Comparison

To experimentally verify a proposed design procedure for the continuity plate weld design, the main variable between the two specimens tested in this research was the column shape; Specimen C1 had a deep (W24) column and Specimen C2 had a shallow (W14) column. Testing showed that fillet welded continuity plates did not experience any damage, and the performances of both RBS connection specimens were no different from those with CJP welds between the continuity plates and the column flanges. Since deep column is prone to twist (Chi and Uang 2002), extra bracings were provided at the top flange near the RBS region and the top end of the column (Figure 2.6); the former was to simulate the bracing effect provided by the concrete slab. Despite this effort, the effect of using a deep column was still significant, as explained below.

The global responses of both specimens are compared in Figure 4.1. Strain gage readings in the column showed that column twisting started at 1.5% drift (Section 3.1.2.2). Therefore, lateral-torsional buckling (LTB) of the beam was more significant [Figure 4.2(a)]. Such coupled column twisting-beam LTB phenomenon caused the strength of the connection to peak at 3% drift and then started to degrade thereafter [Figure 4.1(a)]. Since the simulated top flange bracing was only effective in positive bending, the figure also shows that the strength reached in the negative bending direction was less. For Specimen C2 with a W14 column, column twisting was much less a concern. Therefore, this specimen could reach a higher strength, and strength degradation did not occur until after 4% drift. The higher strength of C2 also means a higher shear in the panel zone, which together with a slightly higher DCR ratio in designing the panel zone (Table 2.2) explains why C2 experienced more significant panel zone shear yielding than C1 [Figure 4.2(b)].

Figure 4.3 summarizes the percentage contributions from the beam, panel zone, and column to the total beam end displacement of both specimens. As expected, beam contributed the most to the total end displacement. For the reason explained above, panel zone of Specimen C2 contributed more to the total displacement; the percentage contribution reduced after 4% drift because the connection strength degraded thereafter.

The panel zone of Specimen C1 could have deformed more, but was limited by the coupled deep column twisting-beam LTB mode.

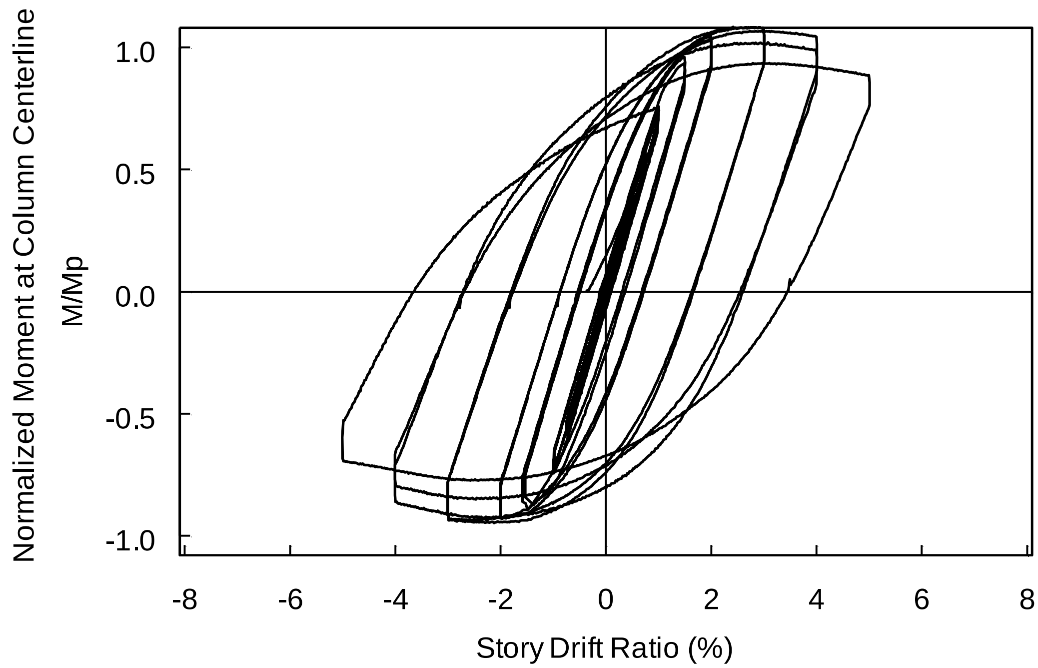
The amount of energy dissipated by each specimen is presented in Figure 4.4, where the energy has been normalized by the plastic moment, M_p, computed based on the tensile coupon test results. The deep-column specimen dissipated less energy.

4.2 Finite Element Analyses

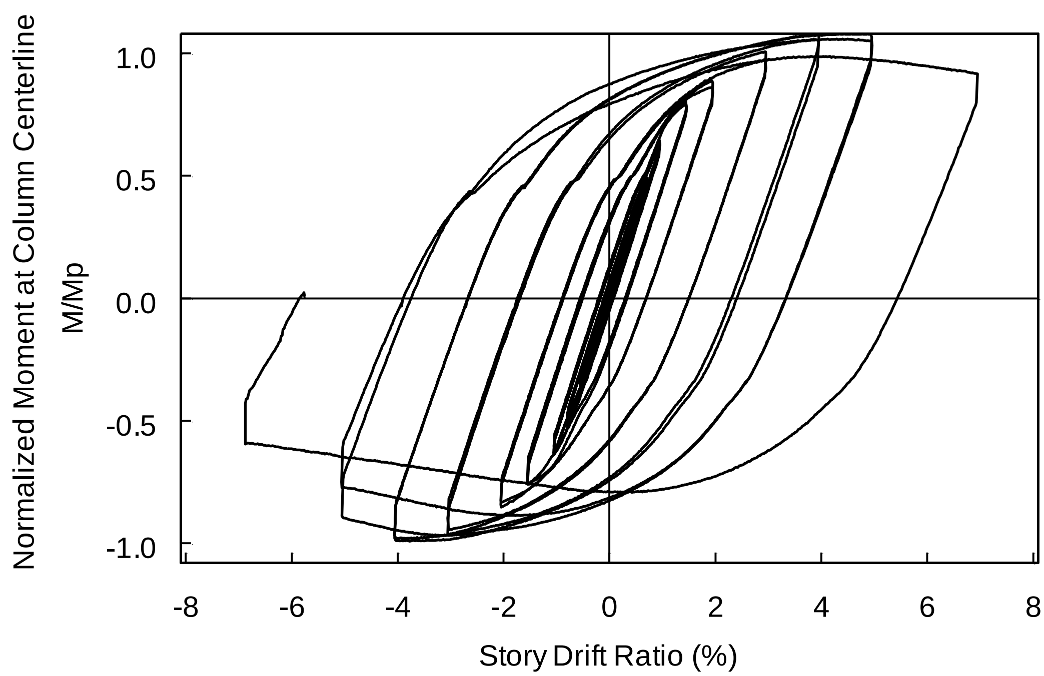
It is difficult to experimentally construct the freebody diagram of the continuity plate from strain gage measurements. Instead, finite element analysis (FEA) by using the commercial software ABAQUS/CAE (2014) was conducted. Freebody diagrams established from the FEA are then compared with those established from the proposed procedure.

Four node, thick-shell brick elements (Type S4R in ABAQUS) were used to model the specimens. Typical steel properties ($E = 29{,}000$ ksi, $\nu = 0.3$) were used in the model to describe the elastic material characteristics. Also for inelastic behavior, following the work of Chaboche (1986), material parameters that could simulate both the kinematic and isotropic hardening responses of an A992/A572 steel coupon under cyclic loading were incorporated. Figure 4.5 shows the FEA models of both specimens. Figure 4.6 compares the experimental and predicted global response of each specimen; the correlation is satisfactory. A comparison of the deformed shapes is presented in Figure 4.7.

Figure 4.8 and Figure 4.9 shows the continuity plate freebody diagrams for both specimens. For one-sided moment connections, the proposed procedure assumes that the left (i.e., the non-loaded column flange) side has no normal force; the normal force from the beam flange is transferred completely to the column web through the continuity plates. The FEA shows that the non-loaded column flange does resist a portion of the normal force from the beam flange; the percentage is higher for shallow columns than for deep columns. This will reduce the shear forces in both the web weld and flange welds. Therefore, the proposed design procedure is somewhat conservative for continuity plate weld design. The conservatism increases when a shallow column is used.



(a) Specimen C1



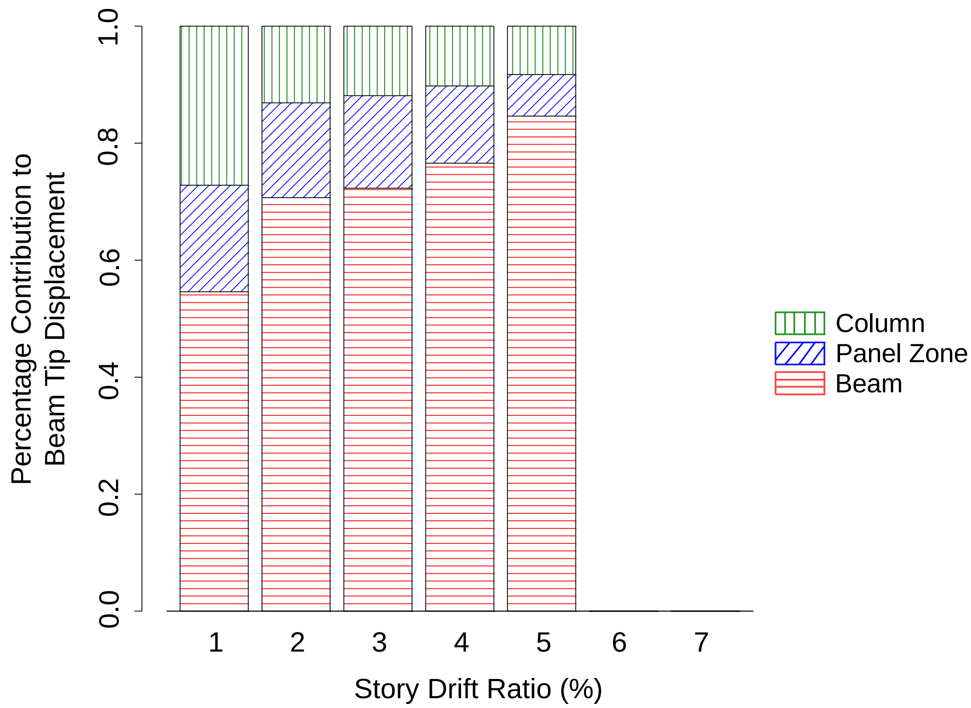
(b) Specimen C2

Figure 4.1 Comparison of Global Responses

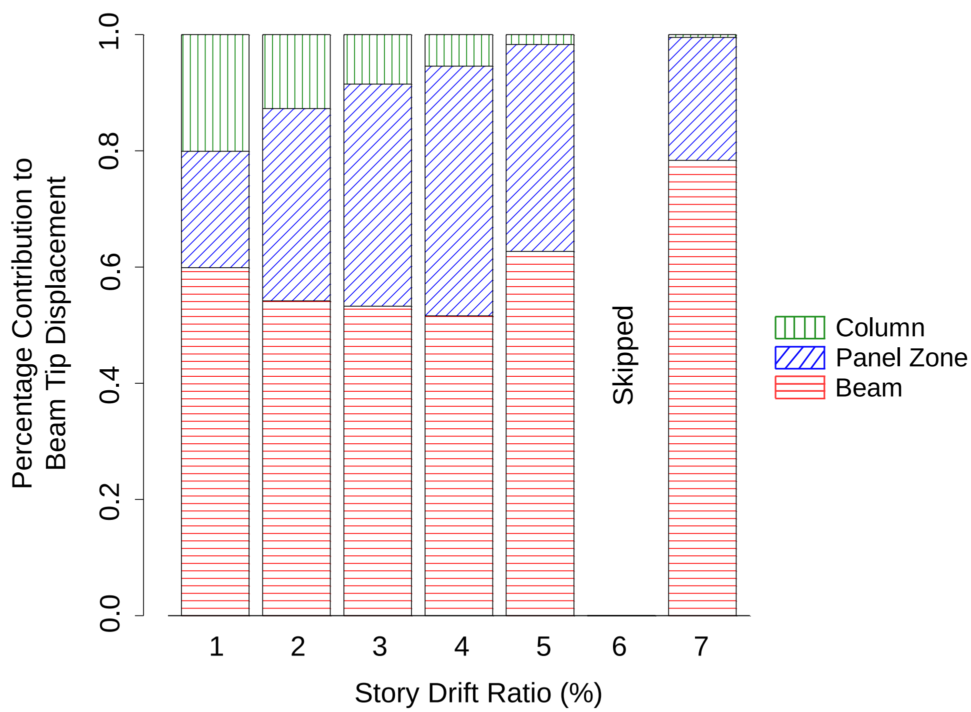
(a) Specimen C1

(b) Specimen C2

Figure 4.2 Comparison of Buckling Mode at 4% Drift

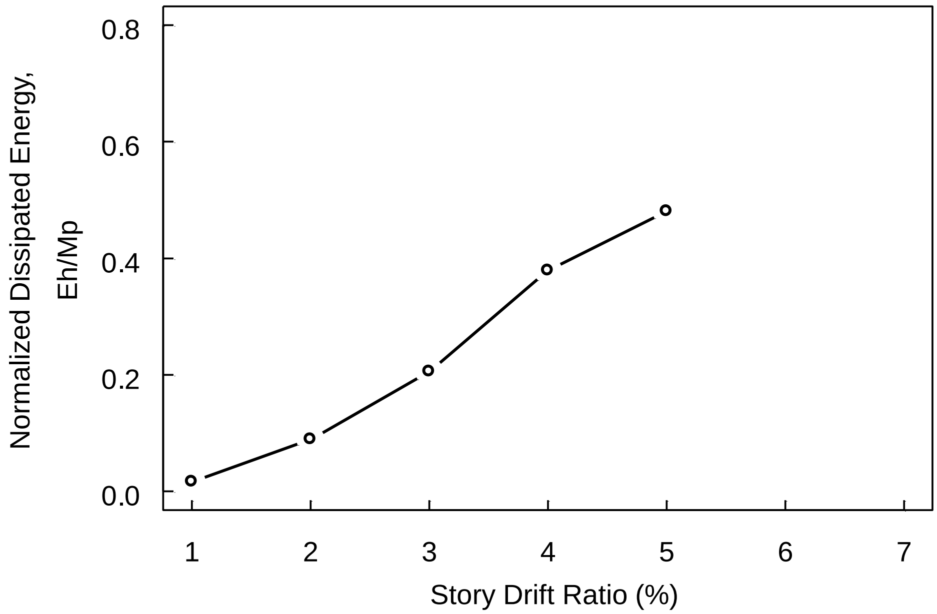


(a) Specimen C1

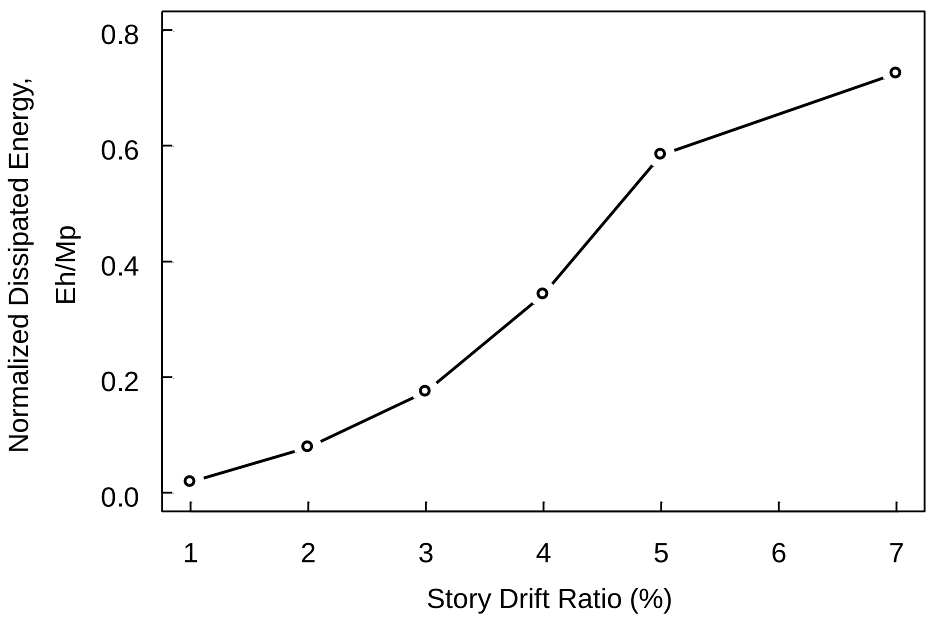


(b) Specimen C2

Figure 4.3 Components of Beam End Displacement

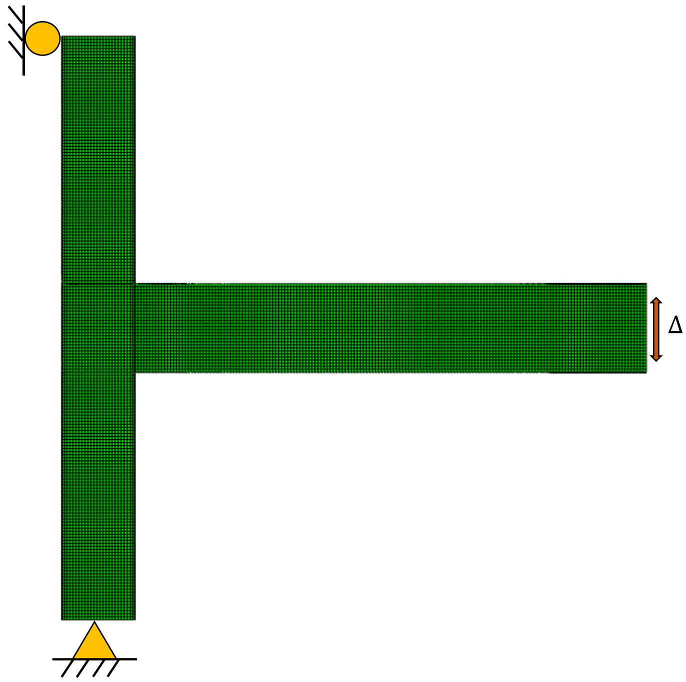


(a) Specimen C1

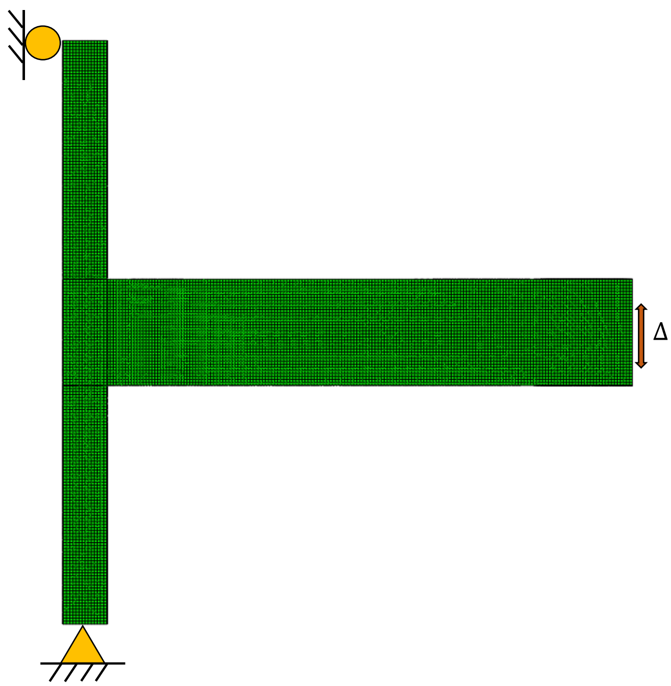


(b) Specimen C2

Figure 4.4 Normalized Dissipated Energy

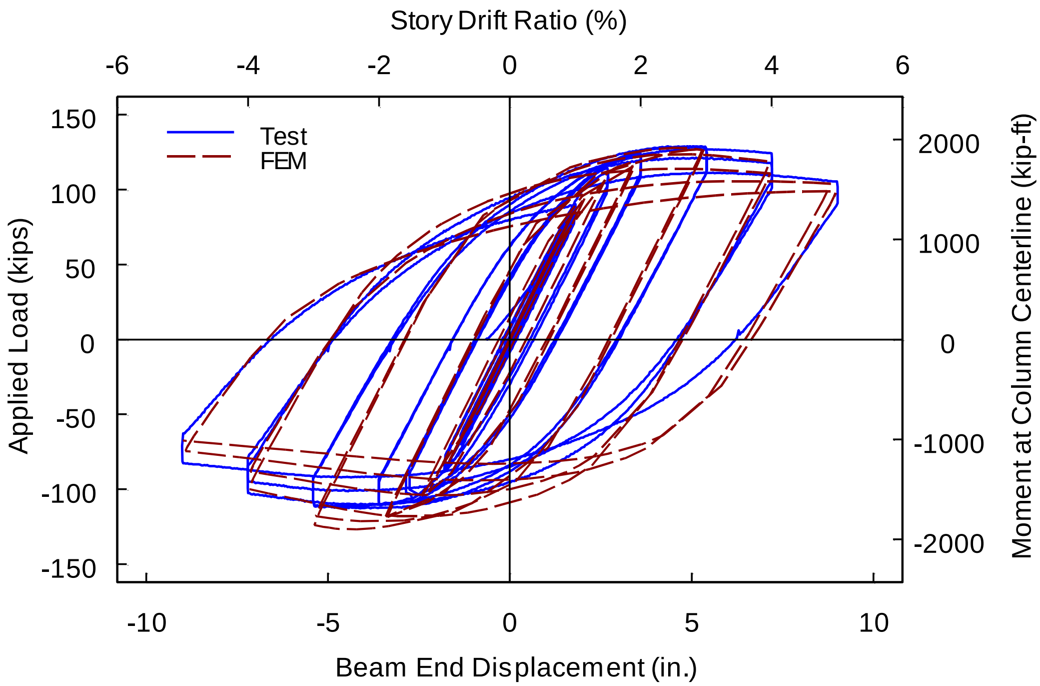


(a) Specimen C1

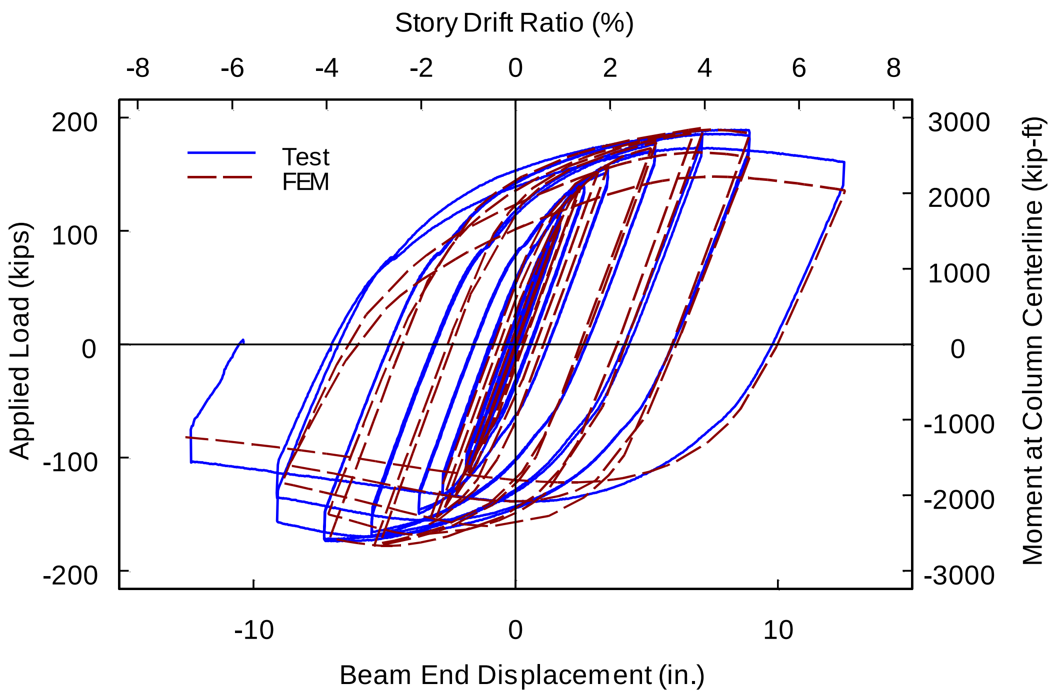


(b) Specimen C2

Figure 4.5 FEM Models

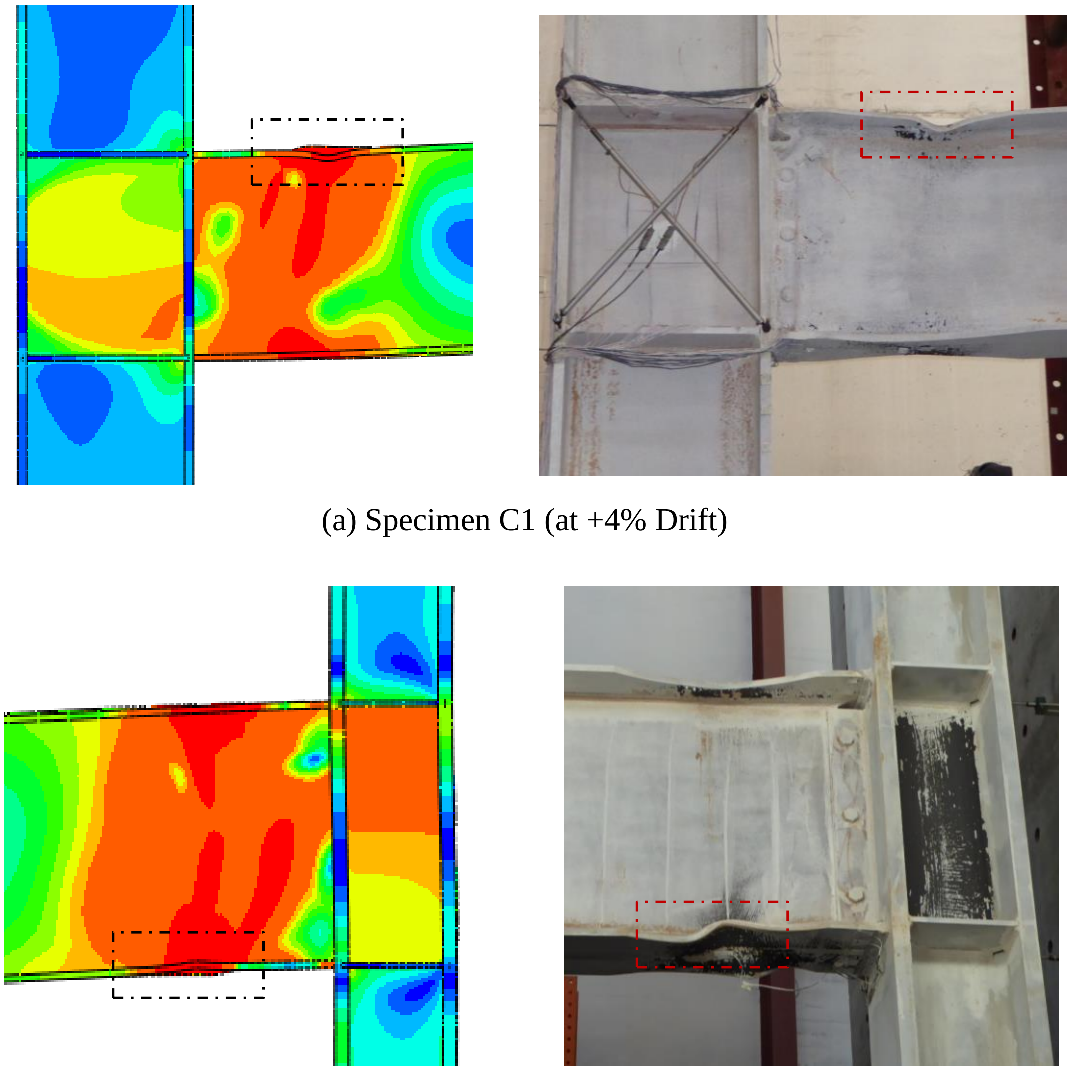


(a) Specimen C1



(b) Specimen C2

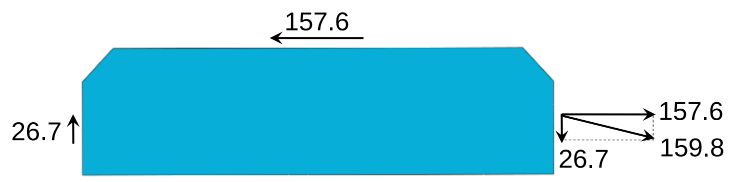
Figure 4.6 Correlation of Global Responses



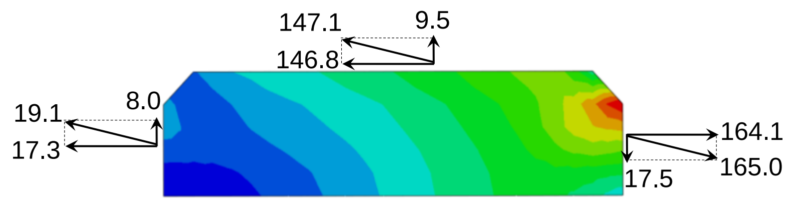
(a) Specimen C1 (at +4% Drift)

(b) Specimen C2 (at -5% Drift)

Figure 4.7 Correlation of Deformed Configurations

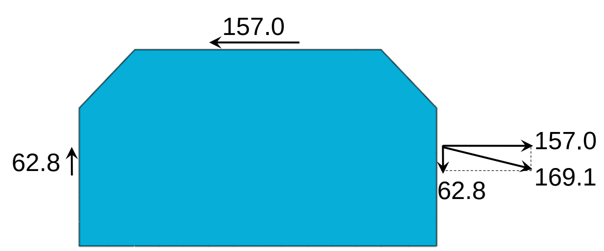


(a) Forces Predicted by Tran et. al, (2013)

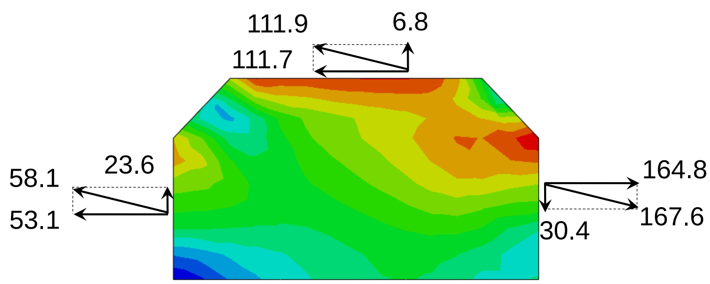


(b) Forces from FEM Analysis

Figure 4.8 Specimen C1 Comparison of Forces Acting on Continuity Plate



(a) Forces Predicted by Tran et. al, (2013)



(b) Forces from FEM Analysis

Figure 4.9 Specimen C2 Comparison of Forces Acting on Continuity Plate

5 SUMMARY, CONCLUSIONS, AND FUTURE RESEARCH NEED

5.1 Summary

Based on a weld detail commonly used in steel moment connection tests conducted in the past, AISC 341 requires that continuity plates in a Special Moment Frame (SMF) be connected to the column flanges by CJP groove welds. This prescriptive requirement, where the calculation of the required forces in the continuity plates is unnecessary, would increase the fabrication cost. As a first step to allowing for other types of weld joints (e.g., fillet welds or partial-point-penetration groove welds) to be used, it is necessary to have a design procedure to quantify the required forces in the continuity plate. Recently, Tran et al. (2013) proposed a procedure that considers the in-plane flexibility (or stiffness) of the continuity plate relative to the out-of-plane flexibility of the column flange being loaded by the beam flange in determining the forces that are transmitted through the continuity plates to the column panel zone.

In the procedure proposed by Tran et al., the edges of the continuity plate next to the column flanges were subjected to both normal and shear forces. This procedure was modified to include the moment component created by the normal force and an eccentricity. As a pilot study to experimentally verify this design procedure, two full-scale, one-sided moment connection specimens with a reduced beam section (RBS) were tested. The specimen design followed AISC 341 and 358, except that the continuity plate thickness and welds were sized based on the modified procedure; the design procedure resulted in fillet welds to connect the continuity plates to the columns. One specimen (C1) used a deep (W24) column, and the other one (C2) had a shallow (W14) column. The continuity plates of Specimen C2 were also undersized to evaluate the effect of yielded continuity plates on the connection performance. While still satisfying the code requirement, the demand-capacity ratio of the panel zone strength was high (0.90 and 0.95 for C1 and C2, respectively) such that the effect of column flange kinking at the fillet welds locations could be evaluated. A992 steel was specified for the beams and columns, and A572 Gr. 50 steel was used for the continuity plates. Both specimens were tested cyclically by using the AISC loading protocol.

5.2 Conclusions

Based on the test results and the associated analytical studies, the following conclusions can be made.

(1) Both specimens performed well and met the 0.04 rad. story drift requirement specified in AISC 341. Using the fillet welds did not affect the performance of the connection; as expected, yielding and buckling in the RBS region as well as shear yielding in the panel zone were observed.

(2) No damage in the fillet welds connecting the continuity plates to the column was observed, indicating that the AISC 341 prescriptive requirement for expensive CJP groove welds can be conservative and may not be always needed.

(3) AISC 341 also specifies a prescriptive requirement for the thickness of the continuity plates: half and full thickness of the beam flange for the exterior and interior moment connections, respectively (the full thickness requirement has been changed to three-quarter thickness for the interior connection in the 2016 edition of AISC 341). The proposed design procedure may result in a continuity plate thickness different from that required by AISC 341. Test results showed that such prescriptive requirement may not be needed; the proposed procedure will consider directly the effect of thickness on the required forces in the continuity plates.

(4) The interface between the continuity plate and the column flanges is subjected to not only normal force but also shear force and moment; the moment is produced by the normal force together with an eccentricity (Figure 1.2 and Figure 1.3). The effect of moment and shear can be significant, especially for continuity plates in shallow columns (Table 2.4). The combined effect of normal force, shear force, and moment needs to be considered in checking the strength of continuity plates (Eq. (1.10)).

(5) AISC 341 implicitly assumes that continuity plates shall remain essentially elastic per the capacity design principles. The continuity plate thickness of one specimen (C2) was undersized. Testing showed that the connection performance was not affected although the continuity plates had yielded.

5.3 Future Research Need

This pilot test program demonstrated that the prescriptive requirement in AISC 341 that requires a specific continuity plate thickness and expensive CJP groove welds to connect the continuity plates to the column flanges may not always be needed. Only two one-sided moment connections were tested in this research. Before the proposed design procedure can be implemented, only two tests are not enough and additional experimental verification is needed to establish the confidence level. Further testing should include two-sided moment connections, different connection types, inclusion of doubler plates, use of partial-joint-penetration groove welds, etc.

For one-sided connections, AISC 341 has been requiring the continuity plate thickness to be at least one-half of the thickness of the beam flange. For two-sided connections, AISC 341 in its 2016 edition reduces the required thickness from full to three-quarter thickness of the beam flange. Experimental verification is needed since these minimum thickness requirements lack any experimental justification.

6 REFERENCES

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[3] AISC. (2010b). ANSI/AISC 358-10, *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications*, American Institute of Steel Construction, Chicago, IL.

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[6] Chaboche, J.L. (1986), "Time-Independent Constitutive Theories for Cyclic Plasticity," International Journal of Plasticity, Vol. 2, No. 2, pp. 149-188.

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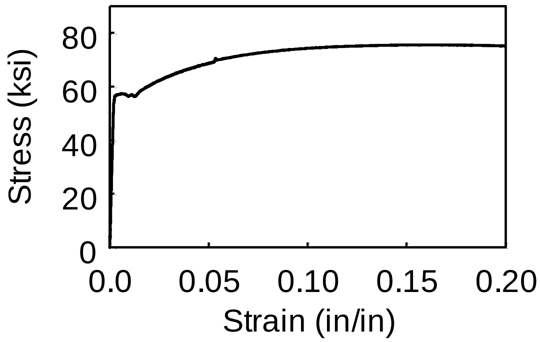
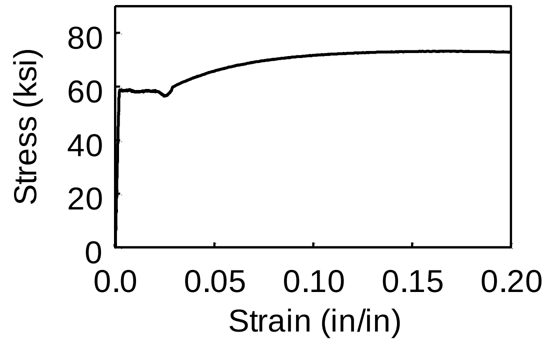
[12] Yu, Q.S., Gilton, C. Uang, C.M. (2000). "Cyclic Response of RBS Moment Connections: Loading Sequence and Lateral Bracing Effects," *Report No. SSRP-*

99/13, Department of Structural Engineering, University of California, San Diego, Jolla, CA.

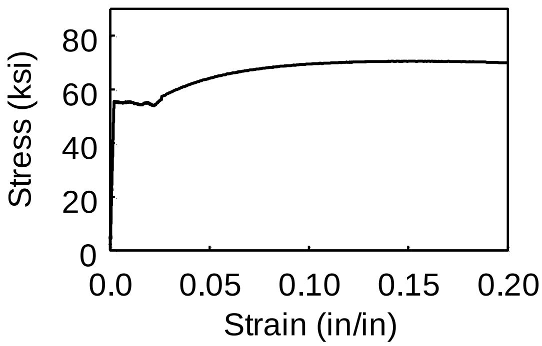
Appendix A Tensile Coupon Test Results



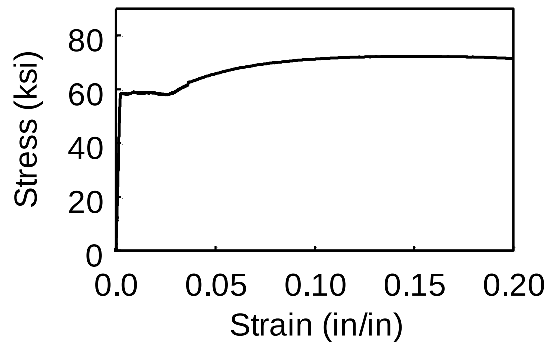
(a) Specimen C1, Beam Flange



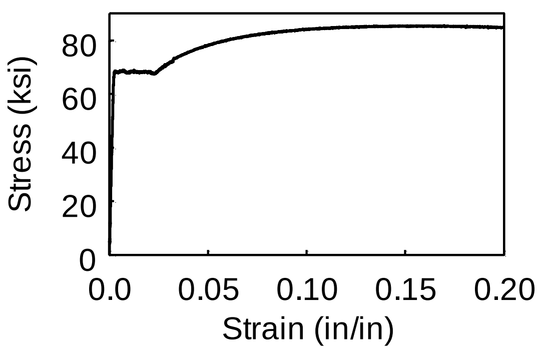
(b) Specimen C1, Beam Web



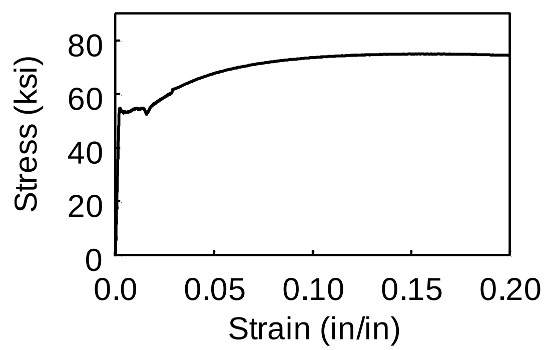
(c) Specimen C1, Column Flange



(d) Specimen C1, Column Web

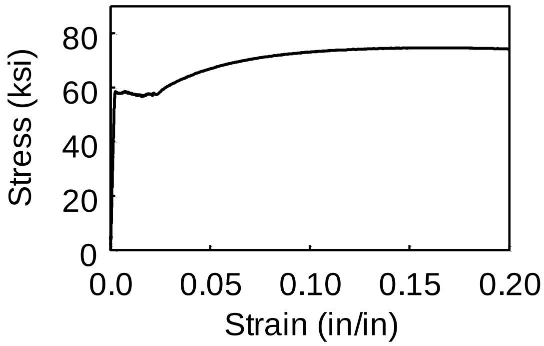


(e) Specimen C1, Continuity Plate

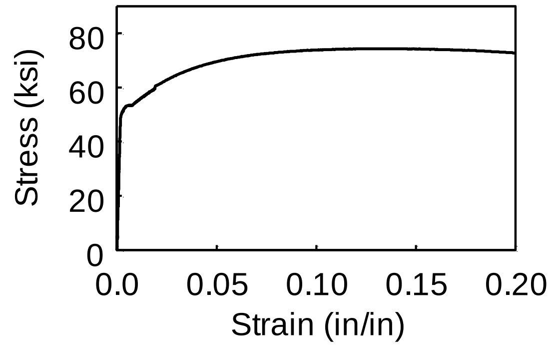


(f) Specimen C2, Beam Flange

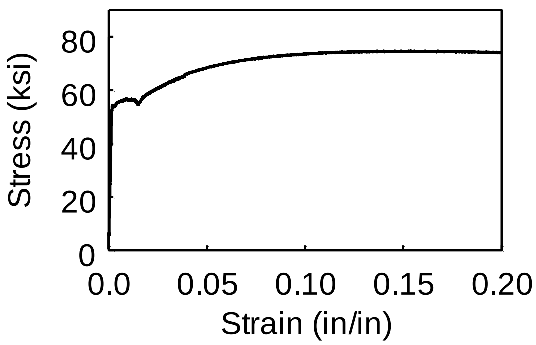
Figure A.1 Tensile Coupon Stress-Strain Relationships



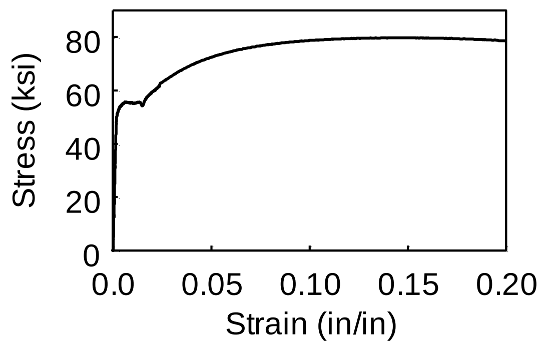
(g) Specimen C2, Beam Web



(h) Specimen C2, Column Flange



(i) Specimen C2, Column Web



(j) Specimen C2, Continuity Plate

Figure A.1 Tensile Coupon Stress-Strain Relationships (continued)

Appendix B Mill Certificates

1500-01298
3299

QUALITY ASSURANCE
REPORT OF TEST AND ANAYLSES

US HWY 12 Burns Harbor, Indiana

SHIPMENT NO.	DATE SHIPPED	CAR OR VEHICLE NO.			
8GA-08120	10-05-15	CUSTOMER TRUCK	T	SYST	PAGE 1

SOLD TO:
KLOECKNER METALS CORP
2465 W HOUSTON AVE
APACHE JUNCTION AZ 85220

SHIP TO:
KLOECKNER METALS CORP
2465 WEST HOUSTON AVE
APACHE JUNCTION AZ 85120

QUALITY STEEL MELTED & MANUFACTURED IN THE U. S. A.
PLATES - AASHTO M270-12 GR 50 KLD FINE GRAIN
PRAC NO IMPACTS REQUIRED TYPE 2,
ASTM A709-11 GR 50, ASTM A572-07 GR 50
TEST CERTS ARE PREPARED IN ACCORD WITH PROCEDURES OUTLINED IN EN
EN 10204:2004 TYPE 3.1
MFST - MFST MILL SERIAL# & PATTERN# MFST PROC ON
GH820-3657A LIFT MAX 15 TON-SIZES & GRADES SEP
UNLDG FORK LIFT-SIDE FOR ULTIMATE DELIVERY
LATER ADDITION 05/08/15
CO# APA-6976762 GH 820-5120A

NOTE / SERIAL NUMBER	PAT NO.	HEAT NUMBER	NO. PCS.	THICKNESS INCHES	WIDTH OR DIA. INCHES	LENGTH INCHES	WEIGHT POUNDS	YIELD POINT PSI	TENSILE STRENGTH PSI	AF FRAC. ELONG. IN	%	RED. %
X54210801		811K12570	1	.625	96	240	4084	59200	84000	8	21	
X54210802		811K12570	1	.625	96	240	4084	59200	84000	8	21	
X54210803		811K12570	1	.625	96	240	4084	59200	84000	8	21	
X54210903		813K75180	1	.625	96	240	4084	58600	82300	8	23	
								56500	82900	8	22	

Q-QUENCH TEMPERATURE T-TEMPER TEMPERATURE N-NORMALIZE TEMPERATURE

SERIAL NUMBER	PAT NO.	HEAT NUMBER	HARD BHN	BEND	THICKNESS INCHES	TYPE	SIZE	DIR	TEST TEMP F	CHARPY IMPACT ENERGY FT LBS 1	2	3	SHEAR(%) 1	2	3	LAT. EXP MILS 1	2	3

HEAT NUMBER	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Ti	Al	B	Cb	N	Sn	MCQUAID GRAIN SIZE
811K12570	.19	1.22	.014	.004	.278	.014	.01	.03	.003	.057	.002	.031	.0002	.002	.006	.002	
813K75180	.18	1.22	.013	.004	.279	.024	.01	.04	.005	.056	.002	.028	.0002	.002	.004	.003	

I certify that the above results are a true and correct copy of actual results contained in records maintained by ArcelorMittal Burns Harbor and are in full compliance with the requirements of the specification cited above. This test report cannot be altered and must be transmitted intact with any subsequent third party test reports, if required.

D. W. ELWOOD PER WNK

BHPLTRPT.TIF SUPV. QUALITY ASSURANCE

QUALITY ASSURANCE
REPORT OF TEST AND ANAYLSES

US HWY 12 Burns Harbor, Indiana

SHIPMENT NO.	DATE SHIPPED	CAR OR VEHICLE NO.	
8GA-08120	10-05-15	CUSTOMER TRUCK T SYST	PAGE 2

SOLD TO: KLOECKNER METALS CORP
2465 W HOUSTON AVE
APACHE JUNCTION AZ 85220

SHIP TO: KLOECKNER METALS CORP
2465 WEST HOUSTON AVE
APACHE JUNCTION AZ 85120

NOTE	SERIAL NUMBER	PAT NO.	HEAT NUMBER	NO. PCS.	SIZE AND QUANTITY THICKNESS	WIDTH OR DIA.	LENGTH	WEIGHT	YIELD POINT	TENSILE STRENGTH	AF FRAC. ELONG.		RED.
					INCHES	INCHES	INCHES	POUNDS	PSI	PSI	IN	%	%

QUALITY STEEL MELTED & MANUFACTURED IN THE U. S. A.
PLATES - AASHTO M270-12 GR 50 KLD FINE GRAIN
PRAC NO IMPACTS REQUIRED TYPE 2,
ASTM A709-11 GR 50, ASTM A572-07 GR 50
TEST CERTS ARE PREPARED IN ACCORD WITH PROCEDURES OUTLINED IN EN
EN 10204:2004 TYPE 3.1
MFST - MFST MILL SERIAL# & PATTERN# MFST PROC ON
GH820-3657A LIFT MAX 15 TON-SIZES & GRADES SEP
UNLDG FORK LIFT-SIDE FOR ULTIMATE DELIVERY
LATER ADDITION 05/08/15
CO# APA-6976762 GH 820-5120A

SERIAL NUMBER	HEAT NUMBER	NO. PCS.	THICKNESS	WIDTH	LENGTH	WEIGHT	YIELD POINT	TENSILE STRENGTH	ELONG. IN	ELONG. %
	813K75180	1	.625	96	240	4084	58600	82300	8	23
							56500	82900	8	22
X54210904										
	813K75180	1	.625	96	240	4084	58600	82300	8	23
							56500	82900	8	22
X54210905										
	823K75240	1	.625	96	240	4084	60300	84800	8	23
X54211003										
	823K75240	1	.625	96	240	4084	60300	84800	8	23
X54211004										

Q-QUENCH TEMPERATURE T-TEMPER TEMPERATURE N-NORMALIZE TEMPERATURE

SERIAL NUMBER	PAT NO.	HEAT NUMBER	HARD BHN	BEND	THICKNESS INCHES	TYPE	SIZE	DIR	TEST TEMP. F	CHARPY IMPACT ENERGY FT LBS 1	2	3	SHEAR(%) 1	2	3	LAT. EXP MILS 1	2	3

HEAT NUMBER	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Ti	Al	B	Cb	N	Sn	MCQUAID GRAIN SIZE
813K75180	.18	1.22	.013	.004	.279	.024	.01	.04	.005	.056	.002	.028	.0002	.002	.004	.003	
823K75240	.18	1.24	.014	.003	.297	.014	.01	.03	.005	.066	.002	.041	.0002	.002	.005	.002	

I certify that the above results are a true and correct copy of actual results contained in records maintained by ArcelorMittal Burns Harbor and are in full compliance with the requirements of the specification cited above. This test report cannot be altered and must be transmitted intact with any subsequent third party test reports, if required.

D. W. ELWOOD PER WNK
SUPV. QUALITY ASSURANCE

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POSCO

Mill Test Certificate/검사증명서

Certificate No./증명서번호 : 140922-FP01PS-00042-0001
Date of Issue/발행일자 : Oct., 08, 2014

Order No./계약번호 : 01S1297247

Supplier /주문자 : GS GLOBAL CORP.

Customer /고객사 : SCHUFF STEEL

PO No./주문번호 : 1500-01034

Commodity /품명 : PLATE

Spec & Type /규격 : ASTM A572-50/A709-50

1500 010 34

Size/치수	Product No. /제품번호	Quantity /수량	Weight /중량 (kg)	Heat No. /제강번호	Position	Tensile Test /인장시험 YP (㎫)	TS (㎫)	EL (%)	Division	Chemical Composition/화학성분 (%) C	Si	Mn	P	S	Cr	Ni	Cu	Mo	Nb	V
0.5000"x96"x240"	PB60760301-0307	7	10,374	SB15106	T	429	574	23	L	0.1503	0.347	1.377	0.0140	0.0020	0.023	0.008	0.010	0.003	0.024	0.003
									P	0.1437	0.345	1.388	0.0147	0.0019	0.022	0.008	0.010	0.001	0.024	0.002
0.5000"x96"x240"	PB60760404-0405	2	2,964	SB15106	T	428	568	24	L	0.1503	0.347	1.377	0.0140	0.0020	0.023	0.008	0.010	0.003	0.024	0.003
									P	0.1437	0.345	1.388	0.0147	0.0019	0.022	0.008	0.010	0.001	0.024	0.002
0.5000"x96"x240"	PB60760201-0205	5	7,410	SB15106	T	423	564	24	L	0.1503	0.347	1.377	0.0140	0.0020	0.023	0.008	0.010	0.003	0.024	0.003
									P	0.1437	0.345	1.388	0.0147	0.0019	0.022	0.008	0.010	0.001	0.024	0.002
0.5000"x96"x240"	PB60760101-0107	7	10,374	SB15106	T	426	574	22	L	0.1503	0.347	1.377	0.0140	0.0020	0.023	0.008	0.010	0.003	0.024	0.003
									P	0.1437	0.345	1.388	0.0147	0.0019	0.022	0.008	0.010	0.001	0.024	0.002
0.5000"x96"x240"	PB60760001-0007	7	10,374	SB15106	T	431	570	25	L	0.1503	0.347	1.377	0.0140	0.0020	0.023	0.008	0.010	0.003	0.024	0.003
									P	0.1437	0.345	1.388	0.0147	0.0019	0.022	0.008	0.010	0.001	0.024	0.002
0.5000"x96"x240"	PC22358501-8507	7	10,374	SB15303	T	426	570	25	L	0.1513	0.355	1.376	0.0132	0.0017	0.026	0.013	0.019	0.000	0.024	0.003
									P	0.1532	0.366	1.362	0.0147	0.0016	0.056	0.029	0.039	0.000	0.022	0.006
0.5000"x96"x240"	PC22453301-3307	7	10,374	SF47936	T	433	579	22	L	0.1550	0.350	1.404	0.0108	0.0023	0.023	0.017	0.024	0.003	0.024	0.003
									P	0.1540	0.352	1.406	0.0113	0.0021	0.023	0.017	0.024	0.002	0.026	0.002
*** Sub Total (010) ***		42	82,244 (kg)																	
0.6250"x96"x240"	PC22249702-9707	6	11,112	SB15303	T	408	565	24	L	0.1513	0.355	1.376	0.0132	0.0017	0.026	0.013	0.019	0.000	0.024	0.003
									P	0.1470	0.357	1.384	0.0138	0.0017	0.019	0.013	0.016	0.000	0.024	0.003
0.6250"x96"x240"	PC22249501	1	1,852	SB15303	T	421	574	26	L	0.1513	0.355	1.376	0.0132	0.0017	0.026	0.013	0.019	0.000	0.024	0.003
									P	0.1470	0.357	1.384	0.0138	0.0017	0.019	0.013	0.016	0.000	0.024	0.003
0.6250"x96"x240"	PC22249901-9907	7	12,964	SB15303	T	419	573	22	L	0.1513	0.355	1.376	0.0132	0.0017	0.026	0.013	0.019	0.000	0.024	0.003
									P	0.1470	0.357	1.384	0.0138	0.0017	0.019	0.013	0.016	0.000	0.024	0.003
*** Sub Total (020) ***		14	25,928 (kg)																	
0.7500"x96"x240"	PB60761201-1206	6	13,332	SB15106	T	391	559	25	L	0.1503	0.347	1.377	0.0140	0.0020	0.023	0.008	0.010	0.003	0.024	0.003
									P	0.1437	0.345	1.388	0.0147	0.0019	0.022	0.008	0.010	0.001	0.024	0.002
0.7500"x96"x240"	PB60761301-1307	7	15,554	SB15106	T	409	558	25	L	0.1503	0.347	1.377	0.0140	0.0020	0.023	0.008	0.010	0.003	0.024	0.003
									P	0.1437	0.345	1.388	0.0147	0.0019	0.022	0.008	0.010	0.001	0.024	0.002

* Position - T : Top, M : Middle, B : Bottom
* Tensile Test. Direction : Transversal, Gauge Length : 200mm(Rectangular),
  YP Method : 0.2% off-set
* Division - L : Ladle Analysis, P : Products Analysis
* Supply Condition : As-Rolled unless otherwise Heat Treated.

We hereby certify that the material herein has been made in accordance with the order and above specification.
This material has been made by vacuum degassing process. This material is fine grained steel.
This material has been fully killed and made by basic oxygen process.
Test Certificate is issued according to EN10204 3.1.

This Mill Test Certificate cannot be copied for any purpose.

Surveyor To :

M.S. JANG

POSCO | Pohang Works, 6262, Donghaean-ro, Nam-gu, Pohang-si, Gyeongsangbuk-do, 790-785, Korea | <PAGE : 2> | Chief of material testing section | Man Soo, Jang

995170-0000

Page 1/1

GERDAU

US-ML-PETERSBURG
25801 HOFHEIMER WAY
PETERSBURG, VA 23803-8905
USA

CERTIFIED MATERIAL TEST REPORT

CUSTOMER SHIP TO BROWN-STRAUSS STEEL 14970 JURUPA ST FONTANA,CA 92337 USA	CUSTOMER BILL TO BROWN STRAUSS STEEL DIVISION O 2495 URAVAN ST AURORA,CO 80011-3539 USA	GRADE A992/A572-50
SALES ORDER 2485543/000030	CUSTOMER MATERIAL N°	SHAPE / SIZE Wide Flange Beam / 36 X 150# / 920 X 223
CUSTOMER PURCHASE ORDER NUMBER 09127	BILL OF LADING 1330-0000059150	DATE 09/04/2015

LENGTH	WEIGHT	HEAT / BATCH
50'00"	15,000 LB	60114091/04

SPECIFICATION / DATE or REVISION
ASTM A6-13A
ASTM A709-13A
ASTM A992-11, A572-13A
CSA G40.21-13 345WM

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.10	1.17	0.011	0.028	0.23	0.38	0.17	0.15	0.044	0.019	0.002	0.018	0.003

CHEMICAL COMPOSITION

CEqyA6 %
0.37

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	Y/T rati %	G/L Inch
57300	74600	395	514	0.768	8.000
56700	75600	391	521	0.750	8.000

MECHANICAL PROPERTIES

G/L mm	Elong. %
200.0	27.60
200.0	25.10

COMMENTS / NOTES

PMNF

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

Bhaskar — BHASKAR YALAMANCHILI, QUALITY DIRECTOR

Alice L. Pitchford — ALICE PITCHFORD, QUALITY ASSURANCE MGR.

995170.000d

Invoice No.	712366
Bill of Lading	207742
Customer No.	7603
Customer P.O	09064

NUCOR-YAMATO STEEL CO.
P.O. BOX 1228: BLYTHEVILLE, AR 72316

PLZT*1

CERTIFIED MILL TEST REPORT
100% Melted and Manufactured in U.S.A
All Shapes produced by Nucor-Yamato Steel are cast and rolled to a fully killed and fine grain practice

Date 2015-08-25

SOLD TO
BROWN STRAUSS STEEL CO.
2495 URAVAN ST
AURORA CO 80011
USA

SHIP TO
BROWN STRAUSS-FONTANA
C/O KEEP ON TRUCKING BNSF
R/R RANCHO CUCAMUNGA, CA FOR TRK
DEL TO FONTANA CA 92335
USA

ASTM A992/A992M-11 A572/A572M GR50-13a
ASTM A709/A709M-13a GR50 (345)
ASTM A709/A709M-13a GR50S (345S)
CSA G40.21-13 50WM (345WM)
ASTM A6/A6M-14

Item	Item Description	QTY	Heat#	Yield to Tensile Ratio	Yield Strength KSI / MPa	Tensile Strength KSI / MPa	ELONG %	Charpy Impact Temp °F / °C	Charpy Impact Energy ft•lbf / J	Loc	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	CE	Sn	Pcm	Cl
1	W30X116.0 50 ft 0 in W760X173 (15.24 m)	3	443484	0.78 0.79	56 57 386 393	72 72 496 496	29 27				.08	1.13	.016	.027	.23	.25	.10	.14	.04	.00	.019	.33	.01	.17	
2	W30X116.0 55 ft 0 in W760X173 (16.76 m)	1	443654	0.77 0.77	55 54 379 372	71 70 490 483	28 28				.08	1.10	.011	.018	.18	.25	.10	.10	.03	.00	.021	.31	.01	.16	

ELONGATION BASED ON 8.00 INCH GAUGE LENGTH

Pcm= C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B(B=Approx .0005)

Corrosion Index= 26.01(%Cu)+3.88(%Ni)+1.2(%Cr)+1.49(%Si)+17.28(%P)-7.29(%Cu)(%Ni)-9.10(%Ni)(%P)-33.39(%Cu)^2

ISO 9001:2008 certified (Registration # 0985-07).

All mechanical testing is performed by the Quality Testing Lab, which is independent of the production departments.

CARBON EQUIVALENT CE= C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15

Mercury has not been used in the direct manufacturing of this material.

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by this material manufacturer are in compliance with the requirements of the material specifications, and when designated by the purchaser, meet the applicable specifications.

Chief Metallurgist

State of Arkansas
County of Mississippi
Sworn to and subscribed before me

on 2015-08-25
My commission expires on 07/17/2023

NOTARY PUBLIC

995170 0000l

Invoice No.	707481
Bill of Lading	204152
Customer No.	7603
Customer P.O	09064

NUCOR-YAMATO STEEL CO.
P O BOX 1228: BLYTHEVILLE, AR 72316

CERTIFIED MILL TEST REPORT

100% Melted and Manufactured in U.S.A

All Shapes produced by Nucor-Yamato Steel are cast and rolled to a fully killed and fine grain practice

Date 2015-07-27

SOLD TO:
BROWN STRAUSS STEEL CO.
2495 URAVAN ST
AURORA CO 80011
USA

SHIP TO:
BROWN STRAUSS-FONTANA
C/O KEEP ON TRUCKING BNSF
R/R RANCHO CUCAMUNGA, CA FOR TRK
DEL TO FONTANA CA 92335
USA

ASTM A992/A992M-11 A572/A572M GR50-13a
ASTM A709/A709M-13a GR50 (345)
ASTM A709/A709M-13a GR50S (345S)
CSA G40 21-13 50WM (345WM)
ASTM A6/A6M-14

Item	Item Description	QTY	Heat#	Yield to Tensile Ratio	Yield Strength KSI / MPa	Tensile Strength KSI / MPa	ELONG %	Charpy Impact Temp °F / °C	Charpy Impact Impact Energy ft•lbf / J	Charpy Impact Loc	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	CE	Sn	Pcm	Cl
1	W24X162 0 60 ft 0 in W610X241 (18 29 m)	1	442226	0 77 0 76	56 55 386 379	73 72 503 496	28 28				08	1 20	013	026	19	32	11	13	03	02	020	35	02	17	
2	W24X162 0 60 ft 0 in W610X241 (18 29 m)	1	442228	0 76 0 77	56 56 386 386	74 73 510 503	27 27				08	1 21	013	028	21	31	12	12	04	02	018	35	01	18	
3	W24X176 0 50 ft 0 in W610X262 (15 24 m)	3	442204	0 75 0 79	54 57 372 393	72 72 496 496	28 26				08	1 30	013	018	25	24	10	13	04	04	002	36	01	18	
4	W24X176 0 55 ft 0 in W610X262 (16 76 m)	3	442208	0 81 0 78	58 57 400 393	72 73 496 503	28 26				08	1 36	018	018	21	22	10	14	03	06	018	37	01	18	

ELONGATION BASED ON 8 00 INCH GAUGE LENGTH

CARBON EQUIVALENT CE= C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15

Pcm= C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B(B=Approx 0005)

Mercury has not been used in the direct manufacturing of this material

Corrosion Index= 26 01(%Cu)+3 88(%Ni)+1 2(%Cr)+1 49(%Si)+17 28(%P)-7 29(%Cu)(%Ni)-9 10(%Ni)(%P)-33 39(%Cu)^2

ISO 9001 2008 certified (Registration # 0985-07)

All mechanical testing is performed by the Quality Testing Lab, which is independent of the production departments

I hereby certify that the contents of this report are accurate and correct All test results and operations performed by this material manufacturer are in compliance with the requirements of the material specifications, and when designated by the purchaser, meet the applicable specifications

Chief Metallurgist

State of Arkansas
County of Mississippi
Sworn to and subscribed before me

PKSF

on 2015-07-27
My commission expires on 07/17/2023

DEBORAH ANN RHODES
NOTARY PUBLIC
STATE OF ARKANSAS-MISSISSIPPI COUNTY

995170 - 00001

CERTIFIED MILL TEST REPORT

100% MELTED AND MANUFACTURED IN U.S.A.
All shapes produced by Nucor-Yamato Steel are cast and rolled to a fully killed and fine grain practice

NUCOR-YAMATO STEEL CO.

P.O. BOX 1228 • BLYTHEVILLE, AR 72316

DATE	5/12/08
INVOICE NO.	228259
BILL OF LADING	908048
CUSTOMER NO.	7674
CUSTOMER P.O.	69835

SHIP TO:
WAIWARD STEEL FAB
OUSC CCID OILGASDISCEN TRK GD89/90
53307 RANGE ROAD 232
SHERWOOD PARK, AB CN

SOLD TO:
WAIWARD STEEL
10030 34TH ST
EDMONTON, ALBERTA
CANADA T6B 2Y5

SPECIFICATIONS:
ASTM A992/A992M-06a A572/A572M GR50-06
ASTM A709/A709M-07 GR50 (345)
ASTM A709/A709M 07 GR50S (345S)
ASTM A6/A6M-07

ITEM #	ITEM DESCRIPTION	QTY	HEAT #	YLD TO TENSILE RATIO	YIELD STRENGTH PSI / MPa	TENSILE STRENGTH PSI / MPa	ELONG. %	CHARPY IMPACT TEMP °F / °C	IMPACT ENERGY FT LBS / JOULES	C	Mn	P	S	Si	Cu	Ni	Cr	Mo / Sn	V / Pcm	Cb	CE / CI
1	W14 -257.0	2	317271	.78	59000	76000	26			08	1 18	020	018	33	32	.1	.11	.03	06	003	38
	40'			76	58000	76000	26											.01	20		
	W360 x382.0				407	524	26														
	12.192 M				405	524	26														
2	W14 -257 0	2	317273	75	56000	75000	27			07	1 35	018	023	30	31	09	10	.02	.05	.002	36
	40'			74	56000	76000	27											.01	19		
	W360 x382 0				386	517	27														
	12 192 M				386	524	27														
3	W14 -257.0	1	317275	76	57000	75000	26			07	1 36	018	023	31	32	09	11	03	05	002	37
	40'			76	57000	75000	26											01	19		
	W360 x382.0				393	517	26														
	12 192 M				393	517	26														
4	W14 -257 0	1	317779	75	54000	72000	29			07	1 35	018	021	23	28	10	09	.03	05	002	36
	40'			77	55000	71000	29											01	17		
	W360 x382 0				372	496	29														
	12 192 M				379	490	29														
5	W14 -257 0	2	315895	.75	56000	75000	27			07	1 35	019	022	27	25	.11	14	.03	05	001	36
	45'			74	56000	76000	27											01	18		
	W360 x382 0				386	517	27														
	13.716 M				385	524	27														
6	W14 -257 0	2	325915	74	53000	72000	28			07	1 37	022	023	26	26	09	15	03	06	001	37
	45'			75	53000	71000	29											01	.18		
	W360 x382 0				365	496	28														
	13 716 M				365	490	29														
7	W14 -257.0	[illegible]	316184	74	55000	74000	27			07	1 37	020	022	23	28	09	10	01	05	001	36
	45'			73	54000	74000	26											01	18		
	W360 x382 0				379	510	27														
	13 716 M				372	510	26														
8	W14 -257 0	2	317265	75	58000	77000	24			08	1 35	014	.019	30	35	10	10	.03	06	002	38
	45'			76	58000	76000	25											01	20		
	W360 x382 0				400	531	24														
	13 716 M				400	524	25														
9	W14 -257 0	2	317275	76	57000	75000	26			07	1 36	018	023	31	32	09	.11	03	05	002	37
	45'			76	57000	75000	26											01	19		
	W360 x382 0				393	517	26														
	13 716 M				393	517	26														

WAIWARD STEEL FABRICATORS LTD		
DES / ID #	NY	731
PAGES	3	OF 3

ELONGATION BASED ON 8 OR INCH GAUGE LENGTH

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by this material manufacturer are in compliance with the requirements of the material specifications listed in the Specifications Block above.

QUALITY ASSURANCE

CUSTOMER COPY

STATE OF ARKANSAS COUNTY OF MISSISSIPPI
SWORN TO AND SUBSCRIBED BEFORE ME THIS

12 Day of 05/08

Charlene Wallis NOTARY PUBLIC

MY COMMISSION EXPIRES 10/21/2018

CHARLENE WALLIS MY Comm. Exp. NOTARY PUBLIC MISSISSIPPI CO. ARKANSAS

NHFK

Appendix C Welding Procedure Specifications

SCHUFF STEEL

Weld Procedures for:

UCSD AISC Testing

Project No.

#	SUBMITTAL #	WPS/PRODUCT	REV.	PQR	DESCRIPTION	SHOP	FIELD
		FCAW-G					
	N/A	N/A					
		SMAW					
	N/A	N/A					
		SAW					
	N/A	N/A					
		FCAW-S					
	1	Lincoln Innershield NR232 (FCAW-S)	11		Standard WPS		X
		Lincoln Innershield NR232 (FCAW-S)			CofC		X
		Lincoln Innershield NR232 (FCAW-S)			D1.8 Certificate, 0.072" Dia.		X
		Lincoln Innershield NR232 (FCAW-S)			Manfuactures Data		X
	2	Lincoln Innershield NR232 (FCAW-S)	0		Skewed T-joint CJP WPS Qualified		x
		Lincoln Innershield NR232 (FCAW-S)	0	190	Skewed T-joint CJP PQR		x

SCHUFF STEEL

PREQUALIFIED FCAW-S WELDING PROCEDURE SPECIFICATION (WPS)

Lincoln Innershield NR-232 (E71T-8) **Rev. 11 Date 2/10/12**

Supporting PQR(s): NA

Process 1	Mfg / Name: Lincoln / Innershield NR-232		FM. Diameter(s):	.068", .072", 5/64"	Position(s):	All
	AWS Class:	E71T-8-H16	Flux/Elect Class:	-	Stringer or Weave:	Either w/in TS limits
	AWS Spec:	A5.20	Shielding:	NA	Single or Multi-Pass:	Either
	Process:	FCAW-S	Composition:	NA	No. of Electrodes:	1
	Equipment	Semi-Auto & Auto / CV	Flow Rate:	NA	Electrode Spacing:	N/A
	Polarity:	DCEN	Gas Cup Size:	NA	CTWD:	3/4" to 1 1/4"

PREHEAT / INTERPASS TEMPERATURE

Thickness	Category B (Excludes materials in last column)	Category C (A572-60, 65, A913-65, API 5L X52)
1/8" to 3/4" incl.	32° F (note 1)	50° F (note 1)
Over 3/4" thru 1-1/2" incl.	50° F (note 1)	150° F
Over 1-1/2" thru 2-1/2" incl.	150° F	225° F
Over 2-1/2"	225° F	300° F
Maximum Interpass Temp. :	550° F	550° F

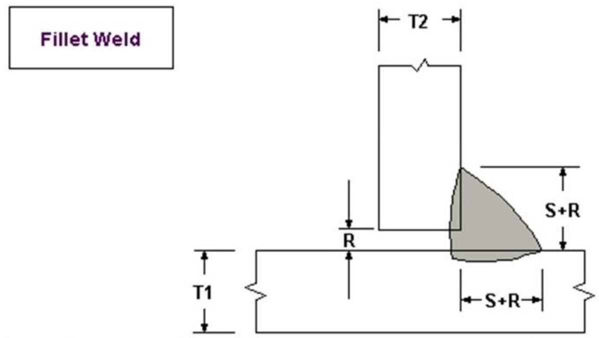
General Note: The minimum preheat or interpass temperature applied to a joint composed of base metals with different minimum preheats shall be the highest of these minimum preheats.

Note 1: When the base metal temperature is below 32° F, the base metal shall be preheated to a minimum of 70° F and the minimum interpass temperature shall be maintained during welding.

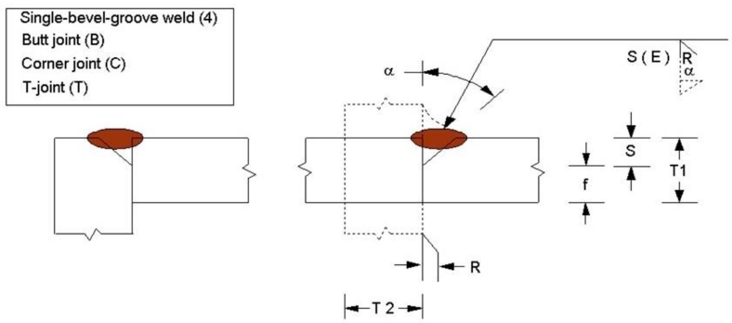
WELDING PROCEDURE

Layer / Pass	Process	Material Thickness	WFS (ipm)	Amps (A)	Volts (V)	Travel Speed (ipm)	Heat Input (kJ/in)	Notes / Other
All	1 (.068")	1/8" ≤ t < U	150	250	20	6.5	46.15	
			135 – 165	225 – 275	19 – 21	5.0-8.0	32.1-69.3	
All	1 (.072")	1/8" ≤ t < U	155	240	20	6.5	44.31	
			140 – 170	217.5 – 262.5	19 – 21	5.0-8.0	31.00-66.2	
All	1 (5/64")	1/8" ≤ t < U	130	285	20	7.0	48.86	
			117.5 – 142.5	257.5 – 312.5	19 – 21	5.5 – 8.5	34.54 – 71.59	

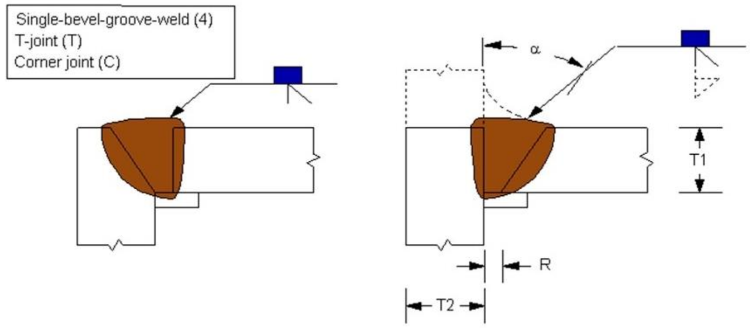
BASE METALS		ATTACHED JOINT DETAILS AND TOLERANCES			
BASE MATERIAL 1	BASE MATERIAL 2	FILLET & OTHER	PJP	CJP	
☒ A 29 (Studs) ☒ A 36 ☒ A 53 Gr. B ☒ A 106 Gr. B ☒ A 500 A, B, C ☒ A 529-50, 55 ☒ A 572-42, 50, 55 ☒ A 572-60, 65 ☒ A 709-36, 50, 50S ☒ A 913-50 ☒ A 913-65 ☒ A 992 ☒ API 5L Gr. B ☒ API 5L X42 ☒ API 5L X52	☒ A 29 (Studs) ☒ A 36 ☒ A 53 Gr. B ☒ A 106 Gr. B ☒ A 500 A, B, C ☒ A 529-50, 55 ☒ A 572-42, 50, 55 ☐ A 572-60, 65 ☒ A 709-36, 50, 50S ☒ A 913-50 ☐ A 913-65 ☒ A 992 ☒ API 5L Gr. B ☒ API 5L X42 ☒ API 5L X52	☒ Fillet (incl. studs)	☐ BC-P2-GF ☐ B-P3-GF ☒ BTC-P4-GF ☐ BTC-P5-GF ☒ BC-P6-GF ☐ B-P7-GF ☐ TC-P8-GF ☐ BC-P8-GF ☐ BTC-P9-GF ☒ BTC-P10-GF ☐ B-P11-GF	☐ B-L1a-GF ☐ B-L1b-GF ☐ TC-L1-GF ☒ B-U2a-GF ☐ C-U2a-GF ☐ B-U2-GF ☐ C-U2-GF ☐ B-U3-GF ☒ B-U4a-GF ☒ TC-U4a-GF ☒ B-U4b-GF	☒ TC-U4b-GF ☒ B-U5-GF ☒ TC-U5-GF ☐ B-U6-GF ☐ C-U6-GF ☒ B-U7-GF ☐ B-U8-GF ☐ TC-U8a-GF ☐ B-U9-GF ☐ TC-U9a-GF
Pipe / Round Tube Diameter:	CJP: D ≥ Any diameter; PJP: Any diameter; Fillet: Any diameter (for applications I.A.W. - 3.9.2, 3.12.4, 3.13.3)				
Box Tube Section Dimensions:	All widths and depths (for applications I.A.W. - 3.9.2, 3.12.4, 3.13.3)				
Backing Material (if applicable):	☒ Steel	☐ Other			
Backgouge Method (if applicable):	☒ Air Carbon Arc	☐ Other			
Interpass Cleaning:	Slag removed by manual or pneumatic hand tool	Peening:	None required. Not permitted on root or cover pass.		



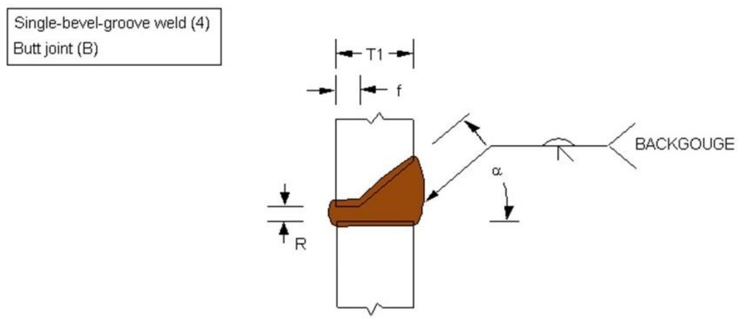
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening	Tolerances: As Detailed	Tolerances: As Fit Up	Permitted Welding Positions	Weld Size (E)	Notes
FCAW-S	Fillet	U	U	R = 0	R = 0	-0, +3/16	All	S	-



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening, Root Face, Groove Angle	Tolerances: As Detailed	Tolerances: As Fit Up	Permitted Welding Positions	Weld Size (E)	Notes
FCAW-S	BTC-P4-GF	1/4 min	U	R = 0 f = 1/8 min α = 45°	+1/16, -0 +U, -0 +10°, -0°	+1/8, -1/16 ± 1/16 +10°, -5°	F, H	S	b, f, g, j, k
							V, OH	S – 1/8	



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T1	T2	Root Opening Groove Angle	Tolerances				
					As Detailed	As Fit-Up			
FCAW-S	TC-U4a-GF	U	U	R = 1/4 α = 45°	+1/16, -0 +10°, -0°	+1/4, -1/16 +10°, -5°	All	Not req.	g, j, k
				R = 3/8 α = 30°	+1/16, -0 +10°, -0°	+1/4, -1/16 +10°, -5°	F	Not req.	g, j, k



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T1	T2	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed	As Fit-Up			
FCAW-S	B-U4b-GF	U	-	R = 0 to1/8 f = 0 to1/8 α = 45°	+1/16, -0 +1/16, -0 +10°, -0°	+1/16, -1/8 Not limited +10°, -5°	All	Not req.	c, d, j

Prequalified Figure Notes:

a: Not prequalified for gas metal arc welding using short circuiting transfer nor GTAW.
b: Joint is welded from one side only.
c: Cyclic load application limits these joints to the horizontal welding position.
d: Backgouge root to sound metal before welding second side.
e: SMAW detailed joints may be used for prequalified GMAW (except GMAW-S) and FCAW.
f: Minimum weld size (E) as shown in Table 3.4. S as specified on drawings.
g: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, these shall be equal to 1/4 T_1 ,but need not exceed 3/8 in. (10 mm). Groove welds in corner and T-joints of cyclically loaded structures shall be reinforced with fillet welds equal to 1/4 T_1, but need not exceed 3/8 in. (10 mm).
h: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.
i: Double-groove welds may have grooves of unequal depth, provided these conform to the limitations of Note f. Also the weld size (E) applies individually to each groove.
j: The orientation of the two members in the joints may vary from 135° to 180° for butt joints, or 45° to 135° for corner joints, or 45° to 90° for T-joints.
k: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.
l: Weld size (E) is based on joints welded flush.
m: For flare-V-groove welds and flare-bevel-groove welds to rectangular tubular sections, r shall be as two times the wall thickness.
n: For flare-V-groove welds to surfaces with different radii r, the smaller r shall be used.

Prequalified FCAW WPS Requirements in accordance with AWS D1.1:

- Maximum Root Pass Thickness: Flat – 3/8", Horizontal – 5/16", Vertical – 1/2", Overhead – 5/16".
- Maximum Fill Pass Thickness: 1/4"
- Maximum single-pass fillet weld: Flat – 1/2", Horizontal –3/8", Vertical – 1/2", Overhead – 5/16".
- Split layers when:
  - Root opening > 1/2", or
  - The layer width w > 5/8" in the F, H, or OH positions for nontubulars, or
  - The layer width w > 1" in the vertical position for nontubulars or the 5G or 6G for tubulars.
- Vertical Progression shall be upward.

PWHT:
None required.

Notes:

Rev.	Date	Summary
11	2/10/12	Revised Heat Input calculations to conform with current D1.8 CofC
10	5/31/2011	Base Metals (A529, A709) added.
9	9/20/2010	Revised Preheat table and Category C preheat added. D1.8 DC clarification. Base Metals added. Revision table added.
8	6/23/2010	Updated WPS format. Updated CTWD to new MfgDat. Add Base Metals. Add studs to Fillet. Add BC-P6 & B-U7. Add pipe/tube info.
7	1/6/2010	Revised Fillet detail. Removed MfgDat and CofC.
6	12/3/2009	Added BC-P6-GF
5	10/28/2009	Added Automatic Revised procedure table to match shop format. Changed Current/Volts/TS to bring heat input within ranges shown on D1.8 CofCs (except 5/64" is based on new NR233 CofC).
4	8/12/2009	Format updates, P10 weld size & notes, U4b & U5 As Fit Tolerances,
3	10/2/2008	Selected A913 materials in BM1. Added B-U5-GF. Misc formatting.
2	9/18/2007	Revised preheat table. Updated B-U4a joint table.
1	9/18/2007	Preheat Table Format. Updated BTC-P10. Added Note m to Figure Notes. Added PWHT and Note 1 to notes page.
0	1/24/2007	Initial release

" Corrections made solely for typographical and/or non essential variable errors will carry the same revision number with a new date and may not be listed here.

This procedure has been prepared in accordance with AWS D1.1, D1.8 (Demand Critical), manufacturer's recommendations, and project specifications.

Prepared by: Mike Echelberger CWI Certification # 04110721

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE

(APPLIES ONLY TO U.S. PRODUCTS)

THE WELDING EXPERTS®

[1Year]

Product: **Innershield® NR®-232**

Classification: **E71T-8-H16**
E71T8-A2-CS3-H16

Specification: **AWS A5.20:2005, ASME SFA-5.20**
AWS A5.36:2012, ASME SFA-5.36

Date **April 29, 2015**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied according to the Quality System Program of the Lincoln Electric Company, Cleveland, Ohio, U.S.A., which meets the requirements of ISO9001, NCA3800, AWS A5.01, and other specification and Military requirements, as applicable. The Quality System Program has been approved by ASME, ABS, and VdTUV.

Operating Settings	E71T-8-H16 Requirements	RESULTS	
Electrode Size		0.068 inch	5/64 inch
Polarity		DC-	DC-
Voltage, V		21	20
Wire Feed Speed, cm/min (in/min)		483 (190)	457 (180)
Current, A		315	340
Average Heat Input, kJ/mm (kJ/in)		1.5 (39)	1.9 (49)
Contact Tip to Work Distance, mm (in)		25 (1)	25 (1)
Pass/Layers		18/7	13/6
Preheat Temperature, °C (°F)	(60 min.)	20 (72)	20 (72)
Interpass Temperature, °C (°F)	(275 - 325)	165 (325)	165 (325)
Postweld Heat Treatment	As-welded	As-welded	As-welded

Mechanical properties of weld deposits

Tensile Strength, MPa (ksi)	(70 - 95)	620 (89)	610 (89)
Yield Strength, 0.2% Offset, MPa (ksi)	(58 min.)	480 (70)	490 (71)
Elongation %	22 min.	26	27
Average Impact Energy Joules @ -29 °C (ft-lbs @ -20 °F)	(20 min.)	58 (43) 56,58,59 (41,43,44)	57 (42) 54,57,60 (40,42,44)
Average Hardness, HRB	Not Required	91	91

Chemical composition of weld deposits (weight %)

C	0.30 max.	0.19	0.17
Mn	1.75 max.	0.61	0.65
Si	0.60 max.	0.27	0.27
S	0.03 max.	0.003	0.003
P	0.03 max.	0.010	0.012
Cr	0.20 max.	0.04	0.04
Ni	0.50 max.	0.02	0.03
Mo	0.30 max.	0.02	0.01
V	0.08 max.	0.00	0.00
Cu	0.35 max.	0.03	0.05
Al	1.8 max.	0.6	0.7

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE

(APPLIES ONLY TO U.S. PRODUCTS)

LINCOLN ELECTRIC
THE WELDING EXPERTS®
[1Year]

Product:	**Innershield® NR®-232**
Classification:	**E71T-8-H16** **E71T8-A2-CS3-H16**
Specification:	**AWS A5.20:2005, ASME SFA-5.20** **AWS A5.36:2012, ASME SFA-5.36**
Date	**April 29, 2015**

Diffusible Hydrogen (per AWS A4.3)	**E71T-8-H16 Requirements**	**RESULTS**	
Electrode Size		0.068 inch	5/64 inch
Polarity		DC-	DC-
Diffusible Hydrogen, mL/100g	16.0 max.	10.7	6.4
Absolute Humidity (grains moisture/lb dry air)		54	54

Cert. No. 22320

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE

(APPLIES ONLY TO U.S. PRODUCTS)

THE WELDING EXPERTS®
[1Year]

Product: Innershield® NR®-232
Classification: E71T-8-H16
E71T8-A2-CS3-H16
Specification: AWS A5.20:2005, ASME SFA-5.20
AWS A5.36:2012, ASME SFA-5.36
Date April 29, 2015

Operating Settings	E71T8-A2-CS3-H16 Requirements	RESULTS	
Electrode Size		0.068 inch	5/64 inch
Polarity		DC-	DC-
Voltage, V		21	20
Wire Feed Speed, cm/min (in/min)		483 (190)	457 (180)
Current, A		315	340
Average Heat Input, kJ/mm (kJ/in)		1.5 (39)	1.9 (49)
Contact Tip to Work Distance, mm (in)		25 (1)	25 (1)
Pass/Layers		18/7	13/6
Preheat Temperature, °C (°F)	(60 min.)	20 (72)	20 (72)
Interpass Temperature, °C (°F)	(275 - 325)	165 (325)	165 (325)
Postweld Heat Treatment	As-welded	As-welded	As-welded

Mechanical properties of weld deposits

Tensile Strength, MPa (ksi)	(70 - 95)	620 (89)	610 (89)
Yield Strength, 0.2% Offset, MPa (ksi)	(58 min.)	480 (70)	490 (71)
Elongation %	22 min.	26	27
Average Impact Energy Joules @ -29 °C (ft-lbs @ -20 °F)	(20 min.)	58 (43) 56,58,59 (41,43,44)	57 (42) 54,57,60 (40,42,44)
Average Hardness, HRB	Not Required	91	91

Chemical composition of weld deposits (weight %)

C	0.30 max.	0.19	0.17
Mn	1.75 max.	0.61	0.65
Si	0.60 max.	0.27	0.27
S	0.030 max.	0.003	0.003
P	0.030 max.	0.010	0.012
Cr	0.20 max.	0.04	0.04
Ni	0.50 max.	0.02	0.03
Mo	0.30 max.	0.02	0.01
V	0.08 max.	0.00	0.00
Cu	0.35 max.	0.03	0.05
Al	1.8 max.	0.6	0.7
B	Not Required	0.002	0.002

Diffusible Hydrogen (per AWS A4.3)	E71T8-A2-CS3-H16 Requirements	RESULTS	
Electrode Size		0.068 inch	5/64 inch
Polarity		DC-	DC-
Diffusible Hydrogen, mL/100g	16 max.	11	6
Absolute Humidity (grains moisture/lb dry air)		54	54

Cert. No. 22320

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE
(APPLIES ONLY TO U.S. PRODUCTS)

THE WELDING EXPERTS®
[1Year]

Product:	**Innershield® NR®-232**
Classification:	**E71T-8-H16** **E71T8-A2-CS3-H16**
Specification:	**AWS A5.20:2005, ASME SFA-5.20** **AWS A5.36:2012, ASME SFA-5.36**
Date	**April 29, 2015**

1. This certificate complies with the requirements of EN 10204, Type 2.2
2. The electrode sizes required to be tested for this classification are 0.068 inch and 5/64 inch. All other sizes manufactured will also meet these requirements.
3. Test assembly constructed of ASTM A36 steel.
4. Fillet Weld Test (positions as required): Met requirements.
5. Radiographic Inspection: Met requirements.
6. The strength and elongation properties reported here were obtained from tensile specimens artificially aged at 105°C (220°F) for 48 hours.
7. Results below the detection limits of the instrument or lower than the precision required by the specification are reported as zero. Strength values in SI units are reported to the nearest 10 MPa converted from actual data. Preheat and interpass temperature values in SI units are reported to the nearest 5 degrees.

Toronto Cunningham April 29, 2015
Toronto Cunningham, Certification Supervisor Date

David A Fink April 29, 2015
Dave Fink, Manager, Compliance Engineering, Consumable R&D Date

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE
(APPLIES ONLY TO U.S. PRODUCTS)

LINCOLN ELECTRIC
THE WELDING EXPERTS®

Product: **Innershield® NR®-232**
Electrode Lot Number: **13891669**
Classification: **E71T-8-H16**
Specification: **AWS D1.8:2009**
Date **August 28, 2014**

This is to certify that the above listed product was manufactured to meet the Class T4 requirement of AWS A5.01 as required by clause 6.3.8.1 of AWS D1.8:2009.

The product stated herein was manufactured and supplied in accordance with the Quality System Program of The Lincoln Eletric Co., Cleveland, Ohio, U.S.A. as outlined in our Quality Assurance Manual. The Quality System Program of The Lincoln Electric Co. has been accepted by ASME, ABS and approved by VdTUV, and is certified to ISO 9001:2013

Operating Settings	**AWS D1.8 Requirements**	**High Heat Input Results**	**Low Heat Input Results**
Electrode Size		0.072 inch	0.072 inch
Polarity		DC-	DC-
Voltage, V		22	20
Wire Feed Speed, cm/min (in/min)		394 (155)	457 (180)
Current, A		250	270
Average Heat Input, kJ/mm (kJ/in)		2.8 (72)	1.2 (31)
Contact Tip to Work Distance, mm (in)		25 (1)	25 (1)
Travel Speed, cm/min (in/min)		13 (5)	28 (11)
Pass/Layers		8/5	20/7
Preheat Temperature, °C (°F)		135 (275)	20 (72)
Interpass Temperature, °C (°F)		230 (450)	120 (250)
Weld Position		3G	1G
Mechanical properties of weld deposits			
Tensile Strength, MPa (ksi)	(70 min.)	590 (85)	630 (92)
Yield Strength, 0.2% Offset, MPa (ksi)	(58 min.)	410 (59)	500 (72)
Elongation %	22 min.	28	25
Average Impact Energy	(40 min.)	112 (83)	97 (71)
Joules @ 21 °C (ft-lbs @ 70 °F)		106,113,118 (78,83,87)	91,99,101 (67,73,74)
Average Impact Energy	(40 min.)	70 (52)	62 (46)
Joules @ -18 °C (ft-lbs @ 0 °F)		68,71,72 (50,53,53)	60,62,65 (44,46,48)

1. This product satisfies the requirements of AWS D1.8:2009, Annex E, after exposure for 1 week at 80°F / 80% relative humidity.
2. The Charpy V-notch impact values reported at -18 °C (0 °F) are required when the Lowest Anticipated Service Temperature (LAST) is -29 °C (-20 °F).
3. The Charpy V-notch impact values reported at 21 °C (70 °F) are required when the Lowest Anticipated Service Temperature (LAST) is 10 °C (50 °F).
4. Test assembly constructed of ASTM A572 Grade 50 steel.
5. The strength and elongation properties reported here were obtained from tensile specimens artificially aged at 105°C (220°F) for 48 hours.
6. Strength values in SI units are reported to the nearest 10 MPa converted from actual data. Preheat and interpass temperature values in SI units are reported to the nearest 5 degrees.

Toronto Cunningham — August 28, 2014
Toronto Cunningham, Certification Supervisor — Date

David A. Fink — August 28, 2014
Dave Fink, Manager, Compliance Engineering, Consumable R&D — Date

Cert. No. 22320

FLUX-CORED SELF-SHIELDED (FCAW-S) WIRE

Innershield® NR®-232

Mild Steel, All Position • AWS E71T-8

Key Features

- High deposition rates for out-of-position welding
- Penetrating arc
- Fast freezing, easy to remove slag system
- Meets AWS D1.8 seismic lot waiver requirements

Typical Applications

- Structural fabrication, including those subject to seismic requirements
- General plate fabrication
- Hull plate and stiffener welding on ships and barges
- Machinery parts, tanks, hoppers, racks and scaffolding

Conformances

AWS A5.20/A5.20M: 2005	E71T-8-H16
ASME SFA-A5.20:	E71T-8-H16
ABS:	3YSA
Lloyd's Register:	3YS H15
DNV Grade:	III YMS H15
GL:	3YH10S
BV Grade:	SA3YMH
CWB/CSA W48-06:	E491T-8 H16
DB:	EN 758 T42 3 Y N 2
TUV:	EN 758 T42 3 Y N 2
MIL-E-24403/1:*	MIL-71T-8AS
FEMA 353	
AWS D1.8	

*Military Grade Classification of MIL-71T-8AS for 0.068 in (1.7 mm) and 0.072 in (1.8 mm) diameters only.

Welding Positions

All

Innershield® NR®-232
(AWS E71T-8)

DIAMETERS / PACKAGING

Diameter in (mm)	13.5 lb (6.1 kg) Coil 54 lb (24.5 kg) Master Carton	13.5 lb (6.1 kg) Coil 54 lb (24.5 kg) Hermetically Sealed Pail	25 lb (11.3 kg) Steel Spool
0.068 (1.7)	ED012518	ED030232	ED030643
0.072 (1.8)	ED012522		ED030644
5/64 (2.0)	ED012525		ED030647

Diameter in (mm)	25 lb (11.3 kg) Plastic Spool (Vacuum Sealed Foil Bag)	50 lb (22.7 kg) Coil
0.068 (1.7)	ED030949	ED012519
0.072 (1.8)		ED012523
5/64 (2.0)		ED012526

MECHANICAL PROPERTIES[1] – *As Required per AWS A5.20/A5.20M: 2005*

	Yield Strength[2] MPa (ksi)	Tensile Strength MPa (ksi)	Elongation %	Hardness Rockwell B	Charpy V-Notch / J ft•lbf) @ -29°C (-20°F)
Requirements - AWS E71T-8	400 (58) min.	480-655 (70-95)	22 min.	–	27 (20) min.
Typical Results[3] - As-Welded	460-520 (66-75)	575-615 (83-89)	25-31	87-90	47-75 (35-55)

DEPOSIT COMPOSITION[1] – *As Required per AWS A5.20/A5.20M: 2005*

	%C	%Mn	%Si	%S	%P	%Al
Requirements - AWS E71T-8	0.30 max.	1.75 max.	0.60 max.	0.03 max.	0.03 max.	1.8 max.
Typical Results[3]	0.16-0.18	0.61-0.72	0.26-0.33	≤0.01	≤0.01	0.5-0.8

TYPICAL OPERATING PROCEDURES

Diameter, Polarity	CTWD[6] mm (in)	Wire Feed Speed m/min (in/min)	Voltage[7] (volts)	Approx. Current (amps)	Melt-Off Rate kg/hr (lb/hr)	Deposition Rate kg/hr (lb/hr)	Efficiency (%)
0.068 in (1.7 mm), DC-	19-32 (3/4-1 1/4)	2.8 (110)	18-19	195	2.3 (5.0)	1.8 (3.9)	78
		3.3 (130)	19-21	225	2.8 (6.2)	2.0 (4.6)	74
		3.8 (150)	19-21	250	3.2 (7.1)	2.4 (5.3)	75
		4.3 (170)	20-22	270	3.5 (7.8)	2.8 (6.1)	78
		5.0 (195)	23-24	300	4.3 (9.4)	3.2 (7.0)	74
		6.4 (250)	23-24	350	5.4 (11.8)	4.0 (9.0)	76
		7.4 (320)	25-27	400	6.9 (15.2)	5.2 (11.4)	75
0.072 in (1.8 mm), DC-	19-32 (3/4-1 1/4)	2.0 (80)	16-18	130	1.8 (4.0)	1.5 (3.3)	83
		3.5 (140)	18-21	225	3.1 (6.8)	2.5 (5.5)	81
		3.9 (155)	19-22	240	3.3 (7.2)	2.7 (6.0)	83
		4.3 (170)	20-23	255	3.6 (8.0)	2.9 (6.5)	81
		6.4 (250)	22-24	315	5.3 (11.7)	4.3 (9.6)	82
		7.4 (290)	23-25	350	6.2 (13.6)	5.0 (11.0)	81
5/64 in (2.0 mm), DC-	19-32 (3/4-1 1/4)	1.5 (60)	16-17	145	1.7 (3.7)	1.2 (2.7)	73
		2.9 (115)	19-20	260	3.2 (7.0)	2.5 (5.5)	78
		3.0 (120)	19-20	270	3.3 (7.3)	2.6 (5.7)	78
		3.3 (130)	20-21	285	3.5 (7.8)	2.8 (6.2)	79
		4.6 (180)	22-23	365	5.0 (10.9)	3.9 (8.7)	80

[1]Typical all weld metal. [2]Measured with 0.2% offset. [3]See test results disclaimer below.
NOTE: FEMA 353 and AWS D1.8 structural steel seismic supplement test data can be found on this product at www.lincolnelectric.com.

Material Safety Data Sheets (MSDS) and Certificates of Conformance are available on our website at www.lincolnelectric.com

TEST RESULTS

Test results for mechanical properties, deposit or electrode composition and diffusible hydrogen levels were obtained from a weld produced and tested according to prescribed standards, and should not be assumed to be the expected results in a particular application or weldment. Actual results will vary depending on many factors, including, but not limited to, weld procedure, plate chemistry and temperature, weldment design and fabrication methods. Users are cautioned to confirm by qualification testing, or other appropriate means, the suitability of any welding consumable and procedure before use in the intended application.

CUSTOMER ASSISTANCE POLICY

The Lincoln Electric Company is manufacturing and selling high quality welding equipment, consumables, and cutting equipment. Our challenge is to meet the needs of our customers and to exceed their expectations. On occasion, purchasers may ask Lincoln Electric for information or advice about their use of our products. Our employees respond to inquiries to the best of their ability based on information provided to them by the customers and the knowledge they may have concerning the application. Our employees, however, are not in a position to verify the information provided or to evaluate the engineering requirements for the particular weldment. Accordingly, Lincoln Electric does not warrant or guarantee or assume any liability with respect to such information or advice. Moreover, the provision of such information or advice does not create, expand, or alter any warranty on our products. Any express or implied warranty that might arise from the information or advice, including any implied warranty of merchantability or any warranty of fitness for any customers' particular purpose is specifically disclaimed.

Lincoln Electric is a responsive manufacturer, but the selection and use of specific products sold by Lincoln Electric is solely within the control of, and remains the sole responsibility of the customer. Many variables beyond the control of Lincoln Electric affect the results obtained in applying these types of fabrication methods and service requirements.

Subject to Change – This information is accurate to the best of our knowledge at the time of printing. Please refer to www.lincolnelectric.com for any updated information.

THE LINCOLN ELECTRIC COMPANY
22801 St. Clair Avenue • Cleveland, OH • 44117-1199 • U.S.A.
Phone: +1.216.481.8100 • www.lincolnelectric.com

THE WELDING EXPERTS®

Issue Date 01/12

SCHUFF STEEL

QUALIFIED FCAW-S WELDING PROCEDURE SPECIFICATION (WPS)

Lincoln Innershield NR-232, Skewed-T **Rev. 0** **Date 9/20/13**

Supporting PQR(s): 0190

Process 1	Mfg / Name:	Lincoln / Innershield NR-232	FM. Diameter:	.072"	Position(s):	V
	AWS Class:	E71T-8-H16	Flux/Elect Class:	-	Stringer or Weave:	Either w/in TS limits
	AWS Spec:	A5.20	Shielding:	NA	Single or Multi-Pass:	Either
	Process:	FCAW-S	Composition:	NA	No. of Electrodes:	1
	Equipment	Semi-Auto & Auto / CV	Flow Rate:	NA	Electrode Spacing:	N/A
	Polarity:	DCEN	Gas Cup Size:	NA	CTWD:	3/4" to 1 1/4"

PREHEAT / INTERPASS TEMPERATURE

Thickness	Category B (Excludes materials in last column)	Category C (A572-60, 65, A913-65, API 5L X52)
1/8" to 3/4" incl.	32° F (note 1)	50° F (note 1)
Over 3/4" thru 1-1/2" incl.	50° F (note 1)	150° F
Over 1-1/2" thru 2-1/2" incl.	150° F	225° F
Over 2-1/2"	225° F	300° F
Maximum Interpass Temp. :	550° F	550° F

General Note: The minimum preheat or interpass temperature applied to a joint composed of base metals with different minimum preheats shall be the highest of these minimum preheats.

Note 1: When the base metal temperature is below 32° F, the base metal shall be preheated to a minimum of 70° F and the minimum interpass temperature shall be maintained during welding.

WELDING PROCEDURE

Layer / Pass	Process	Material Thickness	WFS (ipm)	Amps (A)	Volts (V)	Travel Speed (ipm)	Heat Input (kJ/in)	Notes / Other
All	1 (.072")	1/8" ≤ t < U	170	261	19	5	59.51	
			152-188	235-287	18-20	3.75-6.25	40.61-91.84	
All	1 (.072")	1/8" ≤ t < U	170	261	19	5	59.91	D1.8 DC Applications
			152-188	235-287	18-20	4.5-6.25	40.61-76.53	

BASE METALS: BASE MATERIAL 1	BASE METALS: BASE MATERIAL 2	ATTACHED JOINT DETAILS AND TOLERANCES
☐ A 29 (Studs)	☐ A 29 (Studs)	☒ 23° Skew
☒ A 36	☒ A 36	
☒ A 53 Gr. B	☒ A 53 Gr. B	
☒ A 106 Gr. B	☒ A 106 Gr. B	
☒ A 500 A, B, C	☒ A 500 A, B, C	
☒ A 529-50, 55	☒ A 529-50, 55	
☒ A 572-42, 50, 55	☒ A 572-42, 50, 55	
☐ A 572-60, 65	☐ A 572-60, 65	
☒ A 709-36, 50, 50S	☒ A 709-36, 50, 50S	
☒ A 913-50	☒ A 913-50	
☐ A 913-65	☐ A 913-65	
☒ A 992	☒ A 992	
☒ API 5L Gr. B	☒ API 5L Gr. B	
☒ API 5L X42	☒ API 5L X42	
☒ API 5L X52	☒ API 5L X52	

Pipe / Round Tube Diameter:	NA	
Box Tube Section Dimensions:	NA	
Backing Material (if applicable):	☐ Steel	☐ Other
Backgouge Method (if applicable):	☐ Air Carbon Arc	☐ Other
Interpass Cleaning: Slag removed by manual or pneumatic hand tool	Peening:	None required. Not permitted on root or cover pass.

PROCEDURE QUALIFICATION RECORD WORKSHEET
PQR NUMBER 23 DEG SKEWED CJP

Welder's Name DANA KEITH ID 1081 Welding Test Date 15 AUG 2013
Process FCAW-S Position 3G Joint Detail: ☐ Fig. 5.1 ☐ Fig. 5.2 ☐ Fig. 5.3 ☐ Fig. 5.8 SEE ATTACHED
Electrode(s) Mfg. Designation LINCOLN NR-232
AWS Electrode Classification E-71T-8 Electrical Stick Out 3/4"
Flux Mfg. Designation N/A AWS Flux Classification N/A
Postweld Heat Treatment: Temp. N/A Hold Time N/A Heating/Cooling Rate N/A

		Diam.	Current	WFS*	Voltage	Current and Polarity
Electrode	(1)	.072"	DCEN	N/A	AVG:19.23	AVG:261
	(2)					
	(3)					

Shielding Gas N/A Dew Point N/A Flow Rate N/A Gas Cup Size N/A
Travel Speed: Min. 5 IPM Max. 5 IPM
Base Metal Specification and Thickness 572-50 1" Heat Number 821204420
Backing Metal Specification and Thickness 572-50 Heat Number 821204420
Preheat Temp. 150 DEG F Interpass Temp. Min. 102 DEG F Max. 398 DEG F

			FILLER METAL	CURRENT						TEMPERATURE	
Pass Number	Layer	Process	Diam.	Type & Polarity	Wire Feed Speed	Amp	Volts	Travel Speed	Stick Out	Preheat	Interpass
ROOT	1	FCAW-S	.072"	DCEN		266	19.37	6	3/4"	150	
INTER	2	"	"	"		262	18.9	4	"		248
"	3	"	"	"		250	19.1	5	"		274
"	4	"	"	"		262	19.5	5	"		377
"	5	"	"	"		272	19.63	5	"		323
"	6	"	"	"		279	19.5	5	"		102
"	7	"	"	"		256	19.18	5	"		256
COVER	8	"	"	"		268	19.5	5	"		354
COVER	9	"	"	"		247	19.07	5	"		380
COVER	10	"	"	"		255	19.06	5	"		398
COVER	11	"	"	"		254	18.8	5	"		389
						AVG 261	AVG 19.23	AVG 5			

*Optional
Page 1 of 1

For multiple electrodes list each electrode on separate line. For parallel electrodes show "2 @ ------- " under number and diameter. Preheat and interpass temperature measured at mid length of plates approximately 25 mm [1 in] from the weld center line.

State/3rd Party Witness N/A Mfr./Contractor SCHUFF STEEL

Date

Form N-4

Form N-4—Procedure Qualification Record (PQR) Worksheet

Metallurgical
Mechanical
Physical

DECISIVE TESTING, INC.

AROUND THE GLOBE

N.D.T. Inspection Specialist

CUSTOMER SCHUFF STEEL	DATE: 8-21-13
ADDRESS P.O. BOX 19046 PHOENIX, AZ. 85005	CONTROL# DTS-812
	LOCATION: DTI LAB
P.O.# VERBAL	SPECIFICATION: PER AWS D1.1-10
PART NAME: PLATE	ACCEPTANCE: PER AWS D1.1-10
QUANTITY: 1 EA	PROCESS: FCAW
BASE MATERIAL: A572-50	DTI PROCEDURE#: RT-4C REV.B
FILLER: E-71T-8	JOINT DESIGN: GROOVE
WELDER: DANA KEITH	PROCEDURE #: N/A
POSITION: 3G	THICKNESS: 1" 23°
BADGE: 1081	PERCENT TESTED: 100%

VISUAL & RADIOGRAPHIC INSPECTION
PROCEDURE QUALIFICATION

SERIAL NO.	REJ.	V1								
POSITION:										
3G		1F								

INTERPRETATION LEGEND

1. SMALL	A. LACK OF PENETRATION	D. CRACKS	G. SHRINKAGE
2. MODERATE	B. LACK OF FUSION	E. INCLUSIONS	H. GAS HOLES
3. EXCESSIVE	C. UNDERCUTTING	F. POROSITY	I. LINEAR INDICATIONS
			J. ________

FILM USAGE : 2 EA 4.5" X 17"

QUANTITY ACCEPTED: -1-   QUANTITY REJECTED: -0-

NOTE: Not responsible for any monies over the invoice amount of the job.

RT LEVEL II: BR   BRIAN RUNYAN

RECEIVED BY: ______________________ ______________________
SIGNATURE   PRINT

4735 Myrtle Avenue • San Diego, California 92105 • (619) 285-9006 • FAX (619) 285-9930

Metallurgical
Mechanical
Physical

DECISIVE TESTING, INC.
AROUND THE GLOBE
N.D.T. Inspection Specialist

CUSTOMER: SCHUFF STEEL
ADDRESS:

P.O#.: VERBAL
QUANTITY: 1 EACH (4 BENDS)
MATERIAL: A572-50

DATE: 9-10-13
CONTROL#: DTT-185
SPECIFICATION: PER AWS D1.1
FILLER: E-71T-8
PROCESS: FCAW
WELDER: DANA KEITH
WELDER I.D.: 1081

BEND TEST

1" SKEWED CONNECTION PQR

POSITION	TYPE OF TEST	RESULTS
3G	(4) SIDE BENDS	ACCEPTED

(3) MACRO TEST = ACCEPTED

NOT RESPONSIBLE FOR ANY MONIES OVER THE INVOICE AMOUNT OF THE JOB.

INSPECTOR:

RECEIVED BY: ______________________ ______________________
SIGNATURE PRINT

4735 Myrtle Avenue • San Diego, California 92105 • (619) 285-9006 • FAX (619) 285-9930

Metallurgical
Mechanical
Physical

DECISIVE TESTING, INC.

AROUND THE GLOBE

N.D.T. Inspection Specialist

CUSTOMER: SCHUFF STEEL

ADDRESS:

P.O#.: VERBAL

QUANTITY: 1 EACH (2 TENSILES)

MATERIAL: A572-50

DATE: 9-10-13

CONTROL#: DTT-185

SPECIFICATION: PER AWS D1.1

PART #: 1" SKEWED CONNECTION PQR

FILLER: E-71T-8
PROCESS: FCAW
POSITION: 3G
WELDER NAME: DANA KEITH

TENSILE TEST

I.D.	ACTUAL SIZE	ACTUAL AREA	TENSILE STRENGTH ACTUAL LOAD POUNDS	TENSILE STRENGTH POUNDS PER SQ. IN.	YIELD STRENGTH ACTUAL LOAD POUNDS	YIELD STRENGTH POUNDS PER SQ. IN.	ELONGATION AT FRACTURE IN-2-IN	ELONGATION AT FRACTURE %	REDUCTION OF AREA	
#1	.500 X 1.00	.500	41,480	82,960	/	/	/	/	/	/
#2	.500 X 1.00	.500	40,754	81,508	/	/	/	/	/	/

REMARKS : LOCATION OF BREAK = BASE MATERIAL

NOT RESPONSIBLE FOR ANY MONIES OVER THE INVOICE AMOUNT OF THE JOB.

INSPECTOR: ____________

SIGNATURE

PRINT

4735 Myrtle Avenue • San Diego, California 92105 • (619) 285-9006 • FAX (619) 285-9930

ArcelorMittal Burns Harbor Plate

QUALITY ASSURANCE
REPORT OF TEST AND ANAYLSES

US HWY 12 Burns Harbor, Indiana

SHIPMENT NO.	DATE SHIPPED	CAR OR VEHICLE NO.		PAGE
803-04008	03-05-13	CSS-CHGO-UP	TTPX 081892	7

SOLD TO	SHIP TO
LEECO STEEL L L C 1011 WARRENVILLE RD STE 500 LISLE IL 60532	LEECO STEEL LLC FWWR DELIVERY TRACK 1907 CLEBURNE TX

NOTE	SERIAL NUMBER	PAT NO.	HEAT NUMBER	NO. PCS.	THICKNESS	WIDTH OR DIA.	LENGTH	WEIGHT	YIELD POINT	TENSILE STRENGTH	ELONG.	RED.
					INCHES	INCHES	INCHES	POUNDS	PSI	PSI	IN	% %

QUALITY STEEL MELTED & MANUFACTURED IN THE U. S. A.

PLATES - , CSA G40.21-04 GR 50WT KLD FINE
GRAIN PRAC, ASTM A709-09A GR 50,
ASTM A572-07 GR 50, CH-V A673 FREQ
(H) L 25 FTLB AT -20F --- PLT
CONTROLLED FINISH

MFST - MFST MILL SERIAL# MFST PPI 0048157- 0001 LIFT
MAX 15 TON-GAUGES SEP UNLDG OH-MAGNET LOAD SAME
SIZE & GRADES TOGETHER

CO# V00160 GH 822-6543C

HEAT NUMBER	PAT NO.	NO. PCS.	WIDTH	LENGTH	WEIGHT	YIELD POINT	TENSILE STRENGTH	ELONG.	RED.
— 821Z04420	3	1	96	240	19602	66700	84200	8	29

(M55)MFST REF#:100096240A572-50

1500-00867

Q-QUENCH TEMPERATURE — T-TEMPER TEMPERATURE — N-NORMALIZE TEMPERATURE

SERIAL NUMBER	PAT NO.	HEAT NUMBER	HARD BHN	BEND	THICKNESS INCHES	TYPE	SIZE	DIR	TEST TEMP. F	CHARPY IMPACT ENERGY FT LBS 1	2	3	SHEAR(%) 1	2	3	LAT. EXP MILS 1	2	3
		821Z04420			1.000	V	3/4	L	-20	206	173	180						

HEAT NUMBER	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Ti	Al	B	Cb	N	Sn	MQUAID GRAIN SIZE
821Z04420	.11	1.50	.011	.004	.344	.285	.18	.03	.004	.002	.002	.033	.0003	.037	.005	.005	

I certify that the above results are a true and correct copy of actual results contained in records maintained by ArcelorMittal Burns Harbor and are in full compliance with the requirements of the specification cited above. This test report cannot be altered and must be transmitted intact with any subsequent third party test reports, if required.

D. W. ELWOOD PER WNK

SUPV. QUALITY ASSURANCE

BHPLTRPT.TIF

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE

(APPLIES ONLY TO U.S. PRODUCTS)

LINCOLN ELECTRIC
THE WELDING EXPERTS®
[1Year]

Product:	Innershield®NR®-232
Classification:	E71T-8-H16 E71T8-A2-CS3-H16
Specification:	AWS A5.20:2005, ASME SFA-5.20 AWS A5.36:2012, ASME SFA-5.36
Date	May 09, 2013

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied according to the Quality System Program of the Lincoln Electric Company, Cleveland, Ohio, U.S.A., which meets the requirements of ISO9001, NCA3800, AWS A5.01, and other specification and Military requirements, as applicable. The Quality System Program has been approved by ASME, ABS, and VdTUV.

Operating Settings	E71T-8-H16 Requirements	RESULTS	
Electrode Size		0.068 inch	5/64 inch
Polarity		DC-	DC-
Voltage, V		21	20
Wire Feed Speed, cm/min (in/min)		483 (190)	457 (180)
Current, A		270	340
Average Heat Input, kJ/mm (kJ/in)		1.5 (37)	1.8 (46)
Contact Tip to Work Distance, mm (in)		25 (1)	25 (1)
Pass/Layers		18/7	13/6
Preheat Temperature, °C (°F)	(60 min.)	20 (72)	25 (73)
Interpass Temperature, °C (°F)	(275 - 325)	165 (325)	165 (325)
Postweld Heat Treatment	As-welded	As-welded	As-welded
Mechanical properties of weld deposits			
Tensile Strength, MPa (ksi)	(70 - 95)	560 (82)	590 (85)
Yield Strength, 0.2% Offset, MPa (ksi)	(58 min.)	460 (67)	480 (69)
Elongation %	22 min.	32	28
Average Impact Energy Joules @ -29 °C (ft-lbs @ -20 °F)	(20 min.)	82 (60) 80,81,84 (59,60,62)	72 (53) 72,72,72 (53,53,53)
Average Hardness, HRB	Not Required	88	89

Chemical composition of weld deposits (weight %)

C	0.30 max.	0.15	0.16
Mn	1.75 max.	0.66	0.68
Si	0.60 max.	0.25	0.27
S	0.03 max.	0.004	0.004
P	0.03 max.	0.006	0.010
Cr	0.20 max.	0.02	0.03
Ni	0.50 max.	0.02	0.02
Mo	0.30 max.	0.01	0.01
V	0.08 max.	0.00	0.00
Cu	0.35 max.	0.02	0.02
Al	1.8 max.	0.6	0.8

Diffusible Hydrogen (per AWS A4.3)	E71T-8-H16 Requirements	RESULTS	
Electrode Size		0.068 inch	5/64 inch
Polarity		DC-	DC-
Diffusible Hydrogen, mL/100g	16.0 max.	8.8	7.4
Absolute Humidity (grains moisture/lb dry air)		42	35

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE

(APPLIES ONLY TO U.S. PRODUCTS)

LINCOLN ELECTRIC
THE WELDING EXPERTS®
[1Year]

Product:	**Innershield®NR®-232**
Classification:	**E71T-8-H16**
	E71T8-A2-CS3-H16
Specification:	**AWS A5.20:2005, ASME SFA-5.20**
	AWS A5.36:2012, ASME SFA-5.36
Date	**May 09, 2013**

Operating Settings	E71T8-A2-CS3-H16 Requirements	RESULTS	
Electrode Size		0.068 inch	5/64 inch
Polarity		DC-	DC-
Voltage, V		21	20
Wire Feed Speed, cm/min (in/min)		483 (190)	457 (180)
Current, A		270	340
Average Heat Input, kJ/mm (kJ/in)		1.5 (37)	1.8 (46)
Contact Tip to Work Distance, mm (in)		25 (1)	25 (1)
Pass/Layers		18/7	13/6
Preheat Temperature, °C (°F)	(60 min.)	20 (72)	25 (73)
Interpass Temperature, °C (°F)	(275 - 325)	165 (325)	165 (325)
Postweld Heat Treatment	As-welded	As-welded	As-welded
Mechanical properties of weld deposits			
Tensile Strength, MPa (ksi)	(70 - 95)	560 (82)	590 (85)
Yield Strength, 0.2% Offset, MPa (ksi)	(58 min.)	460 (67)	480 (69)
Elongation %	22 min.	32	28
Average Impact Energy Joules @ -29 °C (ft-lbs @ -20 °F)	(20 min.)	82 (60) 80,81,84 (59,60,62)	72 (53) 72,72,72 (53,53,53)
Average Hardness, HRB	Not Required	88	89
Chemical composition of weld deposits (weight %)			
C	0.30 max.	0.15	0.16
Mn	1.75 max.	0.66	0.68
Si	0.60 max.	0.25	0.27
S	0.030 max.	0.004	0.004
P	0.030 max.	0.006	0.010
Cr	0.20 max.	0.02	0.03
Ni	0.50 max.	0.02	0.02
Mo	0.30 max.	0.01	0.01
V	0.08 max.	0.00	0.00
Cu	0.35 max.	0.02	0.02
Al	1.8 max.	0.6	0.8
B	Not Required	0.001	0.001

Diffusible Hydrogen (per AWS A4.3)	E71T8-A2-CS3-H16 Requirements	RESULTS	
Electrode Size		0.068 inch	5/64 inch
Polarity		DC-	DC-
Diffusible Hydrogen, mL/100g	16 max.	9	7
Absolute Humidity (grains moisture/lb dry air)		42	35

1. This certificate complies with the requirements of EN 10204, Type 2.2.
2. The electrode sizes required to be tested for this classification are 0.068 inch and 5/64 inch. All other sizes manufactured will also meet these requirements.
3. Test assembly constructed of ASTM A36 steel.
4. Fillet Weld Test (positions as required): Met requirements.
5. Radiographic Inspection: Met requirements.
6. The strength and elongation properties reported here were obtained from tensile specimens artificially aged at 105°C (220°F) for 48 hours.
7. Results below the detection limits of the instrument or lower than the precision required by the specification are reported as zero. Strength values in SI units are reported to the nearest 10 MPa converted from actual data. Preheat and interpass temperature values in SI units are reported to the nearest 5 degrees.

Toronto Cunningham — May 09, 2013
Toronto Cunningham, Certification Supervisor — Date

David A. Fink — May 09, 2013
Dave Fink, Manager, Compliance Engineering, Consumable R&D — Date

Innershield® NR®-232

Mild Steel, All Position • AWS E71T-8

Key Features

- High deposition rates for out-of-position welding
- Penetrating arc
- Fast freezing, easy to remove slag system
- Meets AWS D1.8 seismic lot waiver requirements

Typical Applications

- Structural fabrication, including those subject to seismic requirements
- General plate fabrication
- Hull plate and stiffener welding on ships and barges
- Machinery parts, tanks, hoppers, racks and scaffolding

Conformances

AWS A5.20/A5.20M: 2005	E71T-8-H16
ASME SFA-A5.20:	E71T-8-H16
ABS:	3YSA
Lloyd's Register:	3YS H15
DNV Grade:	III YMS H15
GL:	3YH10S
BV Grade:	SA3YMH
CWB/CSA W48-06:	E491T-8 H16
DB:	EN 758 T42 3 Y N 2
TUV:	EN 758 T42 3 Y N 2
MIL-E-24403/1:*	MIL-71T-8AS
FEMA 353	
AWS D1.8	

*Military Grade Classification of MIL-71T-8AS for 0.068 in (1.7 mm) and 0.072 in (1.8 mm) diameters only.

Welding Positions

All

Innershield® NR®-232
(AWS E71T-8)

DIAMETERS / PACKAGING

Diameter in (mm)	13.5 lb (6.1 kg) Coil 54 lb (24.5 kg) Master Carton	13.5 lb (6.1 kg) Coil 54 lb (24.5 kg) Hermetically Sealed Pail	25 lb (11.3 kg) Steel Spool
0.068 (1.7)	ED012518	ED030232	ED030643
0.072 (1.8)	ED012522		ED030644
5/64 (2.0)	ED012525		ED030647

Diameter in (mm)	25 lb (11.3 kg) Plastic Spool (Vacuum Sealed Foil Bag)	50 lb (22.7 kg) Coil
0.068 (1.7)	ED030949	ED012519
0.072 (1.8)		ED012523
5/64 (2.0)		ED012526

MECHANICAL PROPERTIES[1] – *As Required per AWS A5.20/A5.20M: 2005*

	Yield Strength[2] MPa (ksi)	Tensile Strength MPa (ksi)	Elongation %	Hardness Rockwell B	Charpy V-Notch / J ft•lbf) @ -29°C (-20°F)
Requirements - AWS E71T-8	400 (58) min.	480-655 (70-95)	22 min.	–	27 (20) min.
Typical Results[3] - As-Welded	460-520 (66-75)	575-615 (83-89)	25-31	87-90	47-75 (35-55)

DEPOSIT COMPOSITION[1] – *As Required per AWS A5.20/A5.20M: 2005*

	%C	%Mn	%Si	%S	%P	%Al
Requirements - AWS E71T-8	0.30 max.	1.75 max.	0.60 max.	0.03 max.	0.03 max.	1.8 max.
Typical Results[3]	0.16-0.18	0.61-0.72	0.26-0.33	≤0.01	≤0.01	0.5-0.8

TYPICAL OPERATING PROCEDURES

Diameter, Polarity	CTWD[6] mm (in)	Wire Feed Speed m/min (in/min)	Voltage[7] (volts)	Approx. Current (amps)	Melt-Off Rate kg/hr (lb/hr)	Deposition Rate kg/hr (lb/hr)	Efficiency (%)
0.068 in (1.7 mm), DC-	19-32 (3/4-1 1/4)	2.8 (110)	18-19	195	2.3 (5.0)	1.8 (3.9)	78
		3.3 (130)	19-21	225	2.8 (6.2)	2.0 (4.6)	74
		3.8 (150)	19-21	250	3.2 (7.1)	2.4 (5.3)	75
		4.3 (170)	20-22	270	3.5 (7.8)	2.8 (6.1)	78
		5.0 (195)	23-24	300	4.3 (9.4)	3.2 (7.0)	74
		6.4 (250)	23-24	350	5.4 (11.8)	4.0 (9.0)	76
		7.4 (320)	25-27	400	6.9 (15.2)	5.2 (11.4)	75
0.072 in (1.8 mm), DC-	19-32 (3/4-1 1/4)	2.0 (80)	16-18	130	1.8 (4.0)	1.5 (3.3)	83
		3.5 (140)	18-21	225	3.1 (6.8)	2.5 (5.5)	81
		3.9 (155)	19-22	240	3.3 (7.2)	2.7 (6.0)	83
		4.3 (170)	20-23	255	3.6 (8.0)	2.9 (6.5)	81
		6.4 (250)	22-24	315	5.3 (11.7)	4.3 (9.6)	82
		7.4 (290)	23-25	350	6.2 (13.6)	5.0 (11.0)	81
5/64 in (2.0 mm), DC-	19-32 (3/4-1 1/4)	1.5 (60)	16-17	145	1.7 (3.7)	1.2 (2.7)	73
		2.9 (115)	19-20	260	3.2 (7.0)	2.5 (5.5)	78
		3.0 (120)	19-20	270	3.3 (7.3)	2.6 (5.7)	78
		3.3 (130)	20-21	285	3.5 (7.8)	2.8 (6.2)	79
		4.6 (180)	22-23	365	5.0 (10.9)	3.9 (8.7)	80

[1]Typical all weld metal. [2]Measured with 0.2% offset. [3]See test results disclaimer below.
NOTE: FEMA 353 and AWS D1.8 structural steel seismic supplement test data can be found on this product at www.lincolnelectric.com.

Material Safety Data Sheets (MSDS) and Certificates of Conformance are available on our website at www.lincolnelectric.com

TEST RESULTS

Test results for mechanical properties, deposit or electrode composition and diffusible hydrogen levels were obtained from a weld produced and tested according to prescribed standards, and should not be assumed to be the expected results in a particular application or weldment. Actual results will vary depending on many factors, including, but not limited to, weld procedure, plate chemistry and temperature, weldment design and fabrication methods. Users are cautioned to confirm by qualification testing, or other appropriate means, the suitability of any welding consumable and procedure before use in the intended application.

CUSTOMER ASSISTANCE POLICY

The Lincoln Electric Company is manufacturing and selling high quality welding equipment, consumables, and cutting equipment. Our challenge is to meet the needs of our customers and to exceed their expectations. On occasion, purchasers may ask Lincoln Electric for information or advice about their use of our products. Our employees respond to inquiries to the best of their ability based on information provided to them by the customers and the knowledge they may have concerning the application. Our employees, however, are not in a position to verify the information provided or to evaluate the engineering requirements for the particular weldment. Accordingly, Lincoln Electric does not warrant or guarantee or assume any liability with respect to such information or advice. Moreover, the provision of such information or advice does not create, expand, or alter any warranty on our products. Any express or implied warranty that might arise from the information or advice, including any implied warranty of merchantability or any warranty of fitness for any customers' particular purpose is specifically disclaimed.

Lincoln Electric is a responsive manufacturer, but the selection and use of specific products sold by Lincoln Electric is solely within the control of, and remains the sole responsibility of the customer. Many variables beyond the control of Lincoln Electric affect the results obtained in applying these types of fabrication methods and service requirements.

Subject to Change – This information is accurate to the best of our knowledge at the time of printing. Please refer to www.lincolnelectric.com for any updated information.

THE LINCOLN ELECTRIC COMPANY
22801 St. Clair Avenue • Cleveland, OH • 44117-1199 • U.S.A.
Phone: +1.216.481.8100 • www.lincolnelectric.com

THE WELDING EXPERTS®

Issue Date 01/12

The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE OF CONFORMANCE
(APPLIES ONLY TO U.S. PRODUCTS)

LINCOLN ELECTRIC
THE WELDING EXPERTS®

Product:	**Innershield®NR®-232**
Lot Number:	**13235626**
Classification:	**E71T-8-H16**
Specification:	**AWS D1.8:2009**
Date	**March 01, 2013**

This is to certify that the above listed product was manufactured to meet the Class T4 requirement of AWS A5.01 as required by clause 6.3.8.1 of AWS D1.8:2009.

The product stated herein was manufactured and supplied in accordance with the Quality System Program of The Lincoln Eletric Co., Cleveland, Ohio, U.S.A. as outlined in our Quality Assurance Manual. The Quality System Program of The Lincoln Electric Co. has been accepted by ASME, ABS and approved by VdTUV, and is certified to ISO 9001:2012

Operating Settings	**AWS D1.8 Requirements**	**High Heat Input Results**	**Low Heat Input Results**
Electrode Size		0.072 inch	0.072 inch
Polarity		DC-	DC-
Voltage, V		21	20
Wire Feed Speed, cm/min (in/min)		394 (155)	457 (180)
Current, A		260	280
Average Heat Input, kJ/mm (kJ/in)		3.1 (78)	1.1 (28)
Contact Tip to Work Distance, mm (in)		25 (1)	25 (1)
Travel Speed, cm/min (in/min)		10 (4)	28 (11)
Pass/Layers		8/5	19/7
Preheat Temperature, °C (°F)		135 (275)	20 (72)
Interpass Temperature, °C (°F)		205 (400)	120 (250)
Weld Position		3G	1G
Mechanical properties of weld deposits			
Tensile Strength, MPa (ksi)	(70 min.)	600 (87)	640 (93)
Yield Strength, 0.2% Offset, MPa (ksi)	(58 min.)	430 (63)	510 (74)
Elongation %	22 min.	28	26
Average Impact Energy	(40 min.)	114 (84)	104 (77)
Joules @ 21 °C (ft-lbs @ 70 °F)		111,114,117 (82,84,86)	100,106,107 (74,78,79)
Average Impact Energy	(40 min.)	67 (50)	61 (45)
Joules @ -18 °C (ft-lbs @ 0 °F)		66,66,69 (49,49,51)	60,61,62 (44,45,46)

1. This product satisfies the requirements of AWS D1.8:2009, Annex D, after exposure for 1 week at 80°F / 80% relative humidity.
2. The Charpy V-notch impact values reported at -18 °C (0 °F) are required when the Lowest Anticipated Service Temperature (LAST) is -29 °C (-20 °F).
3. The Charpy V-notch impact values reported at 21 °C (70 °F) are required when the Lowest Anticipated Service Temperature (LAST) is 10 °C (50 °F).
4. Test assembly constructed of ASTM A572 Grade 50 steel.
5. The strength and elongation properties reported here were obtained from tensile specimens artificially aged at 105°C (220°F) for 48 hours.
6. Strength values in SI units are reported to the nearest 10 MPa converted from actual data. Preheat and interpass temperature values in SI units are reported to the nearest 5 degrees.

Toronto Cunningham — March 01, 2013
Toronto Cunningham, Certification Supervisor — Date

David A Fink — March 02, 2013
Dave Fink, Manager, Compliance Engineering, Consumable R&D — Date

Cert. No. 22320

Appendix D Welding Inspection Reports

amec foster wheeler
9177 Sky Park Court
San Diego, CA 92123

MAGNETIC PARTICLE TEST REPORT

Job No. ______ Lab / Field Purchase Order ______ Dwg. No. E 1000 Report No. Specimen No. 1 Page 1 of 1 Date 4/15/16

Client: UCSD		Description: AISC - Continuity Plate Weld Study		Material Spec.: ASTM A992
Material Thickness: +13/16	Material Length or Width: Weld Ends	Acceptance Std.: AWS D1.1 & D1.8	Governing Spec.: AWS D1.1 & D1.8	Area Covered by Test: Run Off Tabs Ends
Surface Condition: Ground Radius	Method and Lot: ☒ Dry ☐ Wet ☐ Fluorescent		Type of Machine and S.N.: Parker Contour Probe DA-400 / 6592	Magnetization: ☐ Circular ☒ Longitudinal
Prod. Spacing & Amperage: 1" to 3" / 4 Amps	Demagnetized: N/A	Current: ☒ AC ☐ DC	Procedure Used: Astm E 709	

ID Number	Indication Size and Location	Accept	Reject	Info Only	Remarks
Beam 14000A : Top Flange	None detected	2	0		
Bottom Flange	None detected	2	0		

Worksheet - Field - Metal
Rev 09/01/11

Respectfully submitted,

Inspector/ASNT Level [signature] / II

Form 411

ULTRASONIC TEST REPORT

amec foster wheeler

Client: UCSD
Project: AISC Continuity Plate Weld Study
Job Number:
Date of Inspection: 4/15/16
Instrument type: Krautkramer USN52L
Transducer Type: Benchmark / Gamma RHP
Transducer Frequency: 2.25mhz / 2.25mhz
Calibration Block Serial #: 90-4999

Contractor: Schuff Steel Company
Welding Specification: AWS D1.1-10 Table 6.2
Welding Process: FCAW-S
Type Material: ASTM A992
Instrument Serial Number: 00D94F
Transducer Serial Number: 70° 012476 / 90° - 01D6CK
Calibration Block Type: IIW Block Type II Steel
Report Number: #3 Specimen No.1
Page 1 of 1

GRID LINE INTERSEC.	CONNECTION BETWEEN: PIECE MARK	CONNECTION BETWEEN: PIECE MARK	WELD LOCATION	Base Material Thickness (1)	Indication Number (2)	Transducer Angle (3)	DECIBELS: Indication Level (A, 4)	DECIBELS: Reference Level (B, 5)	DECIBELS: Attenuation Factor (C, 6)	DECIBELS: Indication Rating (D, 7)	DISCONTINUITY: Length (8)	DISCONTINUITY: Length of Sound Path (9)	DISCONTINUITY: Depth from Surface A (10)	DISCONTINUITY: X Distance (11)	DISCONTINUITY: Y Distance (12)	Accepted (13)	Rejected (14)	Comments (15)
Specimen No.1	14000A	10000A	Top Flange	13/16"	1 1/4	90°		18								✓		Lamination Checks-Column.
	Beam	Column	Top Flange	13/16"		69.5		48.2								✓		
			Weld	1/2"		69.5		48.2								✓		
			Bottom Flange	13/16"		69.5		49.2								✓		
			Bottom Flange	13/16"	1 1/4	90°		18								✓		Lamination Checks-Column.

INSPECTOR: [signature]
ASNT LEVEL: II

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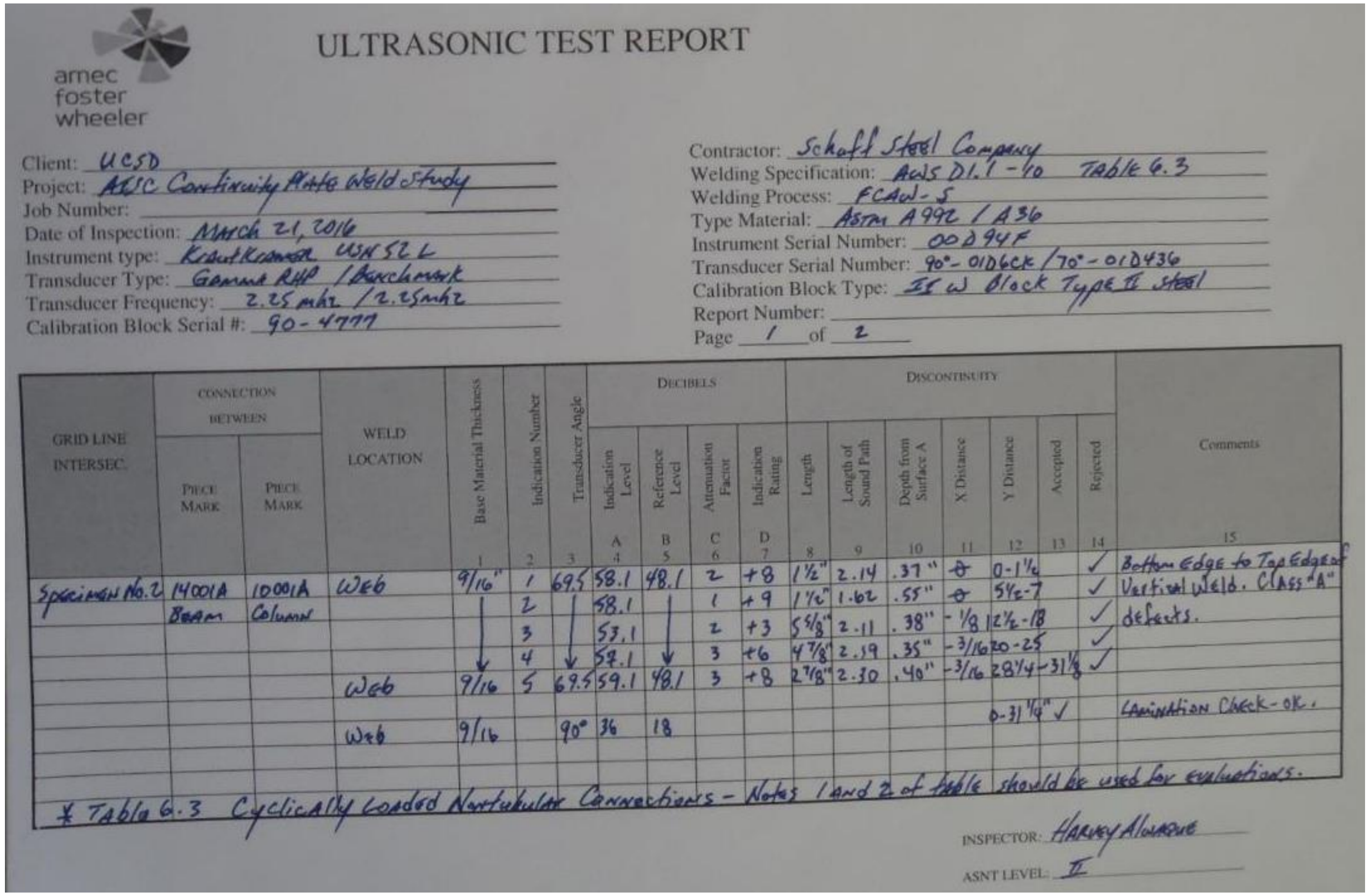


amec foster wheeler

ULTRASONIC TEST REPORT

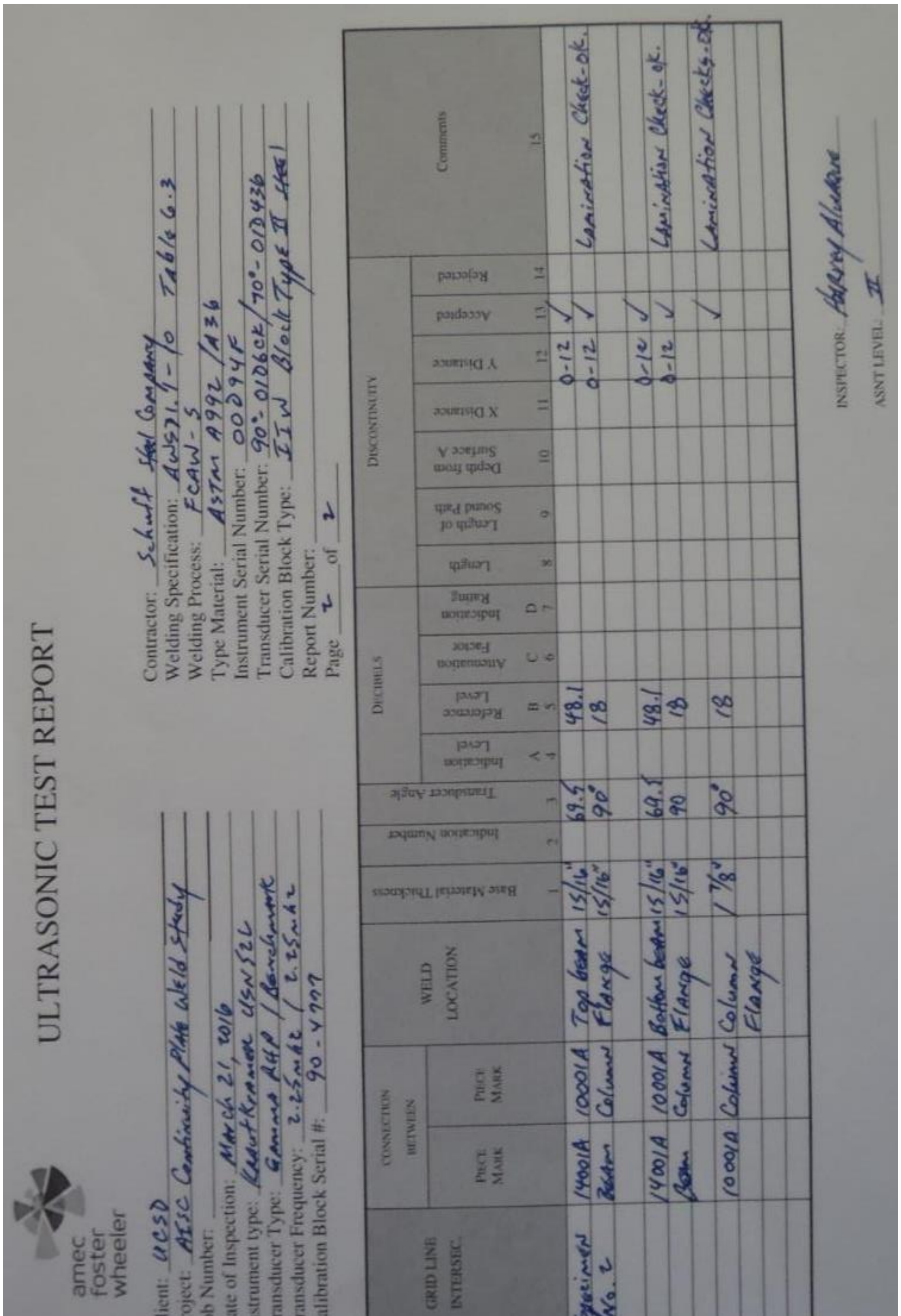
Client: UCSD
Project: AISC Continuity Plate Weld Study
Job Number:
Date of Inspection: March 21, 2016
Instrument type: KrautKramer USN 52 L
Transducer Type: Gamma RHP / Benchmark
Transducer Frequency: 2.25 mhz / 2.25mhz
Calibration Block Serial #: 90-4777

Contractor: Schuff Steel Company
Welding Specification: AWS D1.1-10 Table 6.3
Welding Process: FCAW-S
Type Material: ASTM A992 / A36
Instrument Serial Number: 00D94F
Transducer Serial Number: 90°-01D6CK / 70°-01D436
Calibration Block Type: IIW Block Type II steel
Report Number:
Page 1 of 2

Grid Line Intersec.	Connection Between: Piece Mark	Connection Between: Piece Mark	Weld Location	Base Material Thickness (1)	Indication Number (2)	Transducer Angle (3)	Decibels: Indication Level A (4)	Decibels: Reference Level B (5)	Decibels: Attenuation Factor C (6)	Decibels: Indication Rating D (7)	Discontinuity: Length (8)	Discontinuity: Length of Sound Path (9)	Discontinuity: Depth from Surface A (10)	Discontinuity: X Distance (11)	Discontinuity: Y Distance (12)	Accepted (13)	Rejected (14)	Comments (15)
Specimen No.2	14001A	10001A	Web	9/16"	1	69.5	58.1	48.1	2	+8	1½"	2.14	.37"	0	0-1¼		✓	Bottom Edge to Top Edge of
	Beam	Column		↓	2	↓	58.1	↓	1	+9	1¼"	1.62	.55"	0	5½-7		✓	Vertical Weld. Class "A"
					3		53.1		2	+3	5 5/8"	2.11	.38"	-1/8	12½-18		✓	defects.
					4		57.1		3	+6	4 7/8"	2.19	.35"	-3/16	20-25		✓	
			Web	9/16	5	69.5	59.1	48.1	3	+8	2 7/8"	2.30	.40"	-3/16	28¼-31⅛		✓	
															0-31¼"	✓		Lamination Check - OK.
			Web	9/16		90°	36	18										

* Table 6.3 Cyclically Loaded Nontubular Connections - Notes 1 and 2 of table should be used for evaluations.

Inspector: Harvey Alwarde
ASNT Level: II



amec foster wheeler

ULTRASONIC TEST REPORT

Client: UCSD
Project: AISC Continuity Plate Weld Study
Job Number:
Date of Inspection: March 21, 2016
Instrument type: KrautKramer USN52L
Transducer Type: Gamma AHP / Benchmark
Transducer Frequency: 2.25mhz / 2.25mhz
Calibration Block Serial #: 90-4777

Contractor: Schuff Steel Company
Welding Specification: AWS D1.1-10 Table 6.3
Welding Process: FCAW-S
Type Material: ASTM A992 / A36
Instrument Serial Number: 00094F
Transducer Serial Number: 90°-0106CK / 70°-01D436
Calibration Block Type: IIW Block Type II Steel
Report Number:
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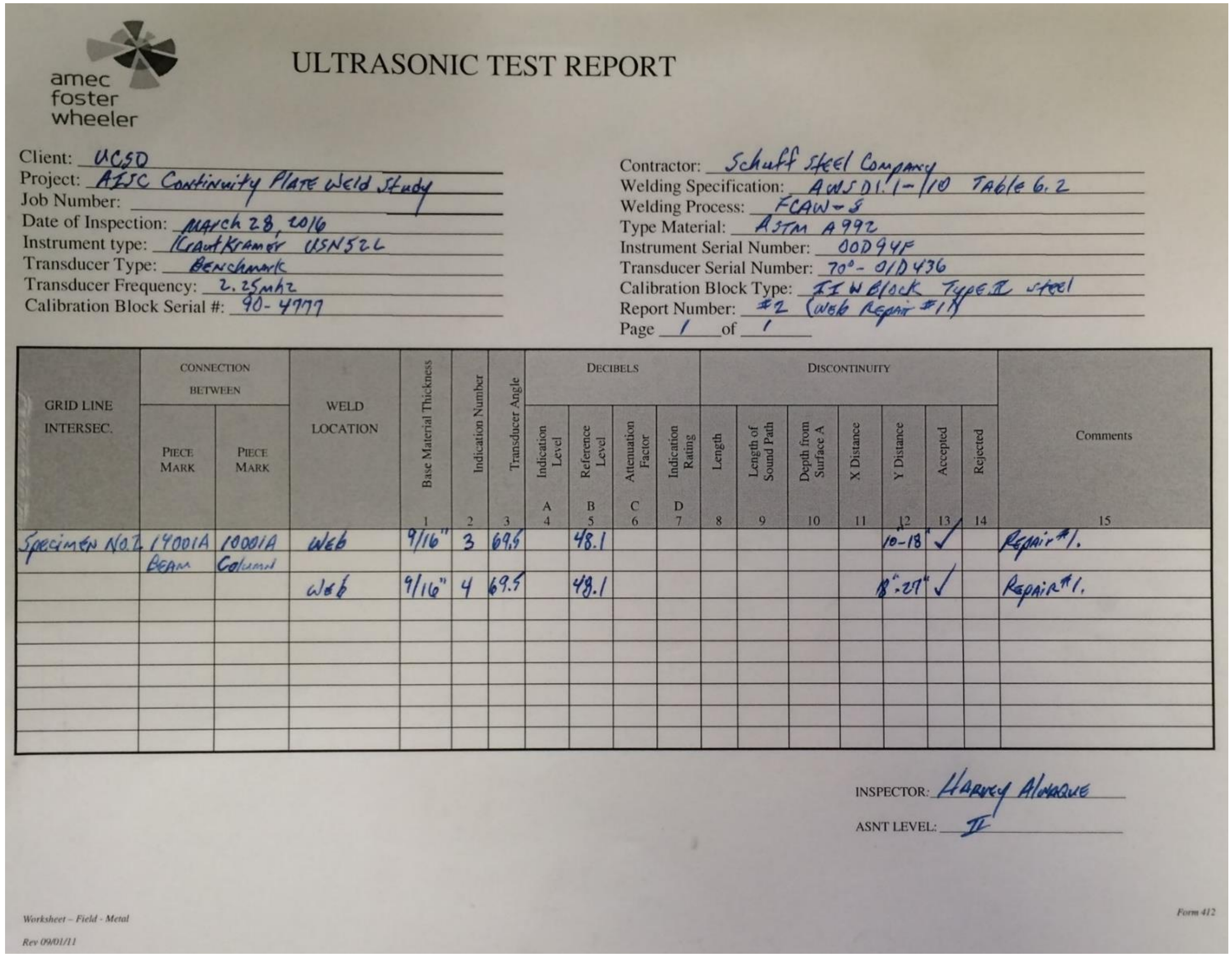
GRID LINE INTERSEC.	CONNECTION BETWEEN		WELD LOCATION	Base Material Thickness	Indication Number	Transducer Angle	DECIBELS				DISCONTINUITY							Comments
	PIECE MARK	PIECE MARK					Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Length of Sound Path	Depth from Surface A	X Distance	Y Distance	Accepted	Rejected	
				1	2	3	A 4	B 5	C 6	D 7	8	9	10	11	12	13	14	15
Specimen No. 2	14001A Beam	10001A Column	Top beam Flange	15/16" 15/16"		69.5 90°		48.1 18							0-12 0-12	✓ ✓		Lamination Check-ok.
	14001A Beam	10001A Column	Bottom beam Flange	15/16" 15/16"		69.5 90		48.1 18							0-12 0-12	✓ ✓		Lamination Check-ok.
	10001A	Column	Column Flange	1 7/8"		90°		18								✓		Lamination Checks-ok.

INSPECTOR: Harvey Alvarez
ASNT LEVEL: II



amec foster wheeler

ULTRASONIC TEST REPORT

Client: UCSD
Project: AISC Continuity Plate Weld Study
Job Number:
Date of Inspection: March 28, 2016
Instrument type: Krautkramer USN52L
Transducer Type: Benchmark
Transducer Frequency: 2.25mhz
Calibration Block Serial #: 90-4777

Contractor: Schuff Steel Company
Welding Specification: AWS D1.1-/10 Table 6.2
Welding Process: FCAW-S
Type Material: ASTM A992
Instrument Serial Number: 00D94F
Transducer Serial Number: 70° - 01D436
Calibration Block Type: II W Block Type II steel
Report Number: #2 (Web Repair #1)
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Grid Line Intersec.	Connection Between: Piece Mark	Connection Between: Piece Mark	Weld Location	Base Material Thickness 1	Indication Number 2	Transducer Angle 3	Decibels: Indication Level A 4	Decibels: Reference Level B 5	Decibels: Attenuation Factor C 6	Decibels: Indication Rating D 7	Discontinuity: Length 8	Discontinuity: Length of Sound Path 9	Discontinuity: Depth from Surface A 10	Discontinuity: X Distance 11	Discontinuity: Y Distance 12	Discontinuity: Accepted 13	Discontinuity: Rejected 14	Comments 15
Specimen No. 2	14001A Beam	10001A Column	Web	9/16"	3	69.5		48.1							10-18"	✓		Repair #1.
			Web	9/16"	4	69.5		48.1							8"-27"	✓		Repair #1.

INSPECTOR: Harvey Alvarque
ASNT LEVEL: II

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