

ANSI/AISC 358-10
ANSI/AISC 358s1-11
An American National Standard

Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications

Including Supplement No. 1

2010
(includes 2011 supplement)

Supersedes ANSI/AISC 358-05 and ANSI/AISC 358s1-09

Approved by the AISC Connection Prequalification Review Panel
and issued by the AISC Board of Directors



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Printed in the United States of America

PREFACE

(This Preface is not part of ANSI/AISC 358-10, *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications*, but is included for informational purposes only.)

This edition of the Standard was developed using a consensus process in concert with the *Specification for Structural Steel Buildings* (ANSI/AISC 360-10) and *Seismic Provisions for Structural Steel Buildings* (ANSI/AISC 341-10). This Standard is incorporated by reference in the *Seismic Provisions*.

The most significant modification to this edition of the Standard is the incorporation of three prequalified connections into the body of the standard that were previously part of a supplement (Chapters 7, 8, and 9). It is anticipated that future supplements will be issued as additional moment connections become prequalified.

This printing includes Supplement No. 1 to *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications* (ANSI/AISC 358s1-11) which consists of the material in Chapter 10. The Supplement was finalized shortly after the completion of this Standard.

The Symbols, Glossary, and Appendices to this Standard are an integral part of the Standard. A non-mandatory Commentary has been prepared to provide background for the provisions of the Standard and the user is encouraged to consult it. Additionally, non-mandatory User Notes are interspersed throughout the Standard to provide concise and practical guidance in the application of the provisions.

The reader is cautioned that professional judgment must be exercised when data or recommendations in this Standard are applied, as described more fully in the disclaimer notice preceding the Preface.

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SYMBOLS

The Standard uses the following symbols in addition to the terms defined in the *Specification for Structural Steel Buildings* (ANSI/AISC 360-10) and the *Seismic Provisions for Structural Steel Buildings* (ANSI/AISC 341-10). Some definitions in the list below have been simplified in the interest of brevity. In all cases, the definitions given in the body of the Standard govern. Symbols without text definitions, used in only one location and defined at that location, are omitted in some cases. The section or table number on the right refers to where the symbol is first used.

Symbol	Definition	Section
A_c	Contact areas between the continuity plate and the column flanges that have attached beam flanges, in. ² (mm ²)	6.7
A_c	Area of concrete in the column, in. ² (mm ²)	10.8
A_s	Area of steel in the column, in. ² (mm ²)	10.8
C_{pr}	Factor to account for peak connection strength, including strain hardening, local restraint, additional reinforcement, and other connection conditions	2.4.3
C_t	Factor used in Equation 6.10-17	6.10
F_{EXX}	Filler metal classification strength, ksi (MPa)	9.9
F_{fu}	Factored beam flange force, kips (N)	6.10
F_{nt}	Nominal tensile strength of bolt from the AISC <i>Specification</i> , ksi (MPa)	6.10
F_{nv}	Nominal shear strength of bolt from the AISC <i>Specification</i> , ksi (MPa)	6.10
F_{su}	Required stiffener strength, kips (N)	6.10
F_u	Specified minimum tensile strength of the yielding element, ksi (MPa)	10.8
F_{ub}	Specified minimum tensile strength of beam material, ksi (MPa)	7.6
F_{uf}	Specified minimum tensile strength of flange material, ksi (MPa)	9.9
F_{up}	Specified minimum tensile strength of end-plate material, ksi (MPa)	6.10
F_{up}	Specified minimum tensile strength of plate material, ksi (MPa)	7.6
F_w	Nominal weld design strength per the AISC <i>Specification</i> , ksi (MPa)	9.9
F_y	Specified minimum yield stress of the yielding element, ksi (MPa)	10.8
F_{yb}	Specified minimum yield stress of beam material, ksi (MPa)	6.10
F_{yc}	Specified minimum yield stress of column flange material, ksi (MPa)	6.10
F_{yf}	Specified minimum yield stress of flange material, ksi (MPa)	9.9
F_{yp}	Specified minimum yield stress of end-plate material, ksi (MPa)	6.10
F_{ys}	Specified minimum yield stress of stiffener material, ksi (MPa)	6.10
H_l	Height of the story below the node, in. (mm)	10.8

Symbol	Definition	Section
H_u	Height of the story above the node, in. (mm)	10.8
L_{bb}	Length of bracket, in. (mm)	Table 9.1
L_h	Distance between <i>plastic hinge locations</i> , in. (mm)	5.8
L_{st}	Length of end plate stiffener, in. (mm)	6.9.4
M_{pb}^*	Moment at the intersection of the beam and column centerlines determined by projecting the beam maximum developed moments from the column face, kip-in. (N-mm)	10.8
M_{pc}^*	Moment at the beam and column centerline determined by projecting the sum of the nominal column plastic moment strength, reduced by the axial stress, kip-in. (N-mm)	10.8
M_{pcl}^*	Plastic moment nominal strength of the column below the node, about the axis under consideration considering simultaneous axial loading and loading about the transverse axis, kip-in. (N-mm)	10.8
M_{pcu}^*	Plastic moment nominal strength of the column above the node, about the axis under consideration considering simultaneous axial loading and loading about the transverse axis, kip-in (N-mm)	10.8
M_{bolts}	Moment at collar bolts, kip-in. (N-mm)	10.8
M_{cf}	Column flange flexural strength, kip-in. (N-mm)	6.9
M_f	Probable maximum moment at face of column, kip-in. (N-mm)	5.8
M_{np}	Moment without prying action in the bolts, kip-in. (N-mm)	Table 6.2
M_{pe}	Plastic moment of beam based on expected yield stress, kip-in. (N-mm)	5.8
M_{pr}	Probable maximum moment at plastic hinge, kip-in. (N-mm)	2.4.3
M_{uv}	Additional moment due to shear amplification from the center of the reduced beam section to the centerline of the column, kip-in. (N-mm)	5.4(2)(a)
N	Thickness of beam flange plus 2 times the <i>reinforcing fillet</i> weld size, in. (mm)	6.10
P	Axial load acting on the column at the section under consideration in accordance with the applicable load combination specified by the building code, but not considering amplified seismic load, kips (N)	10.8
P_t	Minimum specified tensile strength of bolt, kips (N)	Table 6.2
P_{uc}	Required compressive strength using LRFD load combinations, kips (N)	Symbols
R_{pt}	Minimum bolt pretension, kips (N)	10.8
R_n	Required force for continuity plate design, kips (N)	6.10
R_n	Nominal strength	7.6
$R_n^{p_z}$	Nominal panel zone shear strength, kips (N)	10.8
R_t	Ratio of the expected tensile strength to the specified minimum tensile strength for flange material	9.9
$R_u^{p_z}$	Required panel zone shear strength, kips (N)	10.8
R_y	Ratio of the expected yield stress to the specified minimum yield stress, F_y ,	9.9

Symbol	Definition	Section
S_1	Distance from face of the column to the nearest row of bolts, in. (mm)	7.6
S_h	Distance from face of column to the plastic hinge, in. (mm)	2.3.2a
V_{bolts}	Probable maximum shear at collar bolts, kips (N)	10.8
V_{cf}	Probable maximum shear at face of collar flange, kips (N)	10.8
V_{col}	Column shear, kips (N)	10.8
V_f	Probable maximum shear at the face of column, kips (N)	10.8
$V_{gravity}$	Beam shear force resulting from $1.2D + f_1L + 0.2S$, kips (N)	5.8
V_h	Beam shear force at <i>plastic hinge location</i> , kips (N)	7.6
V_{RBS}	Larger of the two values of shear force at the center of the reduced beam section at each end of a beam, kips (N)	5.4(2)(a)
V'_{RBS}	Smaller of the two values of shear force at the center of the reduced beam section at each end of a beam, kips (N)	Commentary 5.8
V_u	Required shear strength of beam and beam web-to-column connection, kips (N)	5.8
Y_c	Column flange yield line mechanism parameter, in. (mm)	Table 6.5
Y_m	Simplified column flange yield-line mechanism parameter	9.9
Y_p	End-plate yield line mechanism parameter, in. (mm)	Table 6.2
Z_c	Plastic section modulus of the column about either axis, in. ³ (mm ³)	10.8
Z_e	Effective plastic modulus of the section (or connection) at the location of a plastic hinge, in. ³ (mm ³)	2.4.3
Z_{RBS}	Plastic section modulus at the center of the reduced beam section, in. ³ (mm ³)	5.8
Z_x	Plastic section modulus about the x-axis, in. ³ (mm ³)	5.8
a	Horizontal distance from face of column flange to the start of a reduced beam section cut, in. (mm)	5.4(2)(a)
a	Distance from the outside face of the collar to the reduced beam section cut, in. (mm)	10.8
b	Width of compression element as defined in the AISC <i>Specification</i> , in. (mm)	2.3.2b(2)
b	Length of a reduced beam section cut, in. (mm)	5.4(2)(a)
b_{bb}	Width of bracket, in. (mm)	Table 9.1
b_{bf}	Width of beam flange, in. (mm)	5.8
b_{cf}	Width of column flange, in. (mm)	9.9
b_f	Width of flange, in. (mm)	5.3.1(7)
b_p	Width of end plate, in. (mm)	Table 6.1
c	Depth of cut at center of the reduced beam section, in. (mm)	5.8
d	Depth of beam, in. (mm)	5.3.1(7)
d_b	Diameter of column flange bolts, in. (mm)	9.9
$d_{b\ req'd}$	Required bolt diameter, in. (mm)	6.10
d_c	Depth of column, in. (mm)	5.4(2)(a)
d_{col}	Depth of the column, in. (mm)	10.8
d_e	Column bolt edge distance, in. (mm)	Table 9.2
d_{eff}	Effective depth of beam, calculated as the centroidal distance between bolt groups in the upper and lower brackets, in. (mm)	9.9

Symbol	Definition	Section
d_{leg}^{CC}	Effective depth of the collar corner assembly leg, in. (mm)	10.8
f_c'	Specified compressive strength of the concrete fill, ksi (MPa)	10.8
f_1	Load factor determined by the applicable building code for live loads but not less than 0.5	5.8
g	Horizontal distance (gage) between fastener lines, in. (mm)	Table 6.1
h_1	Distance from the centerline of a compression flange to the tension-side inner bolt rows in four-bolt extended and four-bolt stiffened extended end-plate moment connections, in. (mm)	Table 6.2
h_{bb}	Height of bracket, in. (mm)	Table 9.1
h_i	Distance from centerline of compression flange to the centerline of the i th tension bolt row, in. (mm)	6.10
h_o	Distance from centerline of compression flange to the tension-side outer bolt row in four-bolt extended and four-bolt stiffened extended end-plate moment connections, in. (mm)	Table 6.2
h_p	Height of plate, in. (mm)	8.6
h_{st}	Height of stiffener, in. (mm)	6.9.4
k_1	Distance from web center line to flange toe of fillet, in. (mm)	3.6
k_c	Distance from outer face of a column flange to web toe of fillet (design value) or fillet weld, in. (mm)	6.9
k_{det}	Largest value of k_1 used in production, in. (mm)	3.6
l	Bracket overlap distance, in. (mm)	9.9
l_w	Length of available fillet weld, in. (mm)	9.9
l_w^{CC}	Total length of available fillet weld at collar corner assembly, in. (mm)	10.8
l_w^{CWX}	Total length of available fillet weld at collar web extension, in. (mm)	10.8
n	Number of bolts	7.6
n_b	Number of bolts at compression flange	6.10
n_{cb}	Number of column bolts	Table 9.1
n_{cf}	Number of collar bolts per collar flange	10.8
n_i	Number of inner bolts	6.10
n_o	Number of outer bolts	6.10
p	Perpendicular tributary length per bolt, in. (mm)	9.9
p_b	Vertical distance between the inner and outer row of bolts in an eight-bolt stiffened extended end-plate moment connection, in. (mm)	Table 6.1
p_b	Column bolt pitch, in. (mm)	Table 9.2
p_{fi}	Vertical distance from the inside of a beam tension flange to the nearest inside bolt row, in. (mm)	Table 6.1
p_{fo}	Vertical distance from the outside of a beam tension flange to the nearest outside bolt row, in. (mm)	Table 6.1
p_{si}	Distance from the inside face of continuity plate to the nearest inside bolt row, in. (mm)	6.9.2
p_{so}	Distance from the outside face of continuity plate to the nearest outside bolt row, in. (mm)	6.9.2

Symbol	Definition	Section
r_h	Radius of horizontal bracket, in. (mm)	Table 9.2
r_{ut}	Required collar bolt tension strength, kips (N)	10.8
r_v	Radius of bracket stiffener, in. (mm)	Table 9.2
s	Distance from the centerline of the most inside or most outside tension bolt row to the edge of a yield line pattern, in. (mm)	Table 6.2
s	Spacing of bolt rows in a bolted flange plate moment connection, in. (mm)	7.6
s_{bolts}	Distance from center of plastic hinge to the centroid of the collar bolts, in. (mm)	10.8
s_f	Distance from center of plastic hinge to face of column, in. (mm)	10.8
s_h	Distance from center of plastic hinge to center of column, in. (mm)	10.8
t_{bf}	Thickness of beam flange, in. (mm)	5.8
t_{bw}	Thickness of beam web, in. (mm)	6.10
t_{col}	Wall thickness of HSS or built-up box column, in. (mm)	10.8
t_{collar}	Distance from the face of the column to the outside face of the collar, in. (mm)	10.8
t_{cw}	Thickness of column web, in. (mm)	6.10
t_f^{CC}	Fillet weld size required to join collar corner assembly to column, in. (mm)	10.8
t_f^{CWX}	Fillet weld size required to join each side of the beam web to the collar web extension, in. (mm)	10.8
t_{leg}^{CC}	Effective thickness of the collar corner assembly leg, in. (mm)	10.8
t_p	Thickness of plate, in. (mm)	Table 6.1
t_s	Thickness of stiffener, in. (mm)	6.10
w	Minimum size of fillet weld, in. (mm)	Table 9.2
w	Uniform beam gravity load, kips per linear ft (N per linear mm)	Commentary 5.8
w_u	Distributed load on the beam, kips/ft (N/mm), using the load combination $1.2D + f_1L + 0.2S$	10.8
ϕ_d	Resistance factor for ductile limit states	2.4.1
ϕ_n	Resistance factor for nonductile limit states	2.4.1

GLOSSARY

The Standard uses the following terms in addition to the terms defined in the 2010 AISC *Specification for Structural Steel Buildings* and the 2010 AISC *Seismic Provisions for Structural Steel Buildings*. Terms defined in this Glossary are *italicized* in the Glossary and where they first appear within a section or long paragraph throughout the Standard.

Air carbon arc cutting. Process of cutting steel by the heat from an electric arc applied simultaneously with an air jet.

Backing. Piece of metal or other material, placed at the weld *root* to facilitate placement of the *root* pass.

Backgouge. Process of removing by grinding or *air carbon arc cutting* all or a portion of the *root* pass of a complete-joint-penetration groove weld, from the reverse side of a joint from which a *root* was originally placed.

Cascaded weld ends. Method of terminating a weld in which subsequent weld beads are stopped short of the previous bead, producing a cascade effect.

Concrete structural slab. Reinforced concrete slab or concrete fill on steel deck with a total thickness of 3 in. (75 mm) or greater and a concrete compressive strength in excess of 2,000 psi (14 MPa).

Nonfusible backing. *Backing* material that will not fuse with the base metals during the welding process.

Plastic hinge location. Location in a column-beam assembly where inelastic energy dissipation is assumed to occur through the development of plastic flexural straining.

Probable maximum moment at the plastic hinge. Expected moment developed at a *plastic hinge location* along a member, considering the probable (mean) value of the material strength for the specified steel and effects of strain hardening.

Reinforcing fillet. Fillet weld applied to a groove welded T-joint to obtain a contour to reduce stress concentrations associated with joint geometry.

Root. Portion of a multi-pass weld deposited in the first pass of welding.

Thermal cutting. Group of cutting processes that severs or removes metal by localized melting, burning or vaporizing of the workpiece.

Weld tab. Piece of metal affixed to the end of a welded joint to facilitate the initiation and termination of weld passes outside the structural joint.

CHAPTER 1

GENERAL

1.1. SCOPE

This Standard specifies design, detailing, fabrication and quality criteria for connections that are prequalified in accordance with the AISC *Seismic Provisions for Structural Steel Buildings* (herein referred to as the AISC *Seismic Provisions*) for use with special moment frames (SMF) and intermediate moment frames (IMF). The connections contained in this Standard are prequalified to meet the requirements in the AISC *Seismic Provisions* only when designed and constructed in accordance with the requirements of this Standard. Nothing in this Standard shall preclude the use of connection types contained herein outside the indicated limitations, nor the use of other connection types, when satisfactory evidence of qualification in accordance with the AISC *Seismic Provisions* is presented to the authority having jurisdiction.

1.2. REFERENCES

The following standards form a part of this Standard to the extent that they are referenced and applicable:

American Institute of Steel Construction (AISC)

ANSI/AISC 341-10 *Seismic Provisions for Structural Steel Buildings* (herein referred to as the AISC *Seismic Provisions*)

ANSI/AISC 360-10 *Specification for Structural Steel Buildings* (herein referred to as the AISC *Specification*)

ASTM International (ASTM)

A354-07a *Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners*

A370-09 *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

A488/A488M-10 *Standard Practice for Steel Castings, Welding, Qualifications of Procedures and Personnel*

A574-11 *Standard Specification for Alloy Steel Socket Head Cap Screws*

A609/A609M-91(2007) *Standard Practice for Castings, Carbon, Low-Alloy, and Martensitic Stainless Steel, Ultrasonic Examination Thereof*

A781/A781M-11 *Standard Specification for Castings, Steel and Alloy, Common Requirements, for General Industrial Use*

A802/A802M-95(2010) *Standard Practice for Steel Castings, Surface Acceptance Standards, Visual Examination*

A903/A903M-99(2007) *Standard Specification for Steel Castings, Surface Acceptance Standards, Magnetic Particle and Liquid Penetrant Inspection*

A958/A958M-10 *Standard Specification for Steel Castings, Carbon and Alloy, with Tensile Requirements, Chemical Requirements Similar to Standard Wrought Grades*
B19-10 *Standard Specification for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks*

B36/B36M *Standard Specification for Brass Plate, Sheet, Strip, And Rolled Bar*

E186-10 *Standard Reference Radiographs for Heavy Walled (2 to 4½ in. (50.8 to 114 mm)) Steel Castings*

E446-10 *Standard Reference Radiographs for Steel Castings Up to 2 in. (50.8 mm) in Thickness*

E709-08 *Standard Guide for Magnetic Particle Examination*

American Welding Society (AWS)

AWS D1.1/D1.1M-2010 *Structural Welding Code—Steel*

AWS D1.8/D1.8M-2009 *Structural Welding Code—Seismic Supplement*

Manufacturers Standardization Society (MSS)

MSS SP-55-2006 *Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components—Visual Method for Evaluation of Surface Irregularities*

Research Council on Structural Connections (RCSC)

Specification for Structural Joints using High-Strength Bolts, 2009 (herein referred to as the *RCSC Specification*)

1.3. GENERAL

All design, materials and workmanship shall conform to the requirements of the AISC *Seismic Provisions* and this Standard. The connections contained in this Standard shall be designed according to the Load and Resistance Factor Design (LRFD) provisions. Connections designed according to this Standard are permitted to be used in structures designed according to the LRFD or Allowable Strength Design (ASD) provisions of the AISC *Seismic Provisions*.

CHAPTER 2

DESIGN REQUIREMENTS

2.1. SPECIAL AND INTERMEDIATE MOMENT FRAME CONNECTION TYPES

The connection types listed in Table 2.1 are prequalified for use in connecting beams to column flanges in special moment frames (SMF) and intermediate moment frames (IMF) within the limitations specified in this Standard.

2.2. CONNECTION STIFFNESS

All connections contained in this Standard shall be considered fully restrained (Type FR) for the purpose of seismic analysis.

2.3. MEMBERS

The connections contained in this Standard are prequalified in accordance with the requirements of the AISC *Seismic Provisions* when used to connect members meeting the limitations of Sections 2.3.1 or 2.3.2, as applicable.

1. Rolled Wide-Flange Members

Rolled wide-flange members shall conform to the cross section profile limitations applicable to the specific connection in this Standard.

2. Built-up Members

Built-up members having a doubly symmetric, I-shaped cross section shall meet the following requirements:

- (1) Flanges and webs shall have width, depth and thickness profiles similar to rolled wide-flange sections meeting the profile limitations for wide-flange sections applicable to the specific connection in this Standard, and
- (2) Webs shall be continuously connected to flanges in accordance with the requirements of Sections 2.3.2a or 2.3.2b, as applicable.

TABLE 2.1.
Prequalified Moment Connections

Connection Type	Chapter	Systems
Reduced beam section (RBS)	5	SMF, IMF
Bolted unstiffened extended end plate (BUEEP)	6	SMF, IMF
Bolted stiffened extended end plate (BSEEP)	6	SMF, IMF
Bolted flange plate (BFP)	7	SMF, IMF
Welded unreinforced flange-welded web (WUF-W)	8	SMF, IMF
Kaiser bolted bracket (KBB)	9	SMF, IMF
ConXtech ConXL moment connection (ConXL)	10	SMF, IMF

2a. Built-up Beams

The web and flanges shall be connected using complete-joint-penetration (CJP) groove welds with a pair of *reinforcing fillet* welds within a zone extending from the beam end to a distance not less than one beam depth beyond the *plastic hinge location*, S_h , unless specifically indicated in this Standard. The minimum size of these fillet welds shall be the lesser of $5/16$ in. (8 mm) and the thickness of the beam web.

Exception: This provision shall not apply where individual connection prequalifications specify other requirements.

2b. Built-up Columns

Built-up columns shall conform to the provisions of subsections (1) through (4), as applicable. Built-up columns shall satisfy the requirements of the AISC *Specification* except as modified in this Section. Transfer of all internal forces and stresses between elements of the built-up column shall be through welds.

(1) I-Shaped Columns

The elements of built-up I-shaped columns shall conform to the requirements of the AISC *Seismic Provisions*.

Within a zone extending from 12 in. (300 mm) above the upper beam flange to 12 in. (300 mm) below the lower beam flange, unless specifically indicated in this Standard, the column webs and flanges shall be connected using CJP groove welds with a pair of reinforcing fillet welds. The minimum size of the fillet welds shall be the lesser of $5/16$ in. (8 mm) and the thickness of the column web.

(2) Boxed Wide-Flange Columns

The wide-flange shape of a boxed wide-flange column shall conform to the requirements of the AISC *Seismic Provisions*.

The width-to-thickness ratio, b/t , of plates used as flanges shall not exceed, $0.6\sqrt{E/F_y}$, where b shall be taken as not less than the clear distance between plates.

The width-to-thickness ratio, h/t_w , of plates used only as webs shall conform to the requirements of the AISC *Seismic Provisions*.

Within a zone extending from 12 in. (300 mm) above the upper beam flange to 12 in. (300 mm) below the lower beam flange, flange and web plates of boxed wide-flange columns shall be joined by CJP groove welds. Outside this zone, plate elements shall be continuously connected by fillet or groove welds.

(3) Built-up Box Columns

The width-to-thickness ratio, b/t , of plates used as flanges shall not exceed, $0.6\sqrt{E/F_y}$, where b shall be taken as not less than the clear distance between web plates.

The width-to-thickness ratio, h/t_w , of plates used only as webs shall conform to the requirements of the AISC *Seismic Provisions*.

Within a zone extending from 12 in. (300 mm) above the upper beam flange to 12 in. (300 mm) below the lower beam flange, flange and web plates of box columns shall be joined by CJP groove welds. Outside this zone, box column web and flange plates shall be continuously connected by fillet welds or groove welds.

(4) Flanged Cruciform Columns

The elements of flanged cruciform columns, whether fabricated from rolled shapes or built up from plates, shall meet the requirements of the AISC *Seismic Provisions*.

Within a zone extending from 12 in. (300 mm) above the upper beam flange to 12 in. (300 mm) below the lower beam flange, the web of the tee-shaped sections shall be welded to the web of the continuous I-shaped section with CJP groove welds with a pair of reinforcing fillet welds. The minimum size of fillet welds shall be the lesser of $5/16$ in. (8 mm) or the thickness of the column web. Continuity plates shall conform to the requirements for wide-flange columns.

2.4. CONNECTION DESIGN PARAMETERS

1. Resistance Factors

Where available strengths are calculated in accordance with the AISC *Specification*, the resistance factors specified therein shall apply. When available strengths are calculated in accordance with this Standard, the resistance factors ϕ_d and ϕ_n shall be used as specified in the applicable section of this Standard. The values of ϕ_d and ϕ_n shall be taken as follows:

- (a) For ductile limit states:

$$\phi_d = 1.00$$

- (b) For nonductile limit states:

$$\phi_n = 0.90$$

2. Plastic Hinge Location

The distance of the plastic hinge from the face of the column, S_h , shall be taken in accordance with the requirements for the individual connection as specified herein.

3. Probable Maximum Moment at Plastic Hinge

The *probable maximum moment at the plastic hinge* shall be:

$$M_{pr} = C_{pr} R_y F_y Z_e \quad (2.4.3-1)$$

where

M_{pr} = probable maximum moment at plastic hinge, kip-in. (N-mm)

R_y = ratio of the expected yield stress to the specified minimum yield stress F_y as specified in the AISC *Seismic Provisions*

Z_e = effective plastic section modulus of the section (or connection) at the location of the plastic hinge, in.³ (mm³)

C_{pr} = factor to account for the peak connection strength, including strain hardening, local restraint, additional reinforcement, and other connection conditions. Unless otherwise specifically indicated in this Standard, the value of C_{pr} shall be:

$$C_{pr} = \frac{F_y + F_u}{2F_y} \leq 1.2 \quad (2.4.3-2)$$

where

F_y = specified minimum yield stress of the yielding element, ksi (MPa)

F_u = specified minimum tensile strength of the yielding element, ksi (MPa)

4. Continuity Plates

Beam flange continuity plates shall be provided in accordance with the AISC *Seismic Provisions*.

Exceptions:

1. For bolted end-plate connections, continuity plates shall be provided in accordance with Section 6.7.
2. For the Kaiser bolted bracket connection, the provisions of Chapter 9 shall apply. When continuity plates are required by Chapter 9, thickness and detailing shall be in accordance with the AISC *Seismic Provisions*.

2.5. PANEL ZONES

Panel zones shall conform to the requirements of the AISC *Seismic Provisions*.

2.6. PROTECTED ZONE

The protected zone shall be as defined for each prequalified connection. Unless otherwise specifically indicated in this Standard, the protected zone of the beam shall be defined as the area from the face of the column flange to one-half of the beam depth beyond the plastic hinge. The protected zone shall meet the requirements of the AISC *Seismic Provisions*, except as indicated in this Standard. Bolt holes in beam webs, when detailed in accordance with the individual connection provisions of this Standard, shall be permitted.

CHAPTER 3

WELDING REQUIREMENTS

3.1. FILLER METALS

Filler metals shall conform to the requirements of the AISC *Seismic Provisions*.

3.2. WELDING PROCEDURES

Welding procedures shall be in accordance with the AISC *Seismic Provisions*.

3.3. BACKING AT BEAM-TO-COLUMN AND CONTINUITY PLATE-TO-COLUMN JOINTS

1. Steel Backing at Continuity Plates

Steel *backing* used at continuity plate-to-column welds need not be removed. At column flanges, steel backing left in place shall be attached to the column flange using a continuous $5/16$ -in. (8-mm) fillet weld on the edge below the CJP groove weld.

When backing is removed, the *root* pass shall be *backgouged* to sound weld metal and backwelded with a *reinforcing fillet*. The reinforcing fillet shall be continuous with a minimum size of $5/16$ in. (8 mm).

2. Steel Backing at Beam Bottom Flange

Where steel backing is used with CJP groove welds between the bottom beam flange and the column, the backing shall be removed.

Following the removal of steel backing, the root pass shall be backgouged to sound weld metal and backwelded with a reinforcing fillet. The size of the reinforcing fillet leg adjacent to the column flange shall be a minimum of $5/16$ in. (8 mm), and the reinforcing fillet leg adjacent to the beam flange shall be such that the fillet toe is located on the beam flange base metal.

Exception: If the base metal and weld root are ground smooth after removal of the backing, the reinforcing fillet adjacent to the beam flange need not extend to base metal.

3. Steel Backing at Beam Top Flange

Where steel backing is used with CJP groove welds between the top beam flange and the column, and the steel backing is not removed, the steel backing shall be attached to the column by a continuous $5/16$ -in. (8-mm) fillet weld on the edge below the CJP groove weld.

4. Prohibited Welds at Steel Backing

Backing at beam flange-to-column flange joints shall not be welded to the underside of the beam flange, nor shall tack welds be permitted at this location. If fillet welds or tack welds are placed between the backing and the beam flange in error, they shall be repaired as follows:

- (1) The weld shall be removed such that the fillet weld or tack weld no longer attaches the backing to the beam flange.
- (2) The surface of the beam flange shall be ground flush and shall be free of defects.
- (3) Any gouges or notches shall be repaired. Repair welding shall be done with E7018 SMAW electrodes or other filler metals meeting the requirements of Section 3.1 for demand critical welds. A special welding procedure specification (WPS) is required for this repair. Following welding, the repair weld shall be ground smooth.

5. Nonfusible Backing at Beam Flange-to-Column Joints

Where *nonfusible backing* is used with CJP groove welds between the beam flanges and the column, the backing shall be removed and the root backgouged to sound weld metal and backwelded with a reinforcing fillet. The size of the reinforcing fillet leg adjacent to the column shall be a minimum of $5/16$ in. (8 mm) and the reinforcing fillet leg adjacent to the beam flange shall be such that the fillet toe is located on the beam flange base metal.

Exception: If the base metal and weld root are ground smooth after removal of the backing, the reinforcing fillet adjacent to the beam flange need not extend to base metal.

3.4. DETAILS AND TREATMENT OF WELD TABS

Where used, *weld tabs* shall be removed to within $1/8$ in. (3 mm) of the base metal surface and the end of the weld finished, except at continuity plates where removal to within $1/4$ in. (6 mm) of the plate edge shall be permitted. Removal shall be by *air carbon arc cutting* (CAC-A), grinding, chipping or *thermal cutting*. The process shall be controlled to minimize errant gouging. The edges where weld tabs have been removed shall be finished to a surface roughness of 500 μ -in. (13 microns) or better. The contour of the weld end shall provide a smooth transition to adjacent surfaces, free of notches, gouges and sharp corners. Weld defects greater than $1/16$ in. (1.5 mm) deep shall be excavated and repaired by welding in accordance with an applicable WPS. Other weld defects shall be removed by grinding, faired to a slope not greater than 1:5.

3.5. TACK WELDS

In the protected zone, tack welds attaching backing and weld tabs shall be placed where they will be incorporated into a final weld.

3.6. CONTINUITY PLATES

Along the web, the corner clip shall be detailed so that the clip extends a distance of at least $1\frac{1}{2}$ in. (38 mm) beyond the published k_{det} dimension for the rolled shape. Along the flange, the plate shall be clipped to avoid interference with the fillet radius of the rolled shape and shall be detailed so that the clip does not exceed a distance of $\frac{1}{2}$ in. (12 mm) beyond the published k_1 dimension. The clip shall be detailed to facilitate suitable weld terminations for both the flange weld and the web weld. When a curved corner clip is used, it shall have a minimum radius of $\frac{1}{2}$ in. (12 mm).

At the end of the weld adjacent to the column web/flange juncture, weld tabs for continuity plates shall not be used, except when permitted by the engineer of record. Unless specified to be removed by the engineer of record, weld tabs shall not be removed when used in this location.

Where continuity plate welds are made without weld tabs near the column fillet radius, weld layers shall be permitted to be transitioned at an angle of 0° to 45° measured from the vertical plane. The effective length of the weld shall be defined as that portion of the weld having full size. Nondestructive testing (NDT) shall not be required on the tapered or transition portion of the weld not having full size.

3.7. QUALITY CONTROL AND QUALITY ASSURANCE

Quality control and quality assurance shall be in accordance with the AISC *Seismic Provisions*.

CHAPTER 4

BOLTING REQUIREMENTS

4.1. FASTENER ASSEMBLIES

Bolts shall be pretensioned high-strength bolts conforming to ASTM A325/A325M, A490/A490M, F1852 or F2280, unless other fasteners are permitted by a specific connection.

4.2. INSTALLATION REQUIREMENTS

Installation requirements shall be in accordance with AISC *Seismic Provisions* and the RCSC *Specification*, except as otherwise specifically indicated in this Standard.

4.3. QUALITY CONTROL AND QUALITY ASSURANCE

Quality control and quality assurance shall be in accordance with the AISC *Seismic Provisions*.

CHAPTER 5

REDUCED BEAM SECTION (RBS) MOMENT CONNECTION

5.1. GENERAL

In a reduced beam section (RBS) moment connection (Figure 5.1), portions of the beam flanges are selectively trimmed in the region adjacent to the beam-to-column connection. Yielding and hinge formation are intended to occur primarily within the reduced section of the beam.

5.2. SYSTEMS

RBS connections are prequalified for use in special moment frame (SMF) and intermediate moment frame (IMF) systems within the limits of these provisions.

5.3. PREQUALIFICATION LIMITS

1. Beam Limitations

Beams shall satisfy the following limitations:

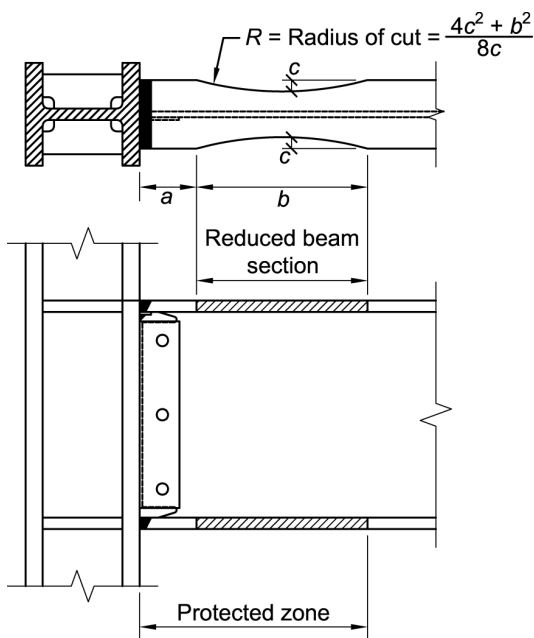


Fig. 5.1. Reduced beam section connection.

- (1) Beams shall be rolled wide-flange or built-up I-shaped members conforming to the requirements of Section 2.3.
- (2) Beam depth is limited to W36 (W920) for rolled shapes. Depth of built-up sections shall not exceed the depth permitted for rolled wide-flange shapes.
- (3) Beam weight is limited to 300 lb/ft (447 kg/m).
- (4) Beam flange thickness is limited to $1\frac{3}{4}$ in. (44 mm).
- (5) The clear span-to-depth ratio of the beam shall be limited as follows:
 - (a) For SMF systems, 7 or greater.
 - (b) For IMF systems, 5 or greater.
- (6) Width-to-thickness ratios for the flanges and web of the beam shall conform to the requirements of the AISC *Seismic Provisions*.
 When determining the width-to-thickness ratio of the flange, the value of b_f shall not be taken as less than the flange width at the ends of the center two-thirds of the reduced section provided that gravity loads do not shift the location of the plastic hinge a significant distance from the center of the reduced beam section.
- (7) Lateral bracing of beams shall be provided in conformance with the AISC *Seismic Provisions*. Supplemental lateral bracing shall be provided near the reduced section in conformance with the AISC *Seismic Provisions* for lateral bracing provided adjacent to the plastic hinges.
 When supplemental lateral bracing is provided, its attachment to the beam shall be located no greater than $d/2$ beyond the end of the reduced beam section farthest from the face of the column, where d is the depth of the beam. No attachment of lateral bracing shall be made to the beam in the region extending from the face of the column to the end of the reduced section farthest from the face of the column.
Exception: For both systems, where the beam supports a *concrete structural slab* that is connected between the protected zones with welded shear connectors spaced a maximum of 12 in. (300 mm) on center, supplemental top and bottom flange bracing at the reduced section is not required.
- (8) The protected zone shall consist of the portion of beam between the face of the column and the end of the reduced beam section cut farthest from the face of the column.

2. Column Limitations

Columns shall satisfy the following limitations:

- (1) Columns shall be any of the rolled shapes or built-up sections permitted in Section 2.3.
- (2) The beam shall be connected to the flange of the column.

- (3) Rolled shape column depth shall be limited to W36 (W920) maximum. The depth of built-up wide-flange columns shall not exceed that for rolled shapes. Flanged cruciform columns shall not have a width or depth greater than the depth allowed for rolled shapes. Built-up box-columns shall not have a width or depth exceeding 24 in. (610 mm). Boxed wide-flange columns shall not have a width or depth exceeding 24 in. (610 mm) if participating in orthogonal moment frames.
- (4) There is no limit on the weight per foot of columns.
- (5) There are no additional requirements for flange thickness.
- (6) Width-to-thickness ratios for the flanges and web of columns shall conform to the requirements of the AISC *Seismic Provisions*.
- (7) Lateral bracing of columns shall conform to the requirements of the AISC *Seismic Provisions*.

5.4. COLUMN-BEAM RELATIONSHIP LIMITATIONS

Beam-to-column connections shall satisfy the following limitations:

- (1) Panel zones shall conform to the requirements of the AISC *Seismic Provisions*.
- (2) Column-beam moment ratios shall be limited as follows:
 - (a) For SMF systems, the column-beam moment ratio shall conform to the requirements of the AISC *Seismic Provisions*. The value of $\sum M_{pb}^*$ shall be taken equal to $\sum(M_{pr} + M_{uv})$, where M_{pr} is computed according to Equation 5.8-5, and where M_{uv} is the additional moment due to shear amplification from the center of the reduced beam section to the centerline of the column. M_{uv} can be computed as $V_{RBS}(a + b/2 + d_c/2)$, where V_{RBS} is the shear at the center of the reduced beam section computed per Step 4 of Section 5.8, a and b are the dimensions shown in Figure 5.1, and d_c is the depth of the column.
 - (b) For IMF systems, the column-beam moment ratio shall conform to the requirements of the AISC *Seismic Provisions*.

5.5. BEAM FLANGE-TO-COLUMN FLANGE WELD LIMITATIONS

Beam flange to column flange connections shall satisfy the following limitations:

- (1) Beam flanges shall be connected to column flanges using complete-joint-penetration (CJP) groove welds. Beam flange welds shall conform to the requirements for demand critical welds in the AISC *Seismic Provisions*.
- (2) Weld access hole geometry shall conform to the requirements of the AISC *Specification*.

5.6. BEAM WEB-TO-COLUMN FLANGE CONNECTION LIMITATIONS

Beam web to column flange connections shall satisfy the following limitations:

- (1) The required shear strength of the beam web connection shall be determined according to Equation 5.8-9.
- (2) Web connection details shall be limited as follows:
 - (a) For SMF systems, the beam web shall be connected to the column flange using a CJP groove weld extending between weld access holes. The single plate shear connection shall extend between the weld access holes as shown in Figure 5.1. The single plate shear connection shall be permitted to be used as *backing* for the CJP groove weld. The thickness of the plate shall be at least $\frac{3}{8}$ in. (10 mm). *Weld tabs* are not required at the ends of the CJP groove weld at the beam web. Bolt holes in the beam web for the purpose of erection are permitted.
 - (b) For IMF systems, the beam web shall be connected to the column flange as required for SMF systems.

Exception: For IMF, it is permitted to connect the beam web to the column flange using a bolted single plate shear connection. The bolted single plate shear connection shall be designed as a slip-critical connection, with the design slip resistance per bolt determined according to the AISC *Specification*. For seismic loading, the nominal bearing strength at bolt holes shall not be taken greater than the value given by Equation J3-6a of the AISC *Specification*. The design shear strength of the single plate shear connection shall be determined based on shear yielding of the gross section and on shear rupture of the net section. The plate shall be welded to the column flange with a CJP groove weld, or with fillet welds on both sides of the plate. The minimum size of the fillet weld on each side of the plate shall be 75% of the thickness of the plate. Standard holes shall be provided in the beam web and in the plate, except that short-slotted holes (with the slot parallel to the beam flanges) may be used in either the beam web or in the plate, but not in both. Bolts are permitted to be pretensioned either before or after welding.

5.7. FABRICATION OF FLANGE CUTS

The reduced beam section shall be made using *thermal cutting* to produce a smooth curve. The maximum surface roughness of the thermally cut surface shall be 500 μ -in. (13 microns) in accordance with ANSI B46.1, as measured using AWS C4.1-77 Sample 4 or a similar visual comparator. All transitions between the reduced beam section and the unmodified beam flange shall be rounded in the direction of the flange length to minimize notch effects due to abrupt transitions. Corners between the reduced section surface and the top and bottom of the flanges shall be ground to remove sharp edges, but a minimum chamfer or radius is not required.

Thermal cutting tolerances shall be plus or minus $\frac{1}{4}$ in. (6 mm) from the theoretical cut line. The beam effective flange width at any section shall have a tolerance of plus or minus $\frac{3}{8}$ in. (10 mm).

Gouges and notches that occur in the thermally cut RBS surface may be repaired by grinding if not more than $\frac{1}{4}$ in. (6 mm) deep. The gouged or notched area shall be

faired in by grinding so that a smooth transition exists, and the total length of the area ground for the transition shall be no less than five times the depth of the removed gouge on each side of the gouge. If a sharp notch exists, the area shall be inspected by magnetic particle testing (MT) after grinding to ensure that the entire depth of notch has been removed. Grinding that increases the depth of the RBS cut more than $\frac{1}{4}$ in. (6 mm) beyond the specified depth of cut is not permitted.

Gouges and notches that exceed $\frac{1}{4}$ in. (6 mm) in depth, but not exceeding $\frac{1}{2}$ in. (12 mm) in depth, and those notches and gouges where repair by grinding would increase the effective depth of the RBS cut beyond tolerance, may be repaired by welding. The notch or gouge shall be removed and ground to provide a smooth root radius of not less than $\frac{1}{4}$ in. (6 mm) in preparation for welding. The repair area shall be preheated to a minimum temperature of 150 °F (65 °C) or the value specified in AWS D1.1/D1.1M, whichever is greater, measured at the location of the weld repair.

Notches and gouges exceeding $\frac{1}{2}$ in. (12 mm) in depth shall be repaired only with a method approved by the engineer of record.

5.8. DESIGN PROCEDURE

Step 1. Choose trial values for the beam sections, column sections and RBS dimensions a , b and c (Figure 5.1) subject to the limits:

$$0.5b_{bf} \leq a \leq 0.75b_{bf} \quad (5.8-1)$$

$$0.65d \leq b \leq 0.85d \quad (5.8-2)$$

$$0.1b_{bf} \leq c \leq 0.25b_{bf} \quad (5.8-3)$$

where

b_{bf} = width of beam flange, in. (mm)

a = horizontal distance from face of column flange to the start of an RBS cut, in. (mm)

b = length of an RBS cut, in. (mm)

c = depth of cut at center of the reduced beam section, in. (mm)

d = depth of beam, in. (mm)

Confirm that the beams and columns are adequate for all load combinations specified by the applicable building code, including the reduced section of the beam, and that the design story drift for the frame complies with applicable limits specified by the applicable building code. Calculation of elastic drift shall consider the effect of the reduced beam section. In lieu of more detailed calculations, effective elastic drifts may be calculated by multiplying elastic drifts based on gross beam sections by 1.1 for flange reductions up to 50% of the beam flange width. Linear interpolation may be used for lesser values of beam width reduction.

Step 2. Compute the plastic section modulus at the center of the reduced beam section:

$$Z_{RBS} = Z_x - 2ct_{bf}(d - t_{bf}) \quad (5.8-4)$$

where

- Z_{RBS} = plastic section modulus at center of the reduced beam section, in.³ (mm³)
 Z_x = plastic section modulus about the x -axis, for full beam cross section, in.³ (mm³)
 t_{bf} = thickness of beam flange, in. (mm)

Step 3. Compute the probable maximum moment, M_{pr} , at the center of the reduced beam section:

$$M_{pr} = C_{pr} R_y F_y Z_{RBS} \quad (5.8-5)$$

Step 4. Compute the shear force at the center of the reduced beam sections at each end of the beam.

The shear force at the center of the reduced beam sections shall be determined from a free body diagram of the portion of the beam between the centers of the reduced beam sections. This calculation shall assume the moment at the center of each reduced beam section is M_{pr} and shall include gravity loads acting on the beam based on the load combination $1.2D + f_1L + 0.2S$, where f_1 is the load factor determined by the applicable building code for live loads, but not less than 0.5.

User Note: The load combination of $1.2D + f_1L + 0.2S$ is in conformance with ASCE/SEI 7. When using the International Building Code, a factor of 0.7 must be used in lieu of the factor of 0.2 when the roof configuration is such that it does not shed snow off of the structure.

Step 5. Compute the probable maximum moment at the face of the column.

The moment at the face of the column shall be computed from a free-body diagram of the segment of the beam between the center of the reduced beam section and the face of the column, as illustrated in Figure 5.2.

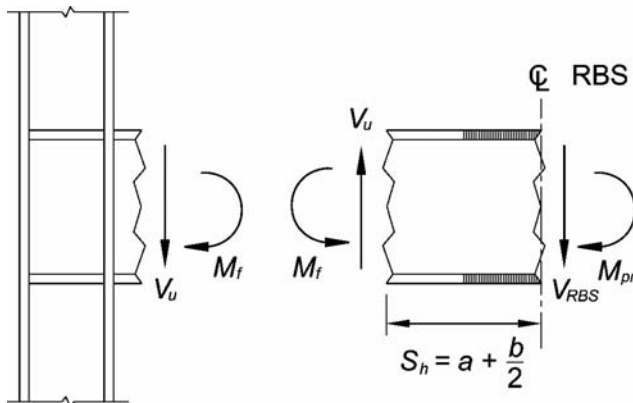


Fig. 5.2. Free-body diagram between center of RBS and face of column.

Based on this free-body diagram, the moment at the face of the column is computed as follows:

$$M_f = M_{pr} + V_{RBS}S_h \quad (5.8-6)$$

where

M_f = probable maximum moment at face of column, kip-in. (N-mm)

S_h = distance from face of the column to the plastic hinge, in. (mm)

= $a + b/2$, in. (mm)

V_{RBS} = larger of the two values of shear force at the center of the reduced beam section at each end of the beam, kips (N)

Equation 5.8-6 neglects the gravity load on the portion of the beam between the center of the reduced beam section and the face of the column. If desired, the gravity load on this small portion of the beam is permitted to be included in the free-body diagram shown in Figure 5.2 and in Equation 5.8-6.

Step 6. Compute M_{pe} , the plastic moment of the beam based on the expected yield stress:

$$M_{pe} = R_y F_y Z_x \quad (5.8-7)$$

Step 7. Check the flexural strength of the beam at the face of the column:

$$M_f \leq \phi_d M_{pe} \quad (5.8-8)$$

If Equation 5.8-8 is not satisfied, adjust the values of c , a and b , or adjust the section size, and repeat Steps 2 through 7.

Step 8. Determine the required shear strength, V_u , of beam and beam web-to-column connection from:

$$V_u = \frac{2 M_{pr}}{L_h} + V_{gravity} \quad (5.8-9)$$

where

V_u = required shear strength of beam and beam web-to-column connection, kips (N)

L_h = distance between *plastic hinge locations*, in. (mm)

$V_{gravity}$ = beam shear force resulting from $1.2D + f_1L + 0.2S$ (where f_1 is the load factor determined by the applicable building code for live loads, but not less than 0.5), kips (N)

Check design shear strength of beam according to Chapter G of the *AISC Specification*.

User Note: The load combination of $1.2D + f_1L + 0.2S$ is in conformance with ASCE/SEI 7. When using the International Building Code, a factor of 0.7 must be used in lieu of the factor of 0.2 when the roof configuration is such that it does not shed snow off of the structure.

Step 9. Design the beam web-to-column connection according to Section 5.6.

Step 10. Check continuity plate requirements according to Chapter 2.

Step 11. Check column-beam relationship limitations according to Section 5.4.

CHAPTER 6

BOLTED UNSTIFFENED AND STIFFENED EXTENDED END-PLATE MOMENT CONNECTIONS

6.1. GENERAL

Bolted end-plate connections are made by welding the beam to an end-plate and bolting the end-plate to a column flange. The three end-plate configurations shown in Figure 6.1 are covered in this section and are prequalified under the AISC *Seismic Provisions* within the limitations of this Standard.

The behavior of this type of connection can be controlled by a number of different limit states including flexural yielding of the beam section, flexural yielding of the end-plates, yielding of the column panel zone, tension rupture of the end-plate bolts, shear rupture of the end-plate bolts, or rupture of various welded joints. The design criteria provide sufficient strength in the elements of the connections to ensure that the inelastic deformation of the connection is achieved by beam yielding.

6.2. SYSTEMS

Extended end-plate moment connections are prequalified for use in special moment frame (SMF) and intermediate moment frame (IMF) systems.

Exception: Extended end-plate moment connections in SMF systems with *concrete structural slabs* are prequalified only if:

- (1) In addition to the limitations of Section 6.3, the nominal beam depth is not less than 24 in. (610 mm);

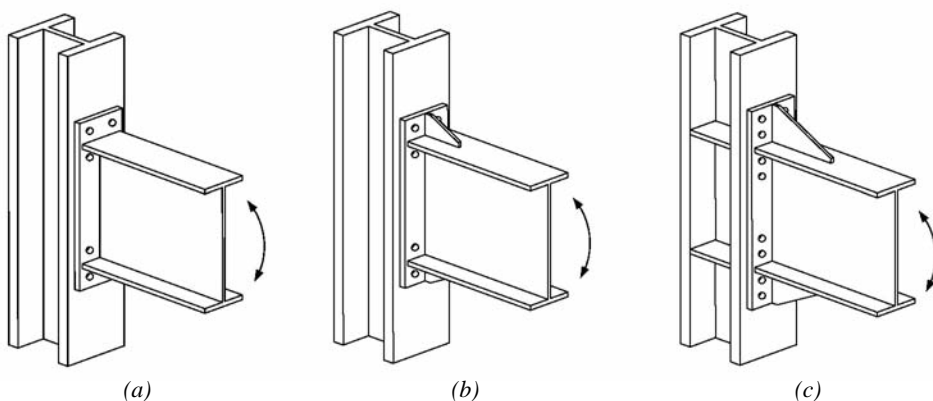


Fig. 6.1. Extended end-plate configurations: (a) four-bolt unstiffened, 4E; (b) four-bolt stiffened, 4ES; (c) eight-bolt stiffened, 8ES.

TABLE 6.1
Parametric Limitations on Prequalification

Parameter	Four-Bolt Unstiffened (4E)		Four-Bolt Stiffened (4ES)		Eight-Bolt Stiffened (8ES)	
	Maximum in. (mm)	Minimum in. (mm)	Maximum in. (mm)	Minimum in. (mm)	Maximum in. (mm)	Minimum in. (mm)
t_{bf}	$3/4$ (19)	$3/8$ (10)	$3/4$ (19)	$3/8$ (10)	1 (25)	$9/16$ (14)
b_{bf}	$9 1/4$ (235)	6 (152)	9 (229)	6 (152)	$12 1/4$ (311)	$7 1/2$ (190)
d	55 (1400)	$13 3/4$ (349)	24 (610)	$13 3/4$ (349)	36 (914)	18 (457)
t_p	$2 1/4$ (57)	$1/2$ (13)	$1 1/2$ (38)	$1/2$ (13)	$2 1/2$ (64)	$3/4$ (19)
b_p	$10 3/4$ (273)	7 (178)	$10 3/4$ (273)	7 (178)	15 (381)	9 (229)
g	6 (152)	4 (102)	6 (152)	$3 1/4$ (83)	6 (152)	5 (127)
p_{fi}, p_{fo}	$4 1/2$ (114)	$1 1/2$ (38)	$5 1/2$ (140)	$1 3/4$ (44)	2 (51)	$1 5/8$ (41)
p_b	—	—	—	—	$3 3/4$ (95)	$3 1/2$ (89)

b_{bf} = width of beam flange, in. (mm)
 b_p = width of end-plate, in. (mm)
 d = depth of connecting beam, in. (mm)
 g = horizontal distance between bolts, in. (mm)
 p_b = vertical distance between the inner and outer row of bolts in an 8ES connection, in. (mm)
 p_{fi} = vertical distance from the inside of a beam tension flange to the nearest inside bolt row, in. (mm)
 p_{fo} = vertical distance from the outside of a beam tension flange to the nearest outside bolt row, in. (mm)
 t_{bf} = thickness of beam flange, in. (mm)
 t_p = thickness of end-plate, in. (mm)

- (2) There are no shear connectors within 1.5 times the beam depth from the face of the connected column flange; and
- (3) The concrete structural slab is kept at least 1 in. (25 mm) from both sides of both column flanges. It is permitted to place compressible material in the gap between the column flanges and the concrete structural slab.

6.3. PREQUALIFICATION LIMITS

Table 6.1 is a summary of the range of parameters that have been satisfactorily tested. All connection elements shall be within the ranges shown.

6.4. BEAM LIMITATIONS

Beams shall satisfy the following limitations:

- (1) Beams shall be rolled wide-flange or built-up I-shaped members conforming to the requirements of Section 2.3. At moment-connected ends of welded built-up sections, within at least the depth of beam or 3 times the width of flange, whichever is less, the beam web and flanges shall be connected using either a complete-joint-penetration (CJP) groove weld or a pair of fillet welds each having a size 75% of the beam web thickness but not less than $\frac{1}{4}$ in. (6 mm). For the remainder of the beam, the weld size shall not be less than that required to accomplish shear transfer from the web to the flanges.
- (2) Beam depth, d , is limited to values shown in Table 6.1.
- (3) There is no limit on the weight per foot of beams.
- (4) Beam flange thickness is limited to the values shown in Table 6.1.
- (5) The clear span-to-depth ratio of the beam shall be limited as follows:
 - (a) For SMF systems, 7 or greater.
 - (b) For IMF systems, 5 or greater.
- (6) Width-to-thickness ratios for the flanges and web of the beam shall conform to the requirements of the AISC *Seismic Provisions*.
- (7) Lateral bracing of beams shall be provided in accordance with the AISC *Seismic Provisions*.
- (8) The protected zone shall be determined as follows:
 - (a) For unstiffened extended end-plate connections: the portion of beam between the face of the column and a distance equal to the depth of the beam or 3 times the width of the beam flange from the face of the column, whichever is less.
 - (b) For stiffened extended end-plate connections: the portion of beam between the face of the column and a distance equal to the location of the end of the stiffener plus one-half the depth of the beam or 3 times the width of the beam flange, whichever is less.

6.5. COLUMN LIMITATIONS

Columns shall satisfy the following limitations:

- (1) The end-plate shall be connected to the flange of the column.
- (2) Rolled shape column depth shall be limited to W36 (W920) maximum. The depth of built-up wide-flange columns shall not exceed that for rolled shapes. Flanged cruciform columns shall not have a width or depth greater than the depth allowed for rolled shapes.
- (3) There is no limit on the weight per foot of columns.
- (4) There are no additional requirements for flange thickness.

- (5) Width-to-thickness ratios for the flanges and web of the column shall conform to the requirements of the AISC *Seismic Provisions*.

6.6. COLUMN-BEAM RELATIONSHIP LIMITATIONS

Beam-to-column connections shall satisfy the following limitations:

- (1) Panel zones shall conform to the requirements of the AISC *Seismic Provisions*.
- (2) Column-beam moment ratios shall conform to the requirements of the AISC *Seismic Provisions*.

6.7. CONTINUITY PLATES

Continuity plates shall satisfy the following limitations:

- (1) The need for continuity plates shall be determined in accordance with Section 6.10.
- (2) When provided, continuity plates shall conform to the requirements of Section 6.10.
- (3) Continuity plates shall be attached to columns by welds in accordance with the AISC *Seismic Provisions*.

Exception: Continuity plates less than or equal to $3/8$ in. (10 mm) shall be permitted to be welded to column flanges using double-sided fillet welds. The required strength of the fillet welds shall not be less than $F_y A_c$, where A_c is defined as the contact areas between the continuity plate and the column flanges that have attached beam flanges and F_y is defined as the specified minimum yield stress of the continuity plate.

6.8. BOLTS

Bolts shall conform to the requirements of Chapter 4.

6.9. CONNECTION DETAILING

1. Gage

The gage, g , is as defined in Figures 6.2 through 6.4. The maximum gage dimension is limited to the width of the connected beam flange.

2. Pitch and Row Spacing

The minimum pitch distance is the bolt diameter plus $1/2$ in. (13 mm) for bolts up to 1 in. (25 mm) diameter, and the bolt diameter plus $3/4$ in. (19 mm) for larger diameter bolts. The pitch distances, p_{fi} and p_{fo} , are the distances from the face of the beam flange to the centerline of the nearer bolt row, as shown in Figures 6.2 through 6.4. The pitch distances, p_{si} and p_{so} , are the distances from the face of the continuity plate to the centerline of the nearer bolt row, as shown in Figures 6.2 through 6.4.

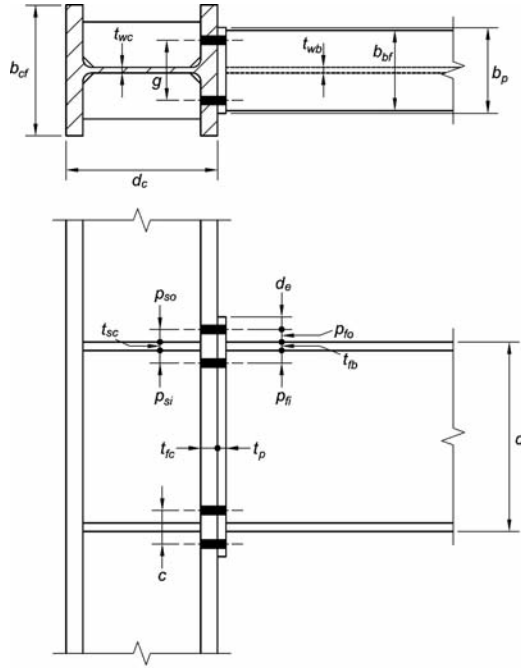


Fig. 6.2. Four-bolt unstiffened extended end-plate (4E) geometry.

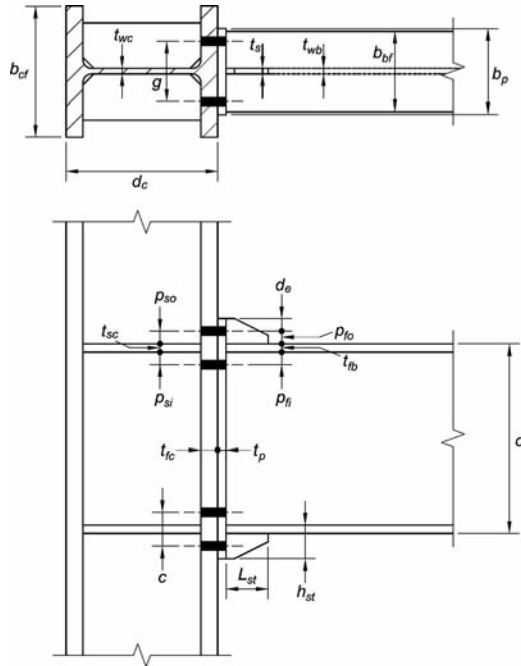


Fig. 6.3. Four-bolt stiffened extended end-plate (4ES) geometry.

The spacing, p_b , is the distance between the inner and outer row of bolts in an 8ES end-plate moment connection and is shown in Figure 6.4. The spacing of the bolt rows shall be at least $2^{2/3}$ times the bolt diameter.

User Note: A distance of 3 times the bolt diameter is preferred. The distance must be sufficient to provide clearance for any welds in the region.

3. End-Plate Width

The width of the end-plate shall be greater than or equal to the connected beam flange width. The effective end-plate width shall not be taken greater than the connected beam flange plus 1 in. (25 mm).

4. End-Plate Stiffener

The two extended stiffened end-plate connections, Figures 6.1(b) and (c), require a stiffener welded between the connected beam flange and the end-plate. The minimum stiffener length shall be:

$$L_{st} = \frac{h_{st}}{\tan 30^\circ} \tag{6.9-1}$$

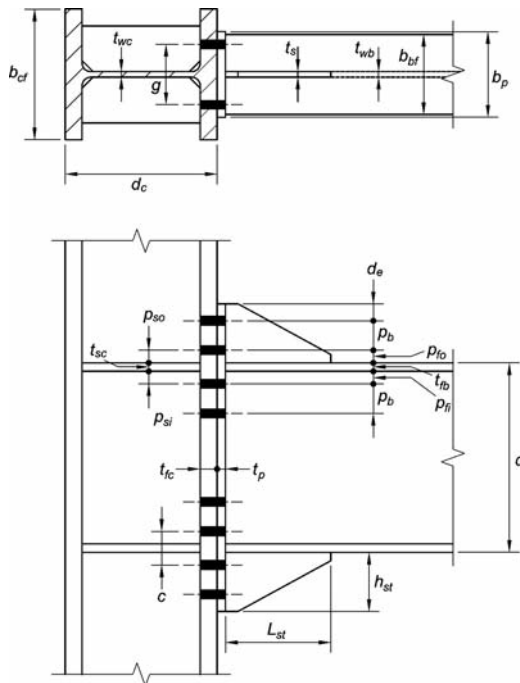


Fig. 6.4. Eight-bolt stiffened extended end-plate (8ES) geometry.

where h_{st} is the height of the stiffener, equal to the height of the end-plate from the outside face of the beam flange to the end of the end-plate as shown in Figure 6.5.

The stiffener plates shall be terminated at the beam flange and at the end of the end-plate with landings approximately 1 in. (25 mm) long. The stiffener shall be clipped where it meets the beam flange and end-plate to provide clearance between the stiffener and the beam flange weld.

When the beam and end-plate stiffeners have the same material strengths, the thickness of the stiffeners shall be greater than or equal to the beam web thickness. If the beam and end-plate stiffener have different material strengths, the thickness of the stiffener shall not be less than the ratio of the beam-to-stiffener plate material yield stresses times the beam web thickness.

5. Finger Shims

The use of finger shims (illustrated in Figure 6.6) at the top and/or bottom of the connection and on either or both sides is permitted, subject to the limitations of the RCSC *Specification*.

6. Composite Slab Detailing for IMF

In addition to the protected zone limitations, welded shear stud connectors shall not be placed along the top flange of the beam for a distance equal to $1\frac{1}{2}$ times the depth of the beam, measured from the face of the column.

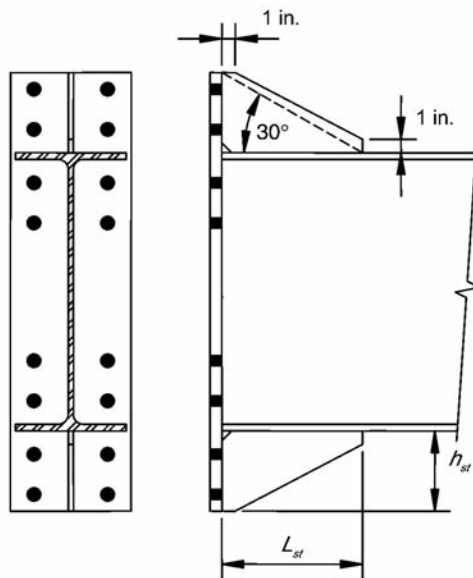


Fig. 6.5. End-plate stiffener layout and geometry for 8ES.
Geometry for 4ES similar.

Compressible expansion joint material, at least 1 in. (25 mm) thick, shall be installed between the slab and the column face.

7. Welding Details

Welding of the beam to the end-plate shall conform to the following limitations:

- (1) Weld access holes shall not be used.
- (2) The beam flange to end-plate joint shall be made using a CJP groove weld without *backing*. The CJP groove weld shall be made such that the *root* of the weld is on the beam web side of the flange. The inside face of the flange shall have a $5/16$ -in. (8-mm) fillet weld. These welds shall be demand critical.
- (3) The beam web to end-plate joint shall be made using either fillet welds or CJP groove welds. When used, the fillet welds shall be sized to develop the full strength of the beam web in tension from the inside face of the flange to 6 in. (150 mm) beyond the bolt row farthest from the beam flange.
- (4) Backgouging of the root is not required in the flange directly above and below the beam web for a length equal to $1.5k_1$. A full-depth PJP groove weld shall be permitted at this location.
- (5) When used, all end-plate-to-stiffener joints shall be made using CJP groove welds.

Exception: When the stiffener is $3/8$ in. (10 mm) thick or less, it shall be permitted to use fillet welds that develop the strength of the stiffener.

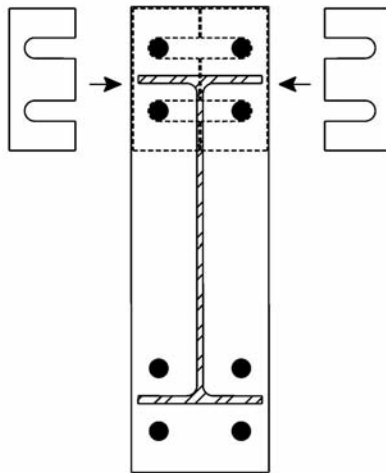


Fig. 6.6. Typical use of finger shims.

6.10. DESIGN PROCEDURE

Connection geometry is shown in Figures 6.2, 6.3 and 6.4 for the 4E, 4ES and 8ES connections, respectively.

1. End-Plate and Bolt Design

Step 1. Determine the sizes of the connected members (beams and column) and compute the moment at the face of the column, M_f .

$$M_f = M_{pr} + V_u S_h \quad (6.10-1)$$

where

M_{pr} = probable maximum moment at plastic hinge, kip-in. (N-mm), given by Equation 2.4.3-1

S_h = distance from face of column to plastic hinge, in. (mm)
 = the lesser of $d/2$ or $3b_{bf}$ for an unstiffened connection (4E)
 = $L_{st} + t_p$ for a stiffened connection (4ES, 8ES)

V_u = shear force at end of beam, kips (N)
 = $\frac{2M_{pr}}{L_h} + V_{gravity}$ (6.10-2)

b_{bf} = width of beam flange, in. (mm)

d = depth of connecting beam, in. (mm)

L_h = distance between *plastic hinge locations*, in. (mm)

L_{st} = length of end-plate the stiffener, as shown in Figure 6.5, in. (mm)

t_p = thickness of end-plate, in. (mm)

$V_{gravity}$ = beam shear force resulting from $1.2D + f_1L + 0.2S$ (where f_1 is a load factor determined by the applicable building code for live loads, but not less than 0.5), kips (N)

User Note: The load combination of $1.2D + f_1L + 0.2S$ is in conformance with ASCE/SEI 7. When using the International Building Code, a factor of 0.7 must be used in lieu of the factor of 0.2 when the roof configuration is such that it does not shed snow off of the structure.

Step 2. Select one of the three end-plate moment connection configurations and establish preliminary values for the connection geometry (g , p_{fi} , p_{fo} , p_b , g , h_i , etc.) and bolt grade.

Step 3. Determine the required bolt diameter, $d_{b req'd}$, using one of the following expressions.

For four-bolt connections (4E, 4ES):

$$d_{b req'd} = \sqrt{\frac{2 M_f}{\pi \phi_n F_{nt} (h_o + h_1)}} \quad (6.10-3)$$

For eight-bolt connections (8ES):

$$d_b \text{ req'd} = \sqrt{\frac{2 M_f}{\pi \phi_n F_{nt} (h_1 + h_2 + h_3 + h_4)}} \quad (6.10-4)$$

where

F_{nt} = nominal tensile strength of bolt from the AISC *Specification*, ksi (MPa)

h_i = distance from the centerline of the beam compression flange to the centerline of the i th tension bolt row.

h_o = distance from centerline of compression flange to the tension-side outer bolt row, in. (mm)

Step 4. Select a trial bolt diameter, d_b , not less than that required in Section 6.10.1 Step 3.

Step 5. Determine the required end-plate thickness, $t_p \text{ req'd}$.

$$t_p \text{ req'd} = \sqrt{\frac{1.11 M_f}{\phi_d F_{yp} Y_p}} \quad (6.10-5)$$

where

F_{yp} = specified minimum yield stress of the end-plate material, ksi (MPa)

Y_p = end-plate yield line mechanism parameter from Tables 6.2, 6.3 or 6.4, in. (mm)

Step 6. Select an end-plate thickness, t_p , not less than the required value.

Step 7. Calculate F_{fu} , the factored beam flange force.

$$F_{fu} = \frac{M_f}{d - t_{bf}} \quad (6.10-6)$$

where

d = depth of the beam, in. (mm)

t_{bf} = thickness of beam flange, in. (mm)

Step 8. Check shear yielding of the extended portion of the four-bolt extended unstiffened end-plate (4E):

$$F_{fu}/2 \leq \phi_d R_n = \phi_d (0.6) F_{yp} b_p t_p \quad (6.10-7)$$

where b_p is the width of the end-plate, in. (mm), to be taken as not greater than the width of the beam flange plus 1 in. (25 mm).

If Equation 6.10-7 is not satisfied, increase the end-plate thickness or increase the yield stress of the end-plate material.

Step 9. Check shear rupture of the extended portion of the end-plate in the four-bolt extended unstiffened end-plate (4E):

$$F_{fu}/2 \leq \phi_n R_n = \phi_n (0.6) F_{up} A_n \quad (6.10-8)$$

TABLE 6.2
Summary of Four-Bolt Extended
Unstiffened End-Plate
Yield Line Mechanism Parameter

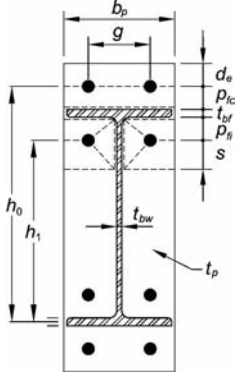
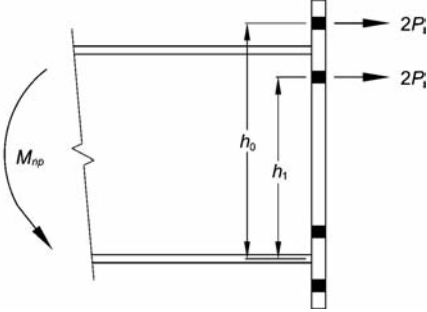
End-Plate Geometry and Yield Line Pattern	Bolt Force Model
	
End-Plate	$Y_p = \frac{b_p}{2} \left[h_1 \left(\frac{1}{\rho_{fi}} + \frac{1}{s} \right) + h_0 \left(\frac{1}{\rho_{fo}} \right) - \frac{1}{2} \right] + \frac{2}{g} [h_1(\rho_{fi} + s)]$ $s = \frac{1}{2} \sqrt{b_p g} \quad \text{Note: If } \rho_{fi} > s, \text{ use } \rho_{fi} = s.$

TABLE 6.3
Summary of Four-Bolt Extended
Stiffened End-Plate
Yield Line Mechanism Parameter

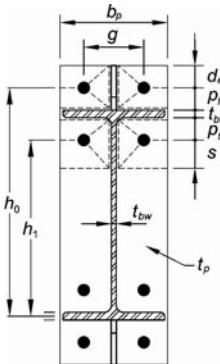
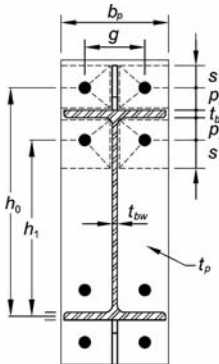
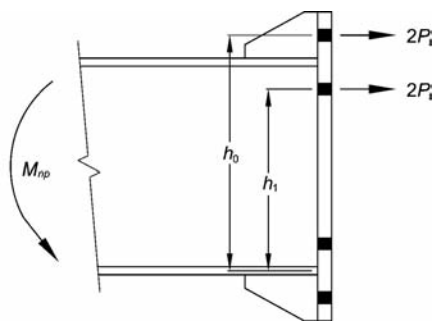
End-Plate Geometry and Yield Line Pattern		Bolt Force Model
Case 1 ($d_e \leq s$)	Case 2 ($d_e > s$)	
		
<p>Case 1 ($d_e \leq s$)</p>	$Y_p = \frac{b_p}{2} \left[h_1 \left(\frac{1}{\rho_{fi}} + \frac{1}{s} \right) + h_0 \left(\frac{1}{\rho_{fo}} + \frac{1}{2s} \right) \right] + \frac{2}{g} [h_1(p_{fi} + s) + h_0(d_e + \rho_{fo})]$	
<p>Case 2 ($d_e > s$)</p>	$Y_p = \frac{b_p}{2} \left[h_1 \left(\frac{1}{\rho_{fi}} + \frac{1}{s} \right) + h_0 \left(\frac{1}{s} + \frac{1}{\rho_{fo}} \right) \right] + \frac{2}{g} [h_1(p_{fi} + s) + h_0(s + \rho_{fo})]$	
<p>$s = \frac{1}{2} \sqrt{b_p g}$ Note: If $\rho_{fi} > s$, use $\rho_{fi} = s$.</p>		

TABLE 6.4
Summary of Eight-Bolt Extended
Stiffened End-Plate
Yield Line Mechanism Parameter

End-Plate Geometry and Yield Line Pattern		Bolt Force Model
Case 1 ($d_e \leq s$)	Case 2 ($d_e > s$)	
<p>Case 1 ($d_e \leq s$)</p>	$Y_p = \frac{b_p}{2} \left[h_1 \left(\frac{1}{2d_e} \right) + h_2 \left(\frac{1}{p_{io}} \right) + h_3 \left(\frac{1}{p_{fi}} \right) + h_4 \left(\frac{1}{s} \right) \right]$ $+ \frac{2}{g} \left[h_1 \left(d_e + \frac{p_b}{4} \right) + h_2 \left(p_{io} + \frac{3p_b}{4} \right) + h_3 \left(p_{fi} + \frac{p_b}{4} \right) + h_4 \left(s + \frac{3p_b}{4} \right) + p_b^2 \right] + g$	
<p>Case 2 ($d_e > s$)</p>	$Y_p = \frac{b_p}{2} \left[h_1 \left(\frac{1}{s} \right) + h_2 \left(\frac{1}{p_{io}} \right) + h_3 \left(\frac{1}{p_{fi}} \right) + h_4 \left(\frac{1}{s} \right) \right]$ $+ \frac{2}{g} \left[h_1 \left(s + \frac{p_b}{4} \right) + h_2 \left(p_{io} + \frac{3p_b}{4} \right) + h_3 \left(p_{fi} + \frac{p_b}{4} \right) + h_4 \left(s + \frac{3p_b}{4} \right) + p_b^2 \right] + g$	
<p>$s = \frac{1}{2} \sqrt{b_p g}$ Note: If $p_{fi} > s$, use $p_{fi} = s$.</p>		

where

$$\begin{aligned}
 F_{up} &= \text{specified minimum tensile stress of end-plate, ksi (MPa)} \\
 A_n &= \text{net area of end-plate} \\
 &= t_p[b_p - 2(d_b + 1/8)] \text{ when standard holes are used, in.}^2 \\
 &= t_p[b_p - 2(d_b + 3)] \text{ when standard holes are used, mm}^2 \\
 d_b &= \text{bolt diameter, in. (mm)}
 \end{aligned}$$

If Equation 6.10-8 is not satisfied, increase the end-plate thickness or increase the yield stress of the end-plate material.

Step 10. If using either the four-bolt extended stiffened end-plate (4ES) or the eight-bolt extended stiffened end-plate (8ES) connection, select the end-plate stiffener thickness and design the stiffener-to-beam flange and stiffener-to-end-plate welds.

$$t_s \geq t_{bw} \left(\frac{F_{yb}}{F_{ys}} \right) \quad (6.10-9)$$

where

$$\begin{aligned}
 t_{bw} &= \text{thickness of beam web, in. (mm)} \\
 t_s &= \text{end plate stiffener thickness, in. (mm)} \\
 F_{yb} &= \text{specified minimum yield stress of beam material, ksi (MPa)} \\
 F_{ys} &= \text{specified minimum yield stress of stiffener material, ksi (MPa)}
 \end{aligned}$$

The stiffener geometry shall conform to the requirements of Section 6.9.4. In addition, to prevent local buckling of the stiffener plate, the following width-to-thickness criterion shall be satisfied.

$$\frac{h_{st}}{t_s} \leq 0.56 \sqrt{\frac{E}{F_{ys}}} \quad (6.10-10)$$

where h_{st} is the height of the stiffener, in. (mm), equal to the height of the end-plate from the outside face of the beam flange to the end of the end-plate.

The stiffener-to-beam-flange and stiffener-to-end-plate welds shall be designed to develop the stiffener plate in shear at the beam flange and in tension at the end-plate. Either fillet or complete-joint-penetration (CJP) groove welds are suitable for the weld of the stiffener plate to the beam flange. CJP groove welds shall be used for the stiffener-to-end-plate weld. If the end-plate is $3/8$ in. (10 mm) thick or less, double-sided fillet welds are permitted.

Step 11. The bolt shear rupture strength of the connection is provided by the bolts at one (compression) flange; thus

$$V_u \leq \phi_n R_n = \phi_n (n_b) F_{nv} A_b \quad (6.10-11)$$

where

n_b = number of bolts at the compression flange

= 4 for 4E and 4ES connections

= 8 for 8ES connections

A_b = nominal gross area of bolt, in.² (mm²)

F_{nv} = nominal shear strength of bolt from the AISC *Specification*, ksi (MPa)

V_u = shear force at the end of the beam, kips (N), given by Equation 6.10-2

Step 12. Check bolt-bearing/tear-out failure of the end-plate and column flange:

$$V_u \leq \phi_n R_n = \phi_n(n_i)r_{ni} + \phi_n(n_o)r_{no} \quad (6.10-12)$$

where

n_i = number of inner bolts

= 2 for 4E and 4ES connections

= 4 for 8ES connections

n_o = number of outer bolts

= 2 for 4E and 4ES connections

= 4 for 8ES connections

$r_{ni} = 1.2 L_c t F_u < 2.4 d_b t F_u$ for each inner bolt

$r_{no} = 1.2 L_c t F_u < 2.4 d_b t F_u$ for each outer bolt

L_c = clear distance, in the direction of force, between the edge of the hole and the edge of the adjacent hole or edge of the material, in. (mm)

F_u = specified minimum tensile strength of end-plate or column flange material, ksi (MPa)

d_b = diameter of the bolt, in. (mm)

t = end-plate or column flange thickness, in. (mm)

Step 13. Design the flange to end-plate and web to end-plate welds using the requirements of Section 6.9.7.

2. Column-Side Design

Step 1. Check the column flange for flexural yielding:

$$t_{cf} \geq \sqrt{\frac{1.11 M_f}{\phi_d F_{yc} Y_c}} \quad (6.10-13)$$

where

F_{yc} = specified minimum yield stress of column flange material, ksi (MPa)

Y_c = unstiffened column flange yield line mechanism parameter from Table 6.5 or Table 6.6, in. (mm)

t_{cf} = column flange thickness, in. (mm)

TABLE 6.5
Summary of Four-Bolt Extended
Column Flange
Yield Line Mechanism Parameter

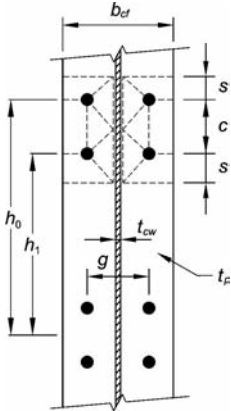
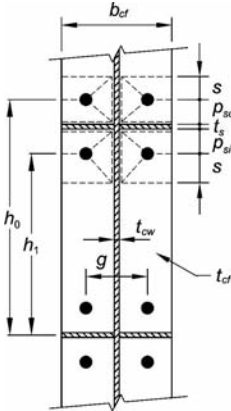
Unstiffened Column Flange Geometry and Yield Line Pattern	Stiffened Column Flange Geometry and Yield Line Pattern
	
<p align="center">Unstiffened Column Flange</p>	$Y_c = \frac{b_{cf}}{2} \left[h_1 \left(\frac{1}{s} \right) + h_0 \left(\frac{1}{s} \right) \right] + \frac{2}{g} \left[h_1 \left(s + \frac{3c}{4} \right) + h_0 \left(s + \frac{c}{4} \right) + \frac{c^2}{2} \right] + \frac{g}{2}$ $s = \frac{1}{2} \sqrt{b_{cf} g}$
<p align="center">Stiffened Column Flange</p>	$Y_c = \frac{b_{cf}}{2} \left[h_1 \left(\frac{1}{s} + \frac{1}{\rho_{si}} \right) + h_0 \left(\frac{1}{s} + \frac{1}{\rho_{so}} \right) \right] + \frac{2}{g} \left[h_1 (s + \rho_{si}) + h_0 (s + \rho_{so}) \right]$ $s = \frac{1}{2} \sqrt{b_{cf} g} \quad \text{Note: If } \rho_{si} > s, \text{ use } \rho_{si} = s.$

TABLE 6.6
Summary of Eight-Bolt Extended
Column Flange
Yield Line Mechanism Parameter

Unstiffened Column Flange Geometry and Yield Line Pattern	Stiffened Column Flange Geometry and Yield Line Pattern
<p>Unstiffened Column Flange</p>	$Y_c = \frac{b_{cf}}{2} \left[h_1 \left(\frac{1}{s} \right) + h_4 \left(\frac{1}{s} \right) \right]$ $+ \frac{2}{g} \left[h_1 \left(p_b + \frac{c}{s} + s \right) + h_2 \left(\frac{p_b}{2} + \frac{c}{4} \right) + h_3 \left(\frac{p_b}{2} + \frac{c}{2} \right) + h_4 (s) \right] + \frac{g}{2}$ $s = \frac{1}{2} \sqrt{b_{cf} g}$
<p>Stiffened Column Flange</p>	$Y_c = \frac{b_{cf}}{2} \left[h_1 \left(\frac{1}{s} \right) + h_2 \left(\frac{1}{p_{so}} \right) + h_3 \left(\frac{1}{p_{si}} \right) + h_4 \left(\frac{1}{s} \right) \right]$ $+ \frac{2}{g} \left[h_1 \left(s + \frac{p_b}{4} \right) + h_2 \left(p_{so} + \frac{3p_b}{4} \right) + h_3 \left(p_{si} + \frac{p_b}{4} \right) + h_4 \left(s + \frac{3p_b}{4} \right) + p_b^2 \right] + g$ $s = \frac{1}{2} \sqrt{b_{cf} g} \quad \text{Note: If } p_{si} > s, \text{ use } p_{si} = s.$

If Equation 6.10-13 is not satisfied, increase the column size or add continuity plates.

If continuity plates are added, check Equation 6.10-13 using Y_c for the stiffened column flange from Tables 6.5 and 6.6.

Step 2. If continuity plates are required for column flange flexural yielding, determine the required stiffener force.

The column flange flexural design strength is

$$\phi_d M_{cf} = \phi_d F_{yc} Y_c t_{cf}^2 \quad (6.10-14)$$

where Y_c is the unstiffened column yield line mechanism parameter from Table 6.5 or Table 6.6, in. (mm). Therefore, the equivalent column flange design force is

$$\phi_d R_n = \frac{\phi_d M_{cf}}{(d - t_{bf})} \quad (6.10-15)$$

Using $\phi_d R_n$, the required force for continuity plate design is determined in Section 6.10.2 Step 6.

Step 3. Check the local column web yielding strength of the unstiffened column web at the beam flanges.

Strength requirement:

$$F_{fu} \leq \phi_d R_n \quad (6.10-16)$$

$$R_n = C_t (6k_c + t_{bf} + 2t_p) F_{yc} t_{cw} \quad (6.10-17)$$

where

$C_t = 0.5$ if the distance from the column top to the top face of the beam flange is less than the depth of the column
 $= 1.0$ otherwise

F_{yc} = specified yield stress of column web material, ksi (MPa)

k_c = distance from outer face of the column flange to web toe of fillet (design value) or fillet weld, in. (mm)

t_{cw} = column web thickness, in. (mm)

If the strength requirement of Equation 6.10-16 is not satisfied, column web continuity plates are required.

Step 4. Check the unstiffened column web buckling strength at the beam compression flange.

Strength requirement:

$$F_{fu} \leq \phi R_n \quad (6.10-18)$$

where $\phi = 0.75$

- (a) When F_{fu} is applied at a distance greater than or equal to $d_c/2$ from the end of the column

$$R_n = \frac{24t_{cw}^3\sqrt{EF_{yc}}}{h} \quad (6.10-19)$$

- (b) When F_{fu} is applied at a distance less than $d_c/2$ from the end of the column

$$R_n = \frac{12t_{cw}^3\sqrt{EF_{yc}}}{h} \quad (6.10-20)$$

where h is the clear distance between flanges less the fillet or corner radius for rolled shapes; clear distance between flanges when welds are used for built-up shapes, in. (mm)

If the strength requirement of Equation 6.10-18 is not satisfied, then column web continuity plates are required.

Step 5. Check the unstiffened column web crippling strength at the beam compression flange.

Strength requirement:

$$F_{fu} \leq \phi R_n \quad (6.10-21)$$

where $\phi = 0.75$

- (a) When F_{fu} is applied at a distance greater than or equal to $d_c/2$ from the end of the column

$$R_n = 0.80 t_{cw}^2 \left[1 + 3 \left(\frac{N}{d_c} \right) \left(\frac{t_{cw}}{t_{cf}} \right)^{1.5} \right] \sqrt{\frac{EF_{yc}t_{cf}}{t_{cw}}} \quad (6.10-22)$$

- (b) When F_{fu} is applied at a distance less than $d_c/2$ from the end of the column

- (i) for $N/d_c \leq 0.2$,

$$R_n = 0.40 t_{cw}^2 \left[1 + 3 \left(\frac{N}{d_c} \right) \left(\frac{t_{cw}}{t_{cf}} \right)^{1.5} \right] \sqrt{\frac{EF_{yc}t_{cf}}{t_{cw}}} \quad (6.10-23)$$

- (ii) for $N/d_c > 0.2$,

$$R_n = 0.40 t_{cw}^2 \left[1 + \left(\frac{4N}{d_c} - 0.2 \right) \left(\frac{t_{cw}}{t_{cf}} \right)^{1.5} \right] \sqrt{\frac{EF_{yc}t_{cf}}{t_{cw}}} \quad (6.10-24)$$

where

N = thickness of beam flange plus 2 times the groove weld reinforcement leg size,
in. (mm)

d_c = overall depth of the column, in. (mm)

If the strength requirement of Equation 6.10-21 is not satisfied, then column web continuity plates are required.

Step 6. If stiffener plates are required for any of the column side limit states, the required strength is

$$F_{su} = F_{fu} - \min(\phi R_n) \quad (6.10-25)$$

where $\min(\phi R_n)$ is the minimum design strength value from Section 6.10.2 Step 2 (column flange bending), Step 3 (column web yielding), Step 4 (column web buckling), and Step 5 (column web crippling)

The design of the continuity plates shall also conform to Chapter E of the AISC *Seismic Provisions*, and the welds shall be designed in accordance with Section 6.7(3).

Step 7. Check the panel zone in accordance with Section 6.6(1).

CHAPTER 7

BOLTED FLANGE PLATE (BFP) MOMENT CONNECTION

7.1. GENERAL

Bolted flange plate (BFP) moment connections utilize plates welded to column flanges and bolted to beam flanges. The top and bottom plates must be identical. Flange plates are welded to the column flange using complete-joint-penetration (CJP) groove welds and beam flange connections are made with high-strength bolts. The beam web is connected to the column flange using a bolted shear tab with bolts in short-slotted holes. Details for this connection type are shown in Figure 7.1. Initial yielding and plastic hinge formation are intended to occur in the beam in the region near the end of the flange plates.

7.2. SYSTEMS

Bolted flange plate connections are prequalified for use in special moment frame (SMF) and intermediate moment frame (IMF) systems within the limitations of these provisions.

Exception: Bolted flange plate connections in SMF systems with *concrete structural slabs* are only prequalified if the concrete structural slab is kept at least 1 in. (25 mm) from both sides of both column flanges. It is permissible to place compressible material in the gap between the column flanges and the concrete structural slab.

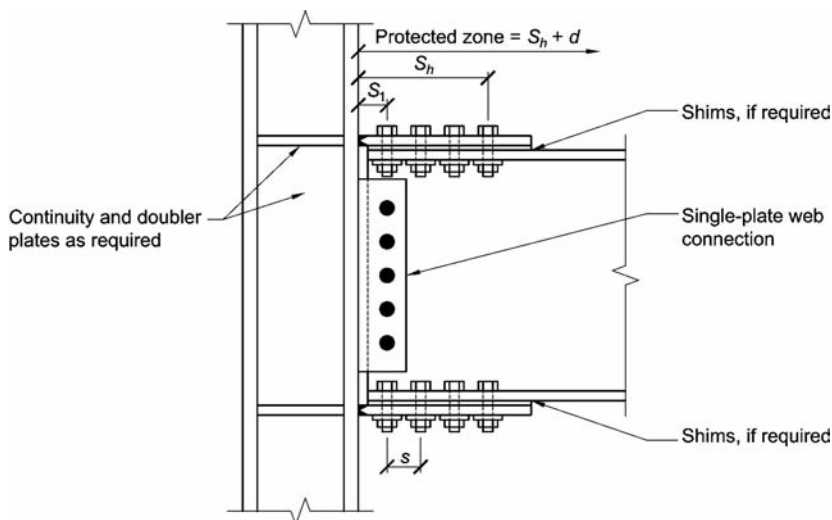


Fig. 7.1. Bolted flange plate moment connection.

7.3. PREQUALIFICATION LIMITS

1. Beam Limitations

Beams shall satisfy the following limitations:

- (1) Beams shall be rolled wide-flange or welded built-up I-shaped members conforming to the requirements in Section 2.3.
- (2) Beam depth is limited to a maximum of W36 (W920) for rolled shapes. Depth of built-up sections shall not exceed the depth permitted for rolled wide-flange shapes.
- (3) Beam weight is limited to a maximum of 150 lb/ft (224 kg/m).
- (4) Beam flange thickness is limited to a maximum of 1 in. (25 mm).
- (5) The clear span-to-depth ratio of the beam is limited as follows:
 - (a) For SMF systems, 9 or greater.
 - (b) For IMF systems, 7 or greater.
- (6) Width-to-thickness ratios for the flanges and web of the beam shall conform to the requirements of the AISC *Seismic Provisions*.
- (7) Lateral bracing of beams shall be provided as follows:

Lateral bracing of beams shall conform to the requirements of the AISC *Seismic Provisions*. To satisfy the requirements of Chapter E of the AISC *Seismic Provisions* for lateral bracing at plastic hinges, supplemental lateral bracing shall be provided at both the top and bottom beam flanges, and shall be located a distance of d to $1.5d$ from the bolt farthest from the face of the column. No attachment of lateral bracing shall be made within the protected zone.

Exception: For both SMF and IMF systems, where the beam supports a concrete structural slab that is connected along the beam span between protected zones with welded shear connectors spaced at a maximum of 12 in. (300 mm) on center, supplemental top and bottom flange bracing at plastic hinges is not required.

- (8) The protected zone consists of the flange plates and the portion of the beam between the face of the column and a distance equal to the beam depth beyond the bolt farthest from the face of the column.

2. Column Limitations

- (1) Columns shall be any of the rolled shapes or welded built-up sections permitted in Section 2.3.
- (2) The beam shall be connected to the flange of the column.
- (3) Rolled shape column depth shall be limited to W36 (W920) maximum when a concrete structural slab is provided. In the absence of a concrete structural slab, the rolled shape column depth is limited to W14 (W360) maximum. Flanged

cruciform columns shall not have a width or depth greater than the depth allowed for rolled shapes. Built-up box columns shall not have a width or depth exceeding 24 in. (610 mm). Boxed wide-flange columns shall not have a width or depth exceeding 24 in. (610 mm) if participating in orthogonal moment frames.

- (4) There is no limit on weight per foot of columns.
- (5) There are no additional requirements for flange thickness.
- (6) Width-to-thickness ratios for the flanges and web of columns shall conform to the requirements of the AISC *Seismic Provisions*.
- (7) Lateral bracing of columns shall conform to the requirements of the AISC *Seismic Provisions*.

7.4. COLUMN-BEAM RELATIONSHIP LIMITATIONS

Beam-to-column connections shall satisfy the following limitations:

- (1) Panel zones shall conform to the requirements of the AISC *Seismic Provisions*.
- (2) Column-beam moment ratios shall conform to the requirements of the AISC *Seismic Provisions*.

7.5. CONNECTION DETAILING

1. Plate Material Specifications

All connection plates shall conform to one of the following specifications: ASTM A36/A36M or A572/A572M Grade 50 (345).

2. Beam Flange Plate Welds

Flange plates shall be connected to the column flange using CJP groove welds and shall be considered demand critical. *Backing*, if used, shall be removed. The *root* pass shall be *backgouged* to sound weld metal and back welded.

3. Single-Plate Shear Connection Welds

The single-plate shear connection shall be welded to the column flange. The single-plate to column-flange connection shall consist of CJP groove welds, two-sided partial-joint-penetration (PJP) groove welds, or two-sided fillet welds.

4. Bolt Requirements

Bolts shall be arranged symmetrically about the axes of the beam and shall be limited to two bolts per row in the flange plate connections. The length of the bolt group shall not exceed the depth of the beam. Standard holes shall be used in beam flanges. Holes in flange plates shall be standard or oversized holes. Bolt holes in beam flanges and in flange plates shall be made by drilling or by sub-punching and reaming. Punched holes are not permitted.

User Note: Although standard holes are permitted in the flange plate, their use will likely result in field modifications to accommodate erection tolerances.

Bolts in the flange plates shall be ASTM A490 or A490M or ASTM F2280 assemblies. Threads shall be excluded from the shear plane. Bolt diameter is limited to $1\frac{1}{8}$ in. (28 mm) maximum.

5. Flange Plate Shims

Shims with a maximum overall thickness of $\frac{1}{4}$ in. (6 mm) may be used between the flange plate and beam flange as shown in Figure 7.1. Shims, if required, may be finger shims or may be made with drilled or punched holes.

7.6. DESIGN PROCEDURE

Step 1. Compute the *probable maximum moment at the plastic hinge*, M_{pr} , in accordance with Section 2.4.3.

Step 2. Compute the maximum bolt diameter to prevent beam flange tensile rupture.

For standard holes with two bolts per row:

$$d_b \leq \frac{b_f}{2} \left(1 - \frac{R_y F_y}{R_t F_u} \right) - \frac{1}{8} \text{ in.} \quad (7.6-2)$$

$$d_b \leq \frac{b_f}{2} \left(1 - \frac{R_y F_y}{R_t F_u} \right) - 3 \text{ mm} \quad (\text{S.I.}) \quad (7.6-2\text{M})$$

Select a bolt diameter. Check that the edge distance for the beam flange holes satisfies the AISC *Specification* requirements.

Step 3. Assume a flange plate thickness, t_p . Estimate the width of the flange plate, b_{fp} , considering bolt gage, bolt edge distance requirements, and the beam flange width. Determine the controlling nominal shear strength per bolt considering bolt shear and bolt bearing:

$$r_n = \min \begin{cases} 1.0 F_{nv} A_b \\ 2.4 F_{ub} d_b t_f \\ 2.4 F_{up} d_b t_p \end{cases} \quad (7.6-3)$$

where

A_b = nominal unthreaded body area of bolt, in.² (mm²)

F_{nv} = nominal shear strength of bolt from the AISC *Specification*, ksi (MPa)

F_{ub} = specified minimum tensile strength of beam material, ksi (MPa)

F_{up} = specified minimum tensile strength of plate material, ksi (MPa)

d_b = nominal bolt diameter, in. (mm)

t_f = beam flange thickness, in. (mm)

t_p = flange plate thickness, in. (mm)

Step 4. Select a trial number of bolts.

User Note: The following equation may be used to estimate the trial number of bolts.

$$n \geq \frac{1.25M_{pr}}{\phi_n r_n (d + t_p)} \quad (7.6-4)$$

where

n = number of bolts rounded to the next higher even number increment

d = beam depth, in. (mm)

Step 5. Determine the beam *plastic hinge location*, S_h , as dimensioned from the face of the column.

$$S_h = S_1 + s \left(\frac{n}{2} - 1 \right) \quad (7.6-5)$$

where

S_1 = distance from face of column to nearest row of bolts, in. (mm)

s = spacing of bolt rows, in. (mm)

The bolt spacing between rows, s , and the edge distance shall be sufficiently large to ensure that L_c , as defined in the AISC *Specification*, is greater than or equal to $2d_b$.

Step 6. Compute the shear force at the beam plastic hinge location at each end of the beam.

The shear force at the hinge location, V_h , shall be determined from a free body diagram of the portion of the beam between the plastic hinge locations. This calculation shall assume the moment at the plastic hinge location is M_{pr} and shall include gravity loads acting on the beam based on the load combination $1.2D + f_1L + 0.2S$, where f_1 is the load factor determined by the applicable building code for live loads, but not less than 0.5.

User Note: The load combination of $1.2D + f_1L + 0.2S$ is in conformance with ASCE/SEI 7. When using the International Building Code, a factor of 0.7 must be used in lieu of the factor of 0.2 when the roof configuration is such that it does not shed snow off of the structure.

Step 7. Calculate the moment expected at the face of the column flange.

$$M_f = M_{pr} + V_h S_h \quad (7.6-6)$$

where V_h is the larger of the two values of shear force at the beam hinge location at each end of the beam, kips (N).

Equation 7.6-6 neglects the gravity load on the portion of the beam between the plastic hinge and the face of the column. If desired, the gravity load on this small portion of the beam is permitted to be included.

Step 8. Compute F_{pr} , the force in the flange plate due to M_f .

$$F_{pr} = \frac{M_f}{(d + t_p)} \quad (7.6-7)$$

where

d = depth of beam, in. (mm)

t_p = thickness of flange plate, in. (mm)

Step 9. Confirm that the number of bolts selected in Step 4 is adequate.

$$n \geq \frac{F_{pr}}{\phi_n r_n} \quad (7.6-8)$$

Step 10. Check that the thickness of the flange plate assumed in Step 3 is adequate:

$$t_p \geq \frac{F_{pr}}{\phi_d F_y b_{fp}} \quad (7.6-9)$$

where

F_y = specified minimum yield stress of flange plate, ksi (MPa)

b_{fp} = width of flange plate, in. (mm)

Step 11. Check the flange plate for tensile rupture.

$$F_{pr} \leq \phi_n R_n \quad (7.6-10)$$

where R_n is defined in the tensile rupture provisions of Chapter J of the AISC *Specification*.

Step 12. Check the beam flange for block shear.

$$F_{pr} \leq \phi_n R_n \quad (7.6-11)$$

where R_n is as defined in the block shear provisions of Chapter J of the AISC *Specification*.

Step 13. Check the flange plate for compression buckling.

$$F_{pr} \leq \phi_n R_n \quad (7.6-12)$$

where R_n is defined in the compression buckling provisions of Chapter J of the AISC *Specification*.

User Note: When checking compression buckling of the flange plate, the effective length, KL , may be taken as $0.65S_1$.

Some iteration from Steps 3 through 13 may be required to determine an acceptable flange plate size.

Step 14. Determine the required shear strength, V_u , of the beam and the beam-web-to-column connection from:

$$V_u = \frac{2M_{pr}}{L_h} + V_{gravity} \quad (7.6-13)$$

where

L_h = distance between plastic hinge locations, in. (mm)

$V_{gravity}$ = beam shear force resulting from $1.2D + f_1L + 0.2S$ (where f_1 is a load factor determined by the applicable building code for live loads, but not less than 0.5), kips (N)

User Note: The load combination of $1.2D + f_1L + 0.2S$ is in conformance with ASCE/SEI 7. When using the International Building Code, a factor of 0.7 must be used in lieu of the factor of 0.2 when the roof configuration is such that it does not shed snow off of the structure.

Check design shear strength of beam according to the AISC *Specification*.

Step 15. Design a single-plate shear connection for the required shear strength, V_u , calculated in Step 14 and located at the face of the column, meeting the requirements of the AISC *Specification*.

Step 16. Check the continuity plate requirements according to Chapter 2.

Step 17. Check the column panel zone according to Section 7.4.

The required shear strength of the panel zone shall be determined from the summation of the moments at the column faces as determined by projecting moments equal to $R_y F_y Z_e$ at the plastic hinge points to the column faces. For d , add twice the thickness of the flange plate to the beam depth.

CHAPTER 8

WELDED UNREINFORCED FLANGE-WELDED WEB (WUF-W) MOMENT CONNECTION

8.1. GENERAL

In the welded unreinforced flange-welded web (WUF-W) moment connection, inelastic rotation is developed primarily by yielding of the beam in the region adjacent to the face of the column. Connection rupture is controlled through special detailing requirements associated with the welds joining the beam flanges to the column flange, the welds joining the beam web to the column flange, and the shape and finish of the weld access holes. An overall view of the connection is shown in Figure 8.1.

8.2. SYSTEMS

WUF-W moment connections are prequalified for use in special moment frame (SMF) and intermediate moment frame (IMF) systems within the limits of these provisions.

8.3. PREQUALIFICATION LIMITS

1. Beam Limitations

Beams shall satisfy the following limitations:

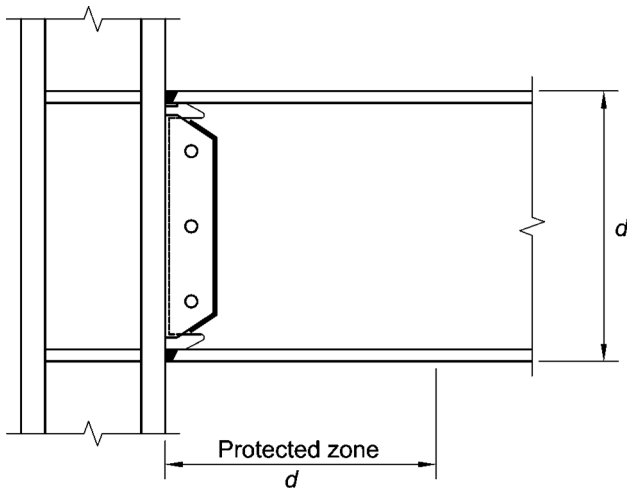


Fig. 8.1. WUF-W moment connection.

- (1) Beams shall be rolled wide-flange or built-up I-shaped members conforming to the requirements of Section 2.3.
- (2) Beam depth is limited to a maximum of W36 (W920) for rolled shapes. Depth of built-up sections shall not exceed the depth permitted for rolled wide-flange shapes.
- (3) Beam weight is limited to a maximum of 150 lb/ft (224 kg/m).
- (4) Beam flange thickness is limited to a maximum of 1 in. (25 mm).
- (5) The clear span-to-depth ratio of the beam is limited as follows:
 - (a) For SMF systems, 7 or greater.
 - (b) For IMF systems, 5 or greater.
- (6) Width-to-thickness ratios for the flanges and web of the beam shall conform to the requirements of the AISC *Seismic Provisions*.
- (7) Lateral bracing of beams shall be provided as follows:

Lateral bracing of beams shall conform to the requirements of the AISC *Seismic Provisions*. To satisfy the requirements of the AISC *Seismic Provisions* for lateral bracing at plastic hinges, supplemental lateral bracing shall be provided at both the top and bottom beam flanges, and shall be located at a distance of d to $1.5d$ from the face of the column. No attachment of lateral bracing shall be made to the beam in the region extending from the face of the column to a distance d from the face of the column.

Exception: For both SMF and IMF systems, where the beam supports a *concrete structural slab* that is connected along the beam span between protected zones with welded shear connectors spaced at a maximum of 12 in. (300 mm) on center, supplemental top and bottom flange bracing at plastic hinges is not required.
- (8) The protected zone consists of the portion of beam between the face of the column and a distance one beam depth, d , from the face of the column.

2. Column Limitations

Columns shall satisfy the following limitations:

- (1) Columns shall be any of the rolled shapes or built-up sections permitted in Section 2.3.
- (2) The beam shall be connected to the flange of the column.
- (3) Rolled shape column depth shall be limited to a maximum of W36 (W920). The depth of built-up wide-flange columns shall not exceed that for rolled shapes. Flanged cruciform columns shall not have a width or depth greater than the depth allowed for rolled shapes. Built-up box columns shall not have a width or depth exceeding 24 in. (610 mm). Boxed wide-flange columns shall not have a width or depth exceeding 24 in. (610 mm) if participating in orthogonal moment frames.

- (4) There is no limit on the weight per foot of columns.
- (5) There are no additional requirements for flange thickness.
- (6) Width-to-thickness ratios for the flanges and web of columns shall conform to the requirements of the AISC *Seismic Provisions*.
- (7) Lateral bracing of columns shall conform to the requirements of the AISC *Seismic Provisions*.

8.4. COLUMN-BEAM RELATIONSHIP LIMITATIONS

Beam-to-column connections shall satisfy the following limitations:

- (1) Panel zones shall conform to the requirements of the AISC *Seismic Provisions*.
- (2) Column-beam moment ratios shall be limited as follows:
 - (a) For SMF systems, the column-beam moment ratio shall conform to the requirements of the AISC *Seismic Provisions*. The value of $\sum M_{pb}^*$ shall be taken equal to $\sum(M_{pr} + M_{uv})$, where M_{pr} is computed according to Step 1 in Section 8.7 and M_{uv} is the additional moment due to shear amplification from the plastic hinge to the centerline of the column. M_{uv} is permitted to be computed as $V_h(d_c/2)$, where V_h is the shear at the plastic hinge computed per Step 3 of Section 8.7, and d_c is the depth of the column.
 - (b) For IMF systems, the column-beam moment ratio shall conform to the requirements of the AISC *Seismic Provisions*.

8.5. BEAM FLANGE-TO-COLUMN FLANGE WELDS

Beam flange-to-column flange connections shall satisfy the following limitations:

- (1) Beam flanges shall be connected to column flanges using complete-joint-penetration (CJP) groove welds. Beam flange welds shall conform to the requirements for demand critical welds in the AISC *Seismic Provisions*.
- (2) Weld access hole geometry shall conform to the requirements of AWS D1.8/D1.8M Section 6.10.1.2. Weld access hole quality requirements shall conform to the requirements of AWS D1.8.

8.6. BEAM WEB-TO-COLUMN CONNECTION LIMITATIONS

The overall details of the beam web-to-column flange connection are shown in Figure 8.2. Single-plate shear connection shall conform to the requirements shown in Figure 8.2. Beam web-to-column flange connections shall satisfy the following limitations:

- (1) A single-plate shear connection shall be provided with a thickness equal at least to that of the beam web. The height of the single plate shall allow a $1/4$ -in. (6-mm) minimum and $1/2$ -in. (12-mm) maximum overlap with the weld access hole at the top and bottom as shown in Figure 8.3. The width shall extend 2 in. (50 mm) minimum beyond the end of the weld access hole.

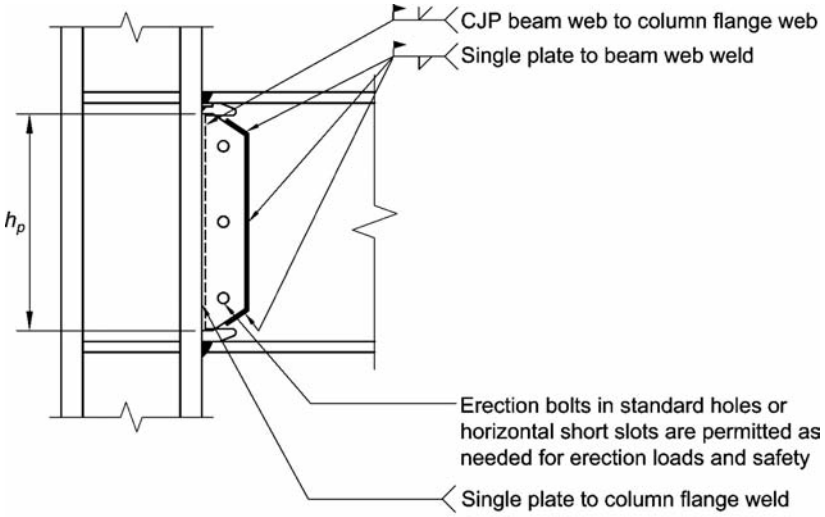
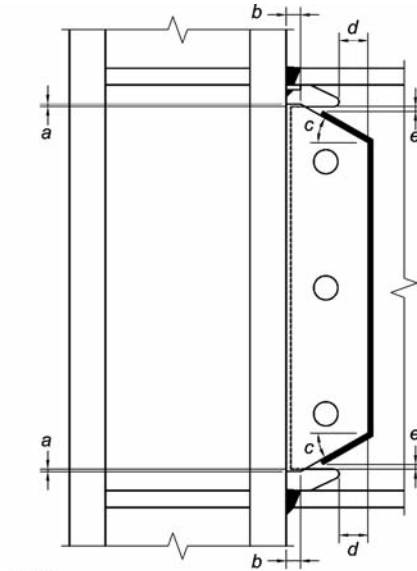


Fig. 8.2. General details of beam web-to-column flange connection.



Notes

- a = 1/4 in. (6 mm) minimum, 1/2 in. (12 mm) maximum
- b = 1 in. (25 mm) minimum
- c = 30° (±10°)
- d = 2 in. (50 mm) minimum
- e = 1/2 in. (12 mm) minimum distance, 1 in. (25 mm) maximum distance from end of fillet weld to edge of access hole

Fig. 8.3. Details at top and bottom of single-plate shear connection.

- (2) The single-plate shear connection shall be welded to the column flange. The design shear strength of the welds shall be at least $h_p t_p (0.6R_y F_{yp})$, where h_p is defined as the length of the plate, as shown in Figure 8.2, and t_p is the thickness of the plate.
- (3) The single-plate shear connection shall be connected to the beam web with fillet welds, as shown in Figures 8.2 and 8.3. The size of the fillet weld shall equal the thickness of the single plate minus $1/16$ in. (2 mm). The fillet welds shall extend along the sloped top and bottom portions of the single plate, and along the vertical single plate length, as shown in Figures 8.2 and 8.3. The fillet welds on the sloped top and bottom portions of the single plate shall be terminated at least $1/2$ in. (12 mm) but not more than 1 in. (25 mm) from the edge of the weld access hole, as shown in Figure 8.3.
- (4) Erection bolts in standard holes or horizontal short slots are permitted as needed.
- (5) A CJP groove weld shall be provided between the beam web and the column flange. This weld shall be provided over the full length of the web between weld access holes, and shall conform to the requirements for demand critical welds in the AISC *Seismic Provisions* and AWS D1.8/D1.8M. *Weld tabs* are not required. Weld tabs, if used, must be removed after welding in accordance with the requirements of Section 3.4. When weld tabs are not used, the use of *cascaded weld ends* within the weld groove shall be permitted at a maximum angle of 45° . Nondestructive testing (NDT) of cascaded weld ends need not be performed.

8.7. DESIGN PROCEDURE

Step 1. Compute the *probable maximum moment at the plastic hinge*, M_{pr} , in accordance with Section 2.4.3. The value of Z_e shall be taken as equal to Z_x of the beam section and the value of C_{pr} shall be taken as equal to 1.4.

User Note: The C_{pr} value of 1.4 for WUF-W moment connections is based on experimental data that shows a high degree of strain hardening.

Step 2. The *plastic hinge location* shall be taken to be at the face of the column; that is, $S_h = 0$.

Step 3. Compute the shear force, V_h , at the plastic hinge location at each end of the beam.

The shear force at the plastic hinge locations shall be determined from a free body diagram of the portion of the beam between the plastic hinges. This calculation shall assume the moment at each plastic hinge is M_{pr} and shall include gravity loads acting on the beam between the hinges based on the load combination $1.2D + f_1L + 0.2S$.

User Note: The load combination of $1.2D + f_1L + 0.2S$ is in conformance with ASCE/SEI 7. When using the International Building Code, a factor of 0.7 must be used in lieu of the factor of 0.2 when the roof configuration is such that it does not shed snow off of the structure.

Step 4. Check column-beam relationship limitations per Section 8.4. For SMF, the required shear strength of the panel zone, per the AISC *Seismic Provisions*, shall be determined from the summation of the probable maximum moments at the face of the column. The probable maximum moment at the face of the column shall be taken as M_{pr} , computed per Step 1. Provide doubler plates as necessary.

Step 5. Check beam design shear strength:

The required shear strength, V_u , of the beam shall be taken equal to the larger of the two values of V_h computed at each end of the beam in Step 3.

Step 6. Check column continuity plate requirements per Section 2.4.4. Provide continuity plates as necessary.

CHAPTER 9

KAISER BOLTED BRACKET (KBB) MOMENT CONNECTION

The user's attention is called to the fact that compliance with this chapter of the standard requires use of an invention covered by patent rights. By publication of this standard, no position is taken with respect to the validity of any claim(s) or of any patent rights in connection therewith. The patent holder has filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license. The statement may be obtained from the standards developer.

9.1. GENERAL

In a Kaiser bolted bracket (KBB) moment connection, a cast high-strength steel bracket is fastened to each beam flange and bolted to the column flange as shown in Figure 9.1. The bracket attachment to the beam flange is permitted to be either welded (Figure 9.1a) or bolted (Figure 9.1b). When welded to the beam flange, the

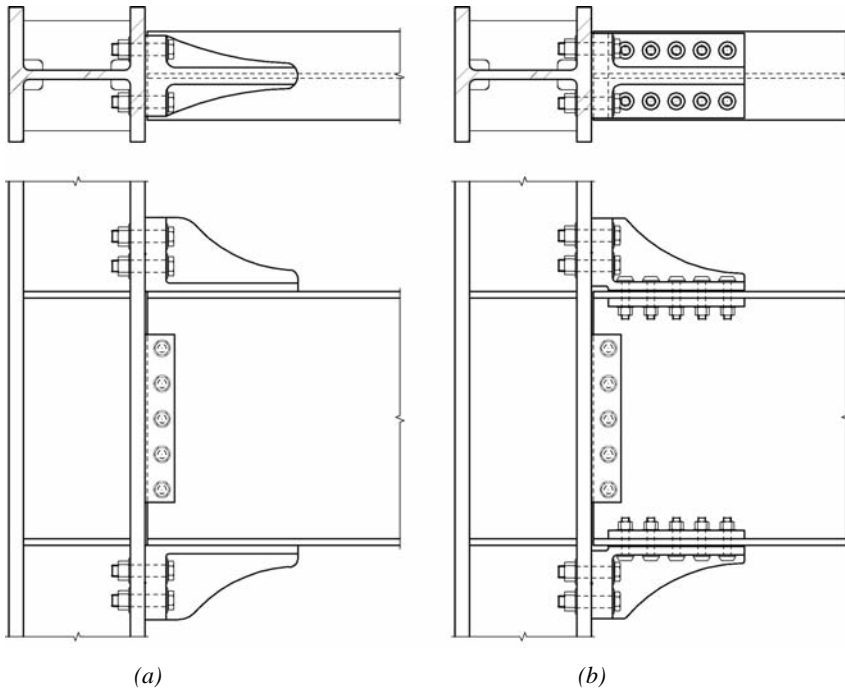


Fig. 9.1. Kaiser bolted bracket connection. (a) W-series connection;
(b) B-series connection.

five W-series bracket configurations available are shown in Figure 9.2. When bolted to the beam flange, the two B-series bracket configurations available are shown in Figure 9.3. The bracket configuration is proportioned to develop the probable maximum moment strength of the connected beam. Yielding and plastic hinge formation are intended to occur primarily in the beam at the end of the bracket away from the column face.

9.2. SYSTEMS

KBB connections are prequalified for use in special moment frame (SMF) and intermediate moment frame (IMF) systems within the limits of these provisions.

Exception: KBB SMF systems with *concrete structural slabs* are prequalified only if the concrete structural slab is kept at least 1 in. (25 mm) from both sides of both column flanges and the vertical flange of the bracket. It is permitted to place compressible material in the gap in this location.

9.3. PREQUALIFICATION LIMITS

1. Beam Limitations

Beams shall satisfy the following limitations:

- (1) Beams shall be rolled wide-flange or built-up I-shaped members conforming to the requirements of Section 2.3.

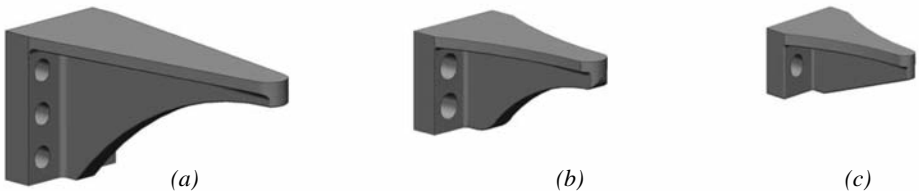


Fig. 9.2. Kaiser bolted bracket W-series configurations:
(a) six column bolts, W1.0; (b) four column bolts, W2.0 and W2.1; and
(c) two column bolts, W3.0 and W3.1.

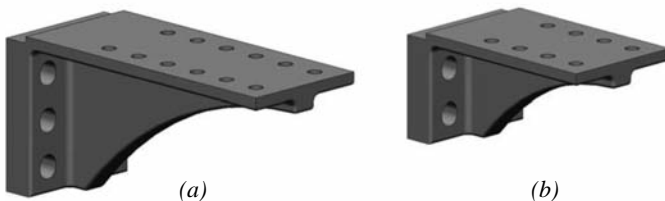


Fig. 9.3. Kaiser bolted bracket B-series configurations:
(a) six column bolts, B1.0, and (b) four column bolts, B2.1.

- (2) Beam depth is limited to a maximum of W33 (W840) for rolled shapes. Depth of built-up sections shall not exceed the depth permitted for rolled wide-flange shapes.
- (3) Beam weight is limited to a maximum of 130 lb/ft (195 kg/m).
- (4) Beam flange thickness is limited to a maximum of 1 in. (25 mm).
- (5) Beam flange width shall be at least 6 in. (152 mm) for W-series brackets and at least 10 in. (250 mm) for B-series brackets.
- (6) The clear span-to-depth ratio of the beam shall be limited to 9 or greater for both SMF and IMF systems.
- (7) Width-to-thickness ratios for the flanges and web of the beam shall conform to the requirements of the AISC *Seismic Provisions*.
- (8) Lateral bracing of beams shall be provided as follows:
 - (a) For SMF systems, in conformance with the AISC *Seismic Provisions*. Supplemental lateral bracing shall be provided at the expected plastic hinge in conformance with the AISC *Seismic Provisions*.

When supplemental lateral bracing is provided, attachment of supplemental lateral bracing to the beam shall be located at a distance d to $1.5d$ from the end of the bracket farthest from the face of the column, where d is the depth of the beam. No attachment of lateral bracing shall be made to the beam in the region extending from the face of the column to a distance d beyond the end of the bracket.
 - (b) For IMF systems, in conformance with the AISC *Seismic Provisions*.

Exception: For both systems, where the beam supports a concrete structural slab that is connected between the protected zones with welded shear connectors spaced at maximum of 12 in. (300 mm) on center, supplemental top and bottom flange bracing at the expected hinge is not required.
- (9) The protected zone consists of the portion of beam between the face of the column and one beam depth, d , beyond the end of the bracket farthest from the face of the column.

2. Column Limitations

The columns shall satisfy the following limitations:

- (1) Columns shall be any of the rolled shapes or built-up sections permitted in Section 2.3.
- (2) The beam shall be connected to the flange of the column.
- (3) The column flange width shall be at least 12 in. (305 mm).
- (4) Rolled shape column depth shall be limited to W36 (W920) maximum when a concrete structural slab is provided. In the absence of a concrete structural slab,

rolled shape column depth is limited to W14 (W360) maximum. The depth of built-up wide-flange columns shall not exceed that for rolled shapes. Flanged cruciform columns shall not have a width or depth greater than the depth allowed for rolled shapes. Built-up box columns shall not have a width or depth exceeding 16 in. (406 mm). Boxed wide-flange columns shall not have a width or depth exceeding 16 in. (406 mm) if participating in orthogonal moment frames.

- (5) There is no limit on the weight per foot of columns.
- (6) There are no additional requirements for flange thickness.
- (7) Width-to-thickness ratios for the flanges and web of columns shall conform to the requirements of the AISC *Seismic Provisions*.
- (8) Lateral bracing of the columns shall conform to the requirements of the AISC *Seismic Provisions*.

3. Bracket Limitations

The high strength cast-steel brackets shall satisfy the following limitations:

- (1) Bracket castings shall conform to the requirements of Appendix A.
- (2) Bracket configuration and proportions shall conform to Section 9.8.
- (3) Holes in the bracket for the column bolts shall be vertical short-slotted holes. Holes for the beam bolts shall be standard holes.
- (4) Material thickness, edge distance and end distance shall have a tolerance of $\pm 1/16$ in. (2 mm). Hole location shall have a tolerance of $\pm 1/16$ in. (2 mm). The overall dimensions of the bracket shall have a tolerance of $\pm 1/8$ in. (3 mm).

9.4. COLUMN-BEAM RELATIONSHIP LIMITATIONS

Beam-to-column connections shall satisfy the following limitations:

- (1) Panel zones shall conform to the requirements in the AISC *Seismic Provisions*.
- (2) Column-beam moment ratios shall conform to the requirements of the AISC *Seismic Provisions*.

9.5. BRACKET-TO-COLUMN FLANGE LIMITATIONS

Bracket-to-column flange connections shall satisfy the following limitations:

- (1) Column flange fasteners shall be pretensioned ASTM A490, A490M, A354 Grade BD bolts, or A354 Grade BD threaded rods, and shall conform to the requirements of Chapter 4.
- (2) Column flange bolt holes shall be $1/8$ in. (3 mm) larger than the nominal bolt diameter. Bolt holes shall be drilled or subpunched and reamed. Punched holes are not permitted.

- (3) The use of finger shims on either or both sides at the top and/or bottom of the bracket connection is permitted, subject to the limitations of the RCSC *Specification*.
- (4) When bolted to a box column, a steel washer plate shall be inserted between the box column and the bracket on both faces of the column. The washer plate shall be ASTM A572/A572M Grade 50 (345) or better and shall be designed to transfer the bolt forces to the outside edges of the column. Where required, the vertical plate depth may extend beyond the contact surface area by up to 4 in. (102 mm). The plate thickness shall not exceed 3 in. (76 mm). The fasteners shall pass through the interior of the box column and be anchored on the opposite face. The opposite face shall also have a steel washer plate.
- (5) When connecting to the orthogonal face of a box column concurrent with a connection on the primary column face, a 1³/₄-in. (44-mm) steel spacer plate shall be inserted between the beam flanges and the brackets of the orthogonal connection. The spacer plate shall be made of any of the structural steel materials included in the AISC *Specification* and shall be the approximate width and length matching that of the bracket contact surface area.

9.6. BRACKET-TO-BEAM FLANGE CONNECTION LIMITATIONS

Bracket-to-beam-flange connections shall satisfy the following limitations:

- (1) When welded to the beam flange, the bracket shall be connected using fillet welds. Bracket welds shall conform to the requirements for demand critical welds in the AISC *Seismic Provisions* and AWS D1.8/D1.8M, and to the requirements of AWS D1.1/D1.1M. The weld procedure specification (WPS) for the fillet weld joining the bracket to the beam flange shall be qualified with the casting material. Welds shall not be started or stopped within 2 in. (51 mm) of the bracket tip and shall be continuous around the tip.
- (2) When bolted to the beam flange, fasteners shall be pretensioned ASTM A490 or A490M bolts with threads excluded from the shear plane and shall conform to the requirements of Chapter 4.
- (3) Beam flange bolt holes shall be 1⁵/₃₂ in. (29 mm) and shall be drilled using the bracket as a template. Punched holes are not permitted.
- (4) When bolted to the beam flange, a 1/₈-in. (3-mm)-thick brass washer plate with an approximate width and length matching that of the bracket contact surface area shall be placed between the beam flange and the bracket. The brass shall be a half-hard tempered ASTM B19 or B36/B36M sheet.
- (5) When bolted to the beam flange, a 1-in. (25-mm)-thick by 4-in. (102-mm)-wide ASTM A572/A572M Grade 50 (345) plate washer shall be used on the opposite side of the connected beam flange.

9.7. BEAM WEB-TO-COLUMN FLANGE CONNECTION LIMITATIONS

Beam web-to-column flange connections shall satisfy the following limitations:

- (1) The required shear strength of the beam web connection shall be determined according to Section 9.9.
- (2) The single-plate shear connection shall be connected to the column flange using a two-sided fillet weld, two-sided PJP groove weld or CJP groove weld.

9.8. CONNECTION DETAILING

If welded to the beam flange, Figure 9.4 shows the connection detailing for the W-series bracket configurations. If bolted to the beam flange, Figure 9.5 shows the connection detailing for the B-series bracket configurations. Table 9.1 summarizes

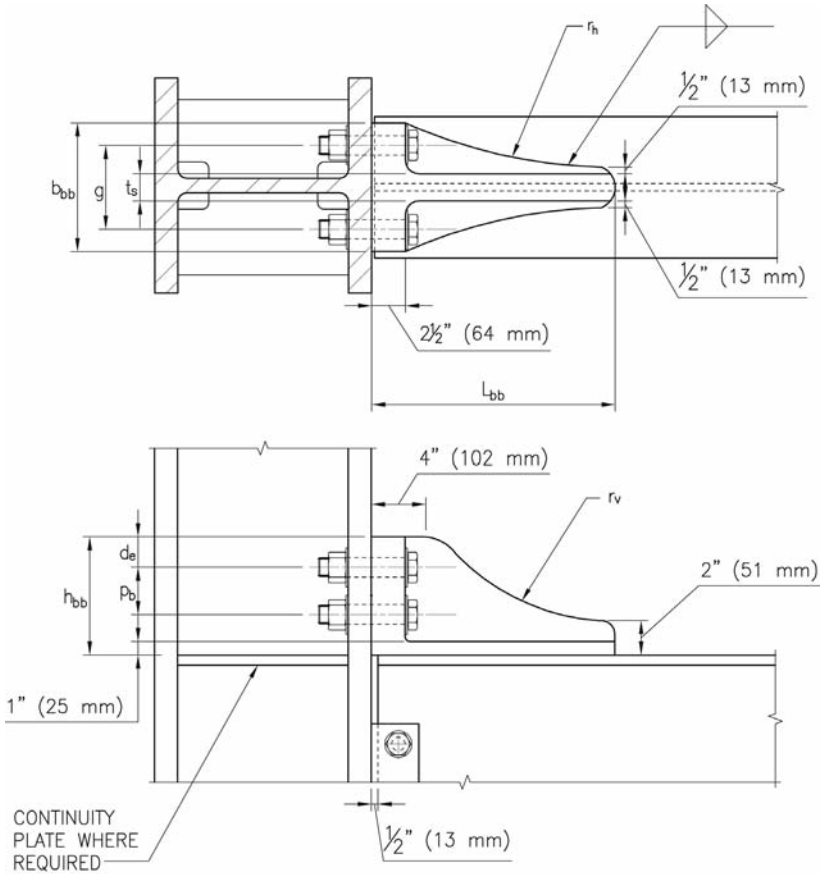


Fig. 9.4. W-series connection detailing.

the KBB proportions and column bolt parameters. Table 9.2 summarizes the design proportions for the W-series bracket configuration. Table 9.3 summarizes the design proportions for the B-series bracket configurations.

9.9. DESIGN PROCEDURE

Step 1. Select beam and column elements which satisfy the limits of Section 9.3.

Step 2. Compute the probable maximum moment, M_{pr} , at the location of the plastic hinge according to Section 2.4.3.

Step 3. Select a trial bracket from Table 9.1.

Step 4. Compute the shear force at the beam hinge location at each end of the beam. The shear force at the hinge location, V_h , shall be determined from a free-body diagram of the portion of the beam between the hinge locations. This calculation shall assume the moment at the hinge location is M_{pr} and shall include gravity loads acting on the beam based on the load combination $1.2D + f_1L + 0.2S$, kips (N) where f_1 is the load factor determined by the applicable building code for live loads, but not less than 0.5.

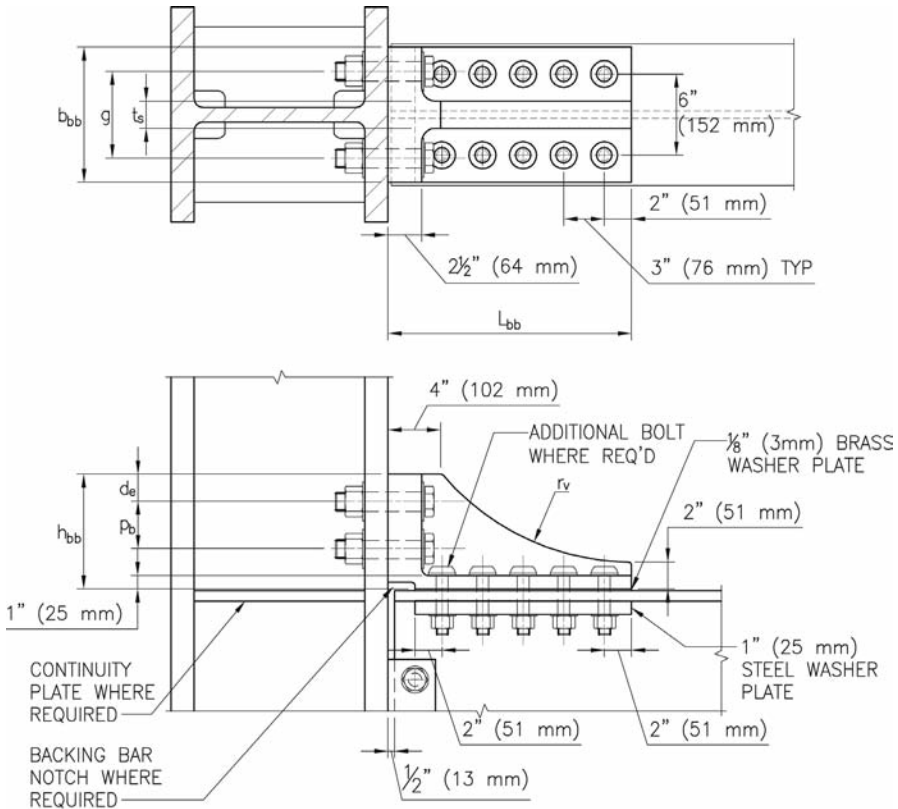


Fig. 9.5. B-series connection detailing.

TABLE 9.1
Kaiser Bolted Bracket Proportions

Bracket Designation	Bracket Length, L_{bb} in. (mm)	Bracket Height, h_{bb} in. (mm)	Bracket Width, b_{bb} in. (mm)	Number of Column Bolts, n_{cb}	Column Bolt Gage, g in. (mm)	Column Bolt Diameter in. (mm)
W3.0	16 (406)	5 $\frac{1}{2}$ (140)	9 (229)	2	5 $\frac{1}{2}$ (140)	1 $\frac{3}{8}$ (35)
W3.1	16 (406)	5 $\frac{1}{2}$ (140)	9 (229)	2	5 $\frac{1}{2}$ (140)	1 $\frac{1}{2}$ (38)
W2.0	16 (406)	8 $\frac{3}{4}$ (222)	9 $\frac{1}{2}$ (241)	4	6 (152)	1 $\frac{3}{8}$ (35)
W2.1	18 (457)	8 $\frac{3}{4}$ (222)	9 $\frac{1}{2}$ (241)	4	6 $\frac{1}{2}$ (165)	1 $\frac{1}{2}$ (38)
W1.0	25 $\frac{1}{2}$ (648)	12 (305)	9 $\frac{1}{2}$ (241)	6	6 $\frac{1}{2}$ (165)	1 $\frac{1}{2}$ (38)
B2.1	18 (457)	8 $\frac{3}{4}$ (222)	10 (254)	4	6 $\frac{1}{2}$ (165)	1 $\frac{1}{2}$ (38)
B1.0	25 $\frac{1}{2}$ (648)	12 (305)	10 (254)	6	6 $\frac{1}{2}$ (165)	1 $\frac{1}{2}$ (38)

TABLE 9.2
W-Series Bracket Design Proportions

Bracket Designation	Column Bolt Edge Distance, d_e in. (mm)	Column Bolt Pitch, p_b in. (mm)	Bracket Stiffener Thickness, t_s in. (mm)	Bracket Stiffener Radius, r_v in. (mm)	Bracket Horizontal Radius, r_h in. (mm)	Minimum Fillet Weld Size, w in. (mm)
W3.0	2 $\frac{1}{2}$ (64)	n.a.	1 (25)	n.a.	28 (711)	$\frac{1}{2}$ (13)
W3.1	2 $\frac{1}{2}$ (64)	n.a.	1 (25)	n.a.	28 (711)	$\frac{5}{8}$ (16)
W2.0	2 $\frac{1}{4}$ (57)	3 $\frac{1}{2}$ (89)	2 (51)	12 (305)	28 (711)	$\frac{3}{4}$ (19)
W2.1	2 $\frac{1}{4}$ (57)	3 $\frac{1}{2}$ (89)	2 (51)	16 (406)	38 (965)	$\frac{7}{8}$ (22)
W1.0	2 (51)	3 $\frac{1}{2}$ (89)	2 (51)	28 (711)	n.a.	$\frac{7}{8}$ (22)

TABLE 9.3
B-Series Bracket Design Proportions

Bracket Designation	Column Bolt Edge Distance, d_e in. (mm)	Column Bolt Pitch, p_b in. (mm)	Bracket Stiffener Thickness, t_s in. (mm)	Bracket Stiffener Radius, r_v in. (mm)	Number of Beam Bolts, n_{bb}	Beam Bolt Diameter in. (mm)
B2.1	2 (51)	3 $\frac{1}{2}$ (89)	2 (51)	16 (406)	8 or 10	1 $\frac{1}{8}$ (29)
B1.0	2 (51)	3 $\frac{1}{2}$ (89)	2 (51)	28 (711)	12	1 $\frac{1}{8}$ (29)

User Note: The load combination of $1.2D + f_1L + 0.2S$ is in conformance with ASCE/SEI 7. When using the International Building Code, a factor of 0.7 must be used in lieu of the factor of 0.2 when the roof configuration is such that it does not shed snow off of the structure.

Step 5. Compute the probable maximum moment at the face of the column:

$$M_f = M_{pr} + V_h S_h \quad (9.9-1)$$

where

M_f = probable maximum moment at the face of the column, kip-in. (N-mm)

S_h = distance from the face of the column to the plastic hinge, in. (mm)

= L_{bb} per Table 9.1, in. (mm)

V_h = larger of the two values of shear force at the beam hinge location at each end of the beam, kips (N)

Equation 9.9-1 neglects the gravity load on the portion of the beam between the plastic hinge and the face of the column. If desired, the gravity load on this small portion of the beam is permitted to be included.

Step 6. The following relationship shall be satisfied for the bracket column bolt tensile strength:

$$r_{ut} \leq \phi_n F_{nt} A_b \quad (9.9-2)$$

where

$$r_{ut} = \frac{M_f}{d_{eff} n_{cb}} \quad (9.9-3)$$

A_b = bolt nominal cross-sectional area, in.² (mm²)

F_{nt} = nominal tensile strength of bolt from the AISC *Specification*, ksi (MPa)

d_{eff} = effective beam depth, calculated as the centroidal distance between bolt groups in the upper and lower brackets, in. (mm)

n_{cb} = number of column bolts per Table 9.1

Step 7. Determine the minimum column flange width to prevent flange tensile rupture:

$$b_{cf} \geq \frac{2 \left[d_b + \frac{1}{8} \text{ in.} \right]}{\left(1 - \frac{R_y F_{yf}}{R_t F_{uf}} \right)} \quad (9.9-4)$$

$$b_{cf} \geq \frac{2 \left[d_b + 3 \text{ mm} \right]}{\left(1 - \frac{R_y F_{yf}}{R_t F_{uf}} \right)} \quad (\text{S.I.}) \quad (9.9-4M)$$

where

b_{cf} = width of column flange, in. (mm)

d_b = diameter of column flange bolts, in. (mm)

F_{yf} = specified minimum yield stress of the flange material, ksi (MPa)

F_{uf} = specified minimum tensile strength of the flange material, ksi (MPa)

R_y = ratio of expected yield stress to the specified minimum yield stress for the flange material

R_t = ratio of expected tensile strength to the specified minimum tensile strength for the flange material

Step 8. Check the minimum column flange thickness to eliminate prying action:

$$t_{cf} \geq \sqrt{\frac{4.44 r_{ut} b'}{\phi_d p F_y}} \quad (9.9-5)$$

where

$$b' = 0.5 (g - k_1 - 0.5 t_{cw} - d_b) \quad (9.9-6)$$

g = column bolt gage, in. (mm)

k_1 = column web centerline distance to the flange toe of the fillet, in. (mm)

p = perpendicular tributary length per bolt, in. (mm)

= 3.5 in. (89 mm) for W1.0/B1.0

= 5.0 in. (127 mm) for all other brackets

t_{cf} = minimum column flange thickness required to eliminate prying action, in. (mm)

t_{cw} = column web thickness, in. (mm)

If the selected column flange thickness is less than that required to eliminate prying action, select a column with a satisfactory flange thickness or include the bolt prying force in Equation 9.9-2 per Part 9 of the AISC *Steel Construction Manual*.

Step 9. The column flange thickness shall satisfy the following requirement to eliminate continuity plates:

$$t_{cf} \geq \sqrt{\frac{M_f}{\phi_d F_{yf} d_{eff} Y_m}} \quad (9.9-7)$$

where

Y_m = simplified column flange yield line mechanism parameter

= 5.9 for W3.0/W3.1

= 6.5 for W2.0/W2.1/B2.1

= 7.5 for W1.0/B1.0

t_{cf} = minimum column flange thickness required to eliminate continuity plates, in. (mm)

Step 10. Continuity Plate Requirements

For W14 and shallower columns, continuity plates are not required if Equation 9.9-7 is satisfied. For column sections deeper than W14, continuity plates shall be provided.

Step 11. If the bracket is welded to the beam flange proceed to Step 14; otherwise, determine the minimum beam flange width to prevent beam flange tensile rupture:

$$b_{bf} \geq \frac{2 \left[d_b + 1/32 \text{ in.} \right]}{\left(1 - \frac{R_y F_{yf}}{R_t F_{uf}} \right)} \quad (9.9-8)$$

$$b_{bf} \geq \frac{2 \left[d_b + 1 \text{ mm} \right]}{\left(1 - \frac{R_y F_{yf}}{R_t F_{uf}} \right)} \quad (\text{S.I.}) \quad (9.9-8\text{M})$$

where

b_{bf} = width of beam flange, in. (mm)

d_b = diameter of beam flange bolts, in. (mm)

Step 12. The following relationship shall be satisfied for the beam bolt shear strength:

$$\frac{M_f}{\phi_n F_{nv} A_b d_{eff} n_{bb}} < 1.0 \quad (9.9-9)$$

where

F_{nv} = nominal shear strength of bolt from the AISC *Specification*, ksi (MPa)

n_{bb} = the number of beam bolts per Table 9.3

Step 13. Check the beam flange for block shear per the following:

$$\frac{M_f}{d_{eff}} \leq \phi_n R_n \quad (9.9-10)$$

where R_n is as defined in the block shear provisions of Chapter J of the AISC *Specification*.

Step 14. If the bracket is bolted to the beam flange proceed to Step 15. Otherwise, the following relationship shall be satisfied for the fillet weld attachment of the bracket to the beam flange:

$$\frac{M_f}{\phi_n F_w d_{eff} l_w (0.707w)} < 1.0 \quad (9.9-11)$$

where

F_w = nominal weld design strength per the AISC *Specification*
 $= 0.60 F_{EXX}$

F_{EXX} = filler metal classification strength, ksi (MPa)

L_{bb} = bracket length per Table 9.3, in. (mm)

$$\begin{aligned}
 l &= \text{bracket overlap distance, in. (mm)} \\
 &= 0 \text{ in. (0 mm) if } b_{bf} \geq b_{bb} \\
 &= 5 \text{ in. (125 mm) if } b_{bf} < b_{bb} \\
 l_w &= \text{length of available fillet weld, in. (mm)} \\
 &= 2(L_{bb} - 2.5 \text{ in.} - l) \qquad (9.9-12) \\
 &= 2(L_{bb} - 64 \text{ mm} - l) \qquad \text{(S.I.)} \quad (9.9-12M) \\
 w &= \text{minimum fillet weld size per Table 9.2, in. (mm)}
 \end{aligned}$$

Step 15. Determine the required shear strength, V_u , of the beam and beam web-to-column connection from:

$$V_u = \frac{2M_{pr}}{L_h} + V_{gravity} \quad (9.9-13)$$

where

$$\begin{aligned}
 L_h &= \text{distance between plastic hinge locations, in. (mm)} \\
 V_{gravity} &= \text{beam shear force resulting from } 1.2D + f_1L + 0.2S \text{ (where } f_1 \text{ is a load factor determined by the applicable building code for live loads, but not less than 0.5), kips (N)}
 \end{aligned}$$

User Note: The load combination of $1.2D + f_1L + 0.2S$ is in conformance with ASCE/SEI 7. When using the International Building Code, a factor of 0.7 must be used in lieu of the factor of 0.2 when the roof configuration is such that it does not shed snow off of the structure.

Check design shear strength of beam according to Chapter G of the AISC *Specification*.

Step 16. Design the beam web-to-column connection according to Section 9.7.

Step 17. Check column panel zone according to Section 9.4. Substitute the effective depth, d_{eff} , of the beam and brackets for the beam depth, d .

Step 18. (Supplemental) If the column is a box configuration, determine the size of the steel washer plate between the column flange and the bracket such that:

$$Z_x \geq \frac{M_f(b_{cf} - t_{cw} - g)}{4\phi_d F_y d_{eff}} \quad (9.9-14)$$

where

$$\begin{aligned}
 F_y &= \text{specified minimum yield stress of the washer material, ksi (MPa)} \\
 Z_x &= \text{plastic section modulus of the washer plate, in.}^3 \text{ (mm}^3\text{)} \\
 g &= \text{column bolt gage, in. (mm)}
 \end{aligned}$$

CHAPTER 10

CONXTECH CONXL MOMENT CONNECTION

The user's attention is called to the fact that compliance with this chapter of the standard requires use of an invention covered by patent rights. By publication of this standard, no position is taken with respect to the validity of any claim(s) or of any patent rights in connection therewith. The patent holder has filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license, and the statement may be obtained from the standards developer.*

10.1 GENERAL

The ConXtech® ConXL™ moment connection permits full-strength, fully restrained connection of wide flange beams to concrete-filled 16 in. (406 mm) square HSS or built-up box columns using a high-strength, field-bolted collar assembly. Beams are shop-welded to forged flange and web fittings (collar flange assembly) and are field-bolted together through forged column fittings (collar corner assembly) that are shop welded to the columns. Beams may be provided with reduced beam section (RBS) cutouts if necessary to meet strong-column/weak-beam criteria. ConXL connections may be used to provide moment connections to columns in orthogonal frames. All moment beams connecting to a ConXL node (intersection of moment beams and column) must be of the same nominal depth.

Figure 10.1 shows the connection geometry and major connection components. Each ConXL collar assembly is made up of forged collar corners and collar flanges conforming to the material requirements of ASTM A572/A572M Grade 50 (Grade 345). At each ConXL node there are four collar corner assemblies (Figure 10.2), one at each corner of the square built-up or HSS column. Each ConXL node also contains four collar flange assemblies (Figure 10.3), one for each face of the square column. Each collar flange assembly can contain the end of a moment beam that is shop-welded to the collar flange assembly. The combination of collar corner assemblies, collar flange assemblies, and square concrete-filled column create the ConXL node.

Figure 10.2 shows the collar corner assemblies. The collar corner assembly is made up of a collar corner top (CCT) piece, a collar corner bottom (CCB) piece; and for beam depths greater than 18 in. (460 mm), a collar corner middle (CCM) piece. The

* The connectors and structures illustrated are covered by one or more of the following U.S. and foreign patents: U.S. Pat. Nos.: 7,941,985; 6,837,016; 7,051,917; 7,021,020; Australia Pat. Nos. 2001288615; 2004319371; Canada Pat. Nos. 2,458,706; 2,564,195; China Pat. Nos. ZL 01 8 23730.4; ZL 2004 8 0042862.5; Japan Pat. Nos. 4165648; 4427080; Mexico Pat. Nos. 262,499; 275284; Hong Kong Pat. No. 1102268. Other U.S. and foreign patent protection pending.

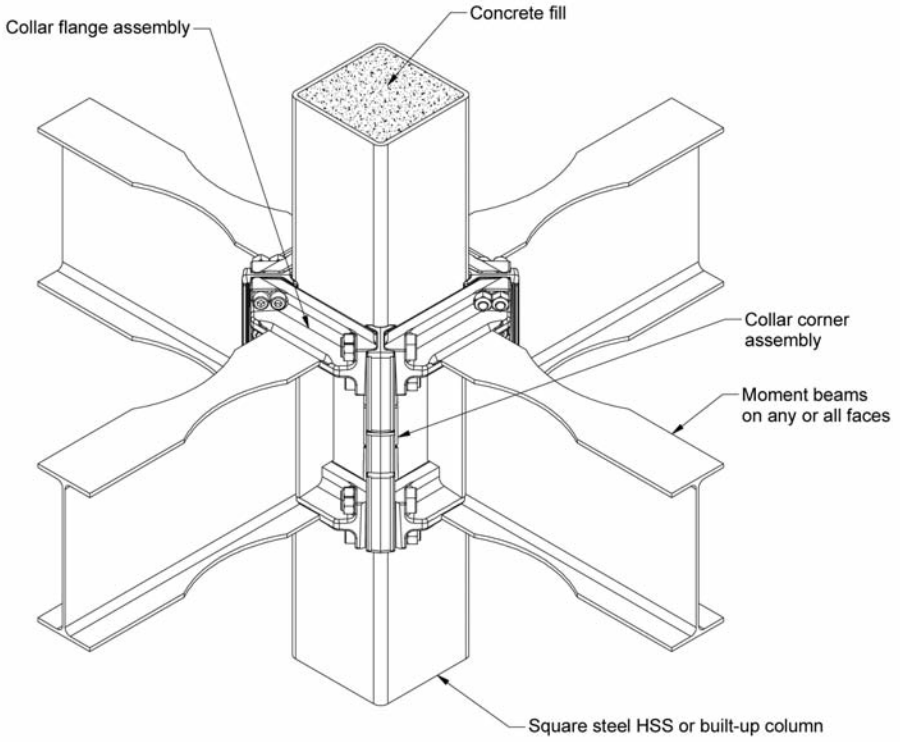


Fig. 10.1. Assembled ConXL moment connection.

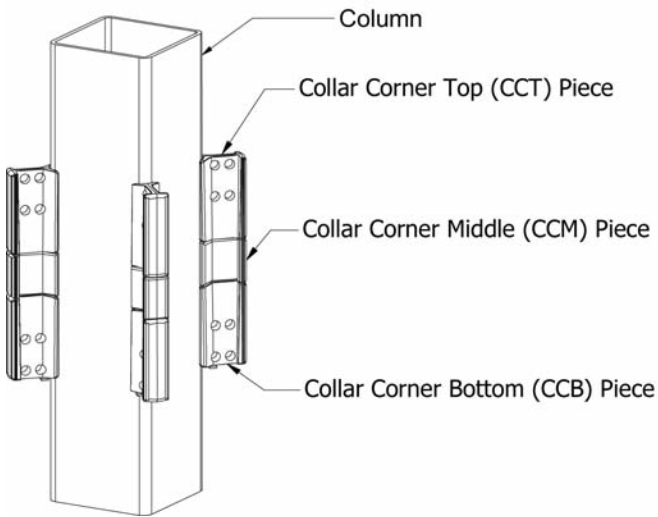


Fig. 10.2. Column with attached collar corner assemblies.

CCT, CCB and CCM are partial joint penetration- (PJP-) welded together to create the collar corner assembly; they are then shop fillet welded to the corners of the square column.

Figure 10.3 shows the collar flange assembly. Each collar flange assembly is made up of a collar flange top (CFT), collar flange bottom (CFB) and a collar web extension (CWX).

If a beam at the node requires a moment connection, the CFT (or CFB) is aligned with and shop-welded to the top (or bottom) flange of the beam.

Moment-connected beam webs are also shop-welded to the CWX. If a beam at the node does not require a moment connection, the size of the CWX remains unchanged and a shear plate connection is shop-welded to the CWX to accommodate a non-moment beam that does not need to match the nominal depth of the moment-connected beam(s).

If no beams exist on a node at a particular column face, the CFT and CFB are aligned at the nominal depth of the moment beam, and the CWX shall be permitted to be optionally omitted.

Section 10.9 contains drawings indicating the dimensions of individual pieces.

Columns are delivered to the job site with the collar corner assemblies shop-welded to the column at the proper floor framing locations. Beams are delivered to the job site with the collar flange assemblies shop-welded to the ends of the beams. During

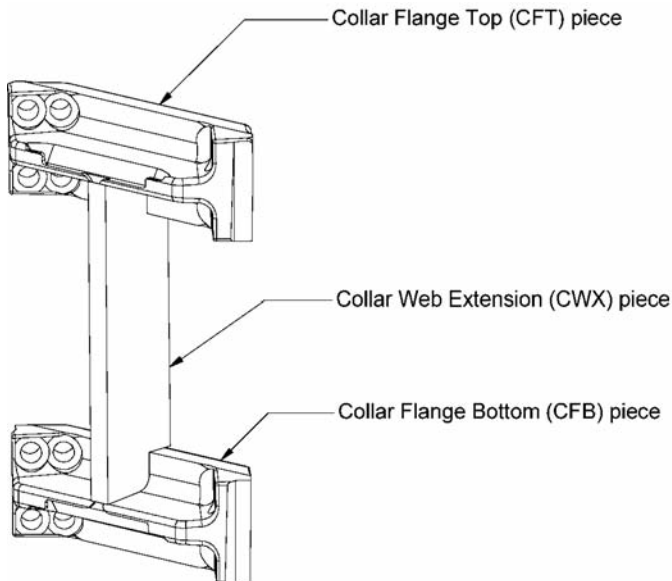


Fig. 10.3. Collar flange assembly.

frame erection the collar flange assemblies with or without beams are lowered into the column collar corner assemblies. When all four faces of the column are filled with collar flanges the collar bolts are inserted and pre-tensioned, effectively clamping and compressing the collar flange assemblies around the collar corner assemblies and square column.

Beam flange flexural forces in moment beams are transferred to the collar flange assemblies via complete joint penetration (CJP) groove welds. Collar flanges transfer compressive beam flange forces to the collar corners through flexure of the collar flange and direct bearing onto the collar corners. The collar flange transfers beam flange tensile forces in flexure to the pre-tensioned collar bolts. The collar bolts transfer these forces in tension through the orthogonal collar flanges, which then transfer the forces through the rear collar bolts attached to the collar flange on the opposite face of the column. These combined forces are then transferred to the column walls through a combination of bearing and the fillet welds attaching the collar corners to the column. Finally, a portion of these forces are transferred to the concrete fill which is in direct contact with the column walls.

The behavior of this connection is controlled by flexural hinging of the beams adjacent to the collar assembly. When RBS cutouts are provided yielding and plastic hinge formation primarily occur within the reduced beam section.

10.2 SYSTEMS

The ConXL moment connection is prequalified for use in special moment frame (SMF) and intermediate moment frame (IMF) systems within the limits of these provisions. The ConXL moment connection is prequalified for use in planar moment-resisting frames or in orthogonal intersecting moment-resisting frames.

ConXL SMF systems with concrete structural slabs are prequalified only if a vertical flexible joint at least 1 in. (25 mm) thick is placed in the concrete slab around the collar assembly and column similar to that shown in Figure 10.4.

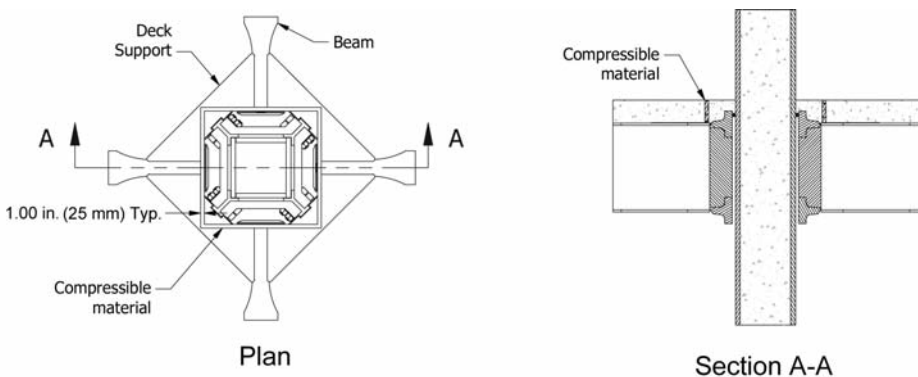


Fig. 10.4. Use of compressible material to isolate structural slab from connection.

10.3 PREQUALIFICATION LIMITS

1. Beam Limitations

Beams shall satisfy the following limitations:

- (1) Beams shall be rolled wide-flange or built-up I-shaped members conforming to the requirements of Section 2.3.
- (2) Beam depths shall be limited to the following beam shapes or their built-up equivalents: W30, W27, W24, W21 and W18.
- (3) Beam flange thickness shall be limited to a maximum of 1 in. (25 mm).
- (4) Beam flange width shall be limited to a maximum of 12 in. (300 mm).
- (5) The clear span-to-depth ratio of the beam shall be limited as follows:
 - (a) For SMF systems, 7 or greater.
 - (b) For IMF systems, 5 or greater.
- (6) Width-thickness ratios for beam flanges and webs shall conform to the limits of the AISC *Seismic Provisions*. The value of b_f used to determine the width-thickness ratio of beams with RBS cutouts shall not be less than the flange width at the center two-thirds of the reduced section provided that gravity loads do not shift the location of the plastic hinge a significant distance from the center of the reduced beam section.
- (7) Lateral bracing of beams shall conform to the applicable limits of the AISC *Seismic Provisions*.

Exception: For SMF and IMF systems, where the beam supports a concrete structural slab that is connected between the protected zones with welded shear connectors spaced at a maximum of 12 in. (300 mm) on center, supplemental top and bottom flange bracing at the expected hinge is not required.

- (8) For RBS connections the protected zone consists of the portion of the connection assembly and beam between the column face and the farthest end of the reduced beam section. For beams without reduced beam sections the protected zone consists of the portion of the connection assembly and beam extending from the column face to a distance of d from the outside face of the collar flange.

2. Column Limitations

Columns shall satisfy the following limitations:

- (1) Columns shall be square 16 in. (406 mm) HSS sections or square 16 in. (406 mm) built-up box sections permitted in Section 2.3.
- (2) There is no limit on column weight per foot.
- (3) Column wall thickness shall not be less than $3/8$ in. (10 mm). Column wall thickness for HSS columns shall not be less than $3/8$ in. (10 mm) nominal.

- (4) Width-thickness ratios for columns shall conform to the applicable limits for filled composite columns in the AISC *Seismic Provisions*.
- (5) Lateral bracing of columns shall conform to the applicable limits in the AISC *Seismic Provisions*.
- (6) Columns shall be completely filled with structural concrete having unit weight not less than 110 pounds per cubic foot (17 kN/m³). Concrete shall have 28-day compressive strength not less than 3,000 psi (21 MPa).

3. Collar Limitations

Collar forgings shall satisfy the following limitations:

- (1) Collar forgings shall conform to the requirements of Appendix B, Forging Requirements.
- (2) Collar configuration and proportions shall conform to Section 10.9, ConXL Part Drawings.
- (3) Collar flange bolt holes shall be $\frac{1}{8}$ in. (3 mm) larger than the nominal bolt diameter. Bolt holes shall be drilled.
- (4) Collar corner bolt holes shall be $\frac{1}{8}$ in. (3 mm) larger than the nominal bolt diameter. Bolt holes shall be drilled.
- (5) Material thickness, edge distance, end distance and overall dimension shall have a tolerance of $\pm \frac{1}{16}$ in. (2 mm).
- (6) Faying surfaces shall be machined and meet the requirements for Class A slip-critical surfaces.

10.4. COLLAR CONNECTION LIMITATIONS

Collar connections shall satisfy the following limitations:

- (1) Collar bolts shall be pretensioned $1\frac{1}{4}$ -in.- (31.8-mm-) diameter high-strength bolts conforming to ASTM A574 with threads excluded from the shear plane and shall conform to the requirements of Sections 4.2 and 4.3.
- (2) The collar bolts shall be pretensioned to the requirements for ASTM A490 bolts in the RCSC *Specification*.
- (3) Welding of CCT, CCM and CCB pieces to form collar corner assemblies shall consist of partial joint penetration groove welds per Figure 10.5
- (4) Welding of collar corner assemblies to columns shall consist of flare bevel groove welds with $\frac{3}{8}$ in. (10 mm) fillet reinforcing per Figure 10.6
- (5) Collar flanges shall be welded to CWX pieces with $\frac{5}{16}$ in. (8 mm) fillet welds, each side per Figure 10.7

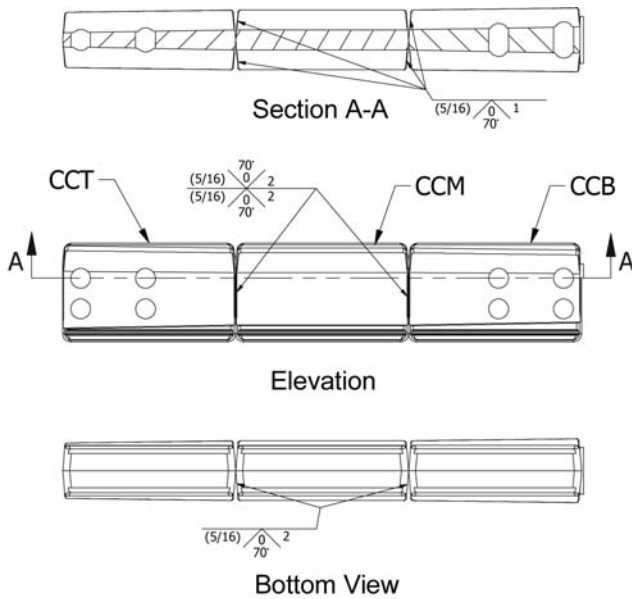


Fig. 10.5. Collar corner assembly welding.

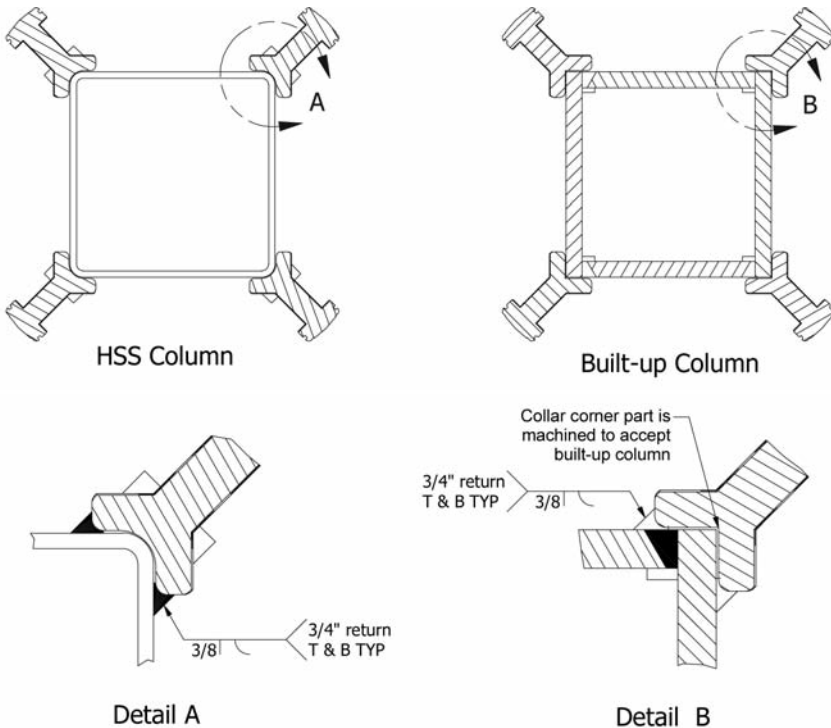


Fig. 10.6. Collar-corner-assembly-to-column weld, plan view.

- (6) Beams shall be welded to collar flange assemblies with complete joint penetration groove welds per Figure 10.8

10.5 BEAM WEB-TO-COLLAR CONNECTION LIMITATIONS

Beam-web-to-collar connections shall satisfy the following limitations:

- (1) The required shear strength of the beam web connection shall be determined according to Section 10.8.
- (2) The beam web is welded to the collar web extension (CWX) with a two-sided fillet weld. The fillet welds shall be sized to develop the required shear strength of the connection.

10.6 BEAM FLANGE-TO-COLLAR FLANGE WELDING LIMITATIONS

Welding of the beam to the collar flange shall conform to the following limitations:

- (1) Weld access holes are not allowed. Welding access to top and bottom flanges shall be made available by rotating the beam to allow a CJP weld in the flat position (Position 1G per AWS D1.1).

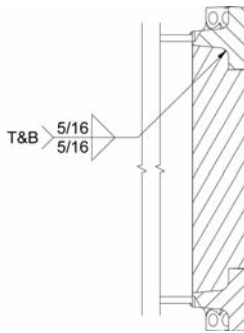


Fig. 10.7. Collar-web-extension-to-collar-flange welds, elevation.

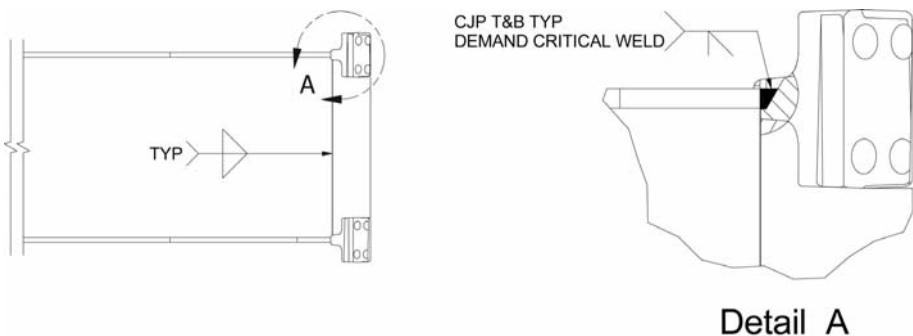


Fig. 10.8. Collar-flange-assembly-to-beam welds, elevation.

- (2) The beam-flange-to-collar-flange weld shall be made with a CJP groove weld within the weld prep area of the collar flange. Reinforcing $5/16$ -in. (8 mm) fillet welds shall be placed on the back side of the CJP groove welds. The CJP flange weld shall conform to the requirements for demand critical welds in the AISC *Seismic Provisions* and AWS D1.8 and to the requirements of AWS D1.1.

10.7 COLUMN-BEAM RELATIONSHIP LIMITATIONS

Beam-to-column connections shall satisfy the following limitations:

- (1) Panel zones shall conform to the applicable requirements of the AISC *Seismic Provisions*.
- (2) Column-beam moment ratios shall be limited as follows:
- (a) For SMF systems, the column-beam moment ratio about each principal axis shall conform to the requirements of the AISC *Seismic Provisions* considering simultaneous development of the expected plastic moments in the moment-connected beams framing into all sides of the ConXL node.
- (b) For IMF systems, the column-beam moment ratio shall conform to the requirements of the AISC *Seismic Provisions*.

10.8 DESIGN PROCEDURE

Step 1. Compute the probable maximum moment at the plastic hinge, M_{pr} , in accordance with Section 2.4.3.

$$M_{pr} = C_{pr} R_y F_y Z_e \quad (2.4.3-1)$$

where

$$C_{pr} = \frac{F_y + F_u}{2F_y} \leq 1.2 \quad (\text{for RBS beams}) \quad (2.4.3-2)$$

$$C_{pr} = 1.1 \quad (\text{for non-RBS beams})$$

R_y = ratio of the expected yield stress to the specified minimum yield stress, F_y , as specified in the AISC *Seismic Provisions*

F_y = specified minimum yield stress of the yielding element, ksi (MPa)

F_u = specified minimum tensile strength of the yielding element, ksi (MPa)

Z_e = effective plastic section modulus of the section at the location of the plastic hinge, in.³ (mm³)

For beams with an RBS cutout, the plastic hinge shall be assumed to occur at the center of the reduced section of beam flange. For beams without an RBS cutout, the plastic hinge shall be assumed to occur at a distance $d/2$ from the outside face of the collar (see Figure 10.9) where d is the beam depth.

Step 2. Compute the shear force, V_h , at the location of the plastic hinge at each end of the beam.

The shear force at each plastic hinge location shall be determined from a free body diagram of the portion of the beam between the plastic hinge locations. This calculation shall assume that the moment at the center of the plastic hinge is M_{pr} and shall consider gravity loads acting on the beams between plastic hinges in accordance with the equation:

$$V_h = \frac{2M_{pr}}{L_h} + V_{gravity} \quad (10.8-1)$$

where

L_h = distance between plastic hinge locations, in. (mm)

$V_{gravity}$ = beam shear force resulting from $1.2D + f_1L + 0.2S$ (where f_1 is the load factor determined by the applicable building code for live loads, but not less than 0.5), kips (N)

User Note: The load combination of $1.2D + f_1L + 0.2S$ is in conformance with ASCE 7. When using the International Building Code, a factor of 0.7 must be used in lieu of the factor of 0.2 when the roof configuration is such that it does not shed snow off of the structure.

When concentrated loads are present on the beam between the points of plastic hinging they must be considered using standard considerations of statics when calculating the beam shear and using the same load combination.

Step 3. Confirm that columns are adequate to satisfy biaxial strong column-weak beam conditions. For the purpose of satisfying this requirement, it shall be permitted to take the yield strength of the column material as the specified F_y and to consider the full composite behavior of the column for axial load and flexural action.

User Note: The specified value of F_y need not be the minimum value associated with the grade of steel if project specifications require a higher minimum yield strength.

The value of $\sum M_{pb}^*$ about each axis shall be taken equal to $\sum(M_{pr} + M_v)$, where M_{pr} is computed according to Equation 2.4.3-1, and where M_v is the additional moment due to the beam shear acting on a lever arm extending from the assumed point of plastic hinging to the centerline of the column. M_v on each side of the column can be computed as the quantity $V_h s_h$, where V_h is the shear at the point of theoretical plastic hinging, computed in accordance with Equation 10.8-1 and s_h is the distance of the assumed point of plastic hinging to the column centerline.

For beams with reduced beam section (RBS) cutout, the distance s_h shall be taken as the distance from the center of the column to the center of the reduced section of beam flange. For beams without an RBS cutout, the distance s_h shall be taken as the distance from the center of the column to a point one-half the beam depth ($d/2$) from the outside face of collar (see Figure 10.9).

The value of ΣM_{pc}^* about each axis shall be taken as:

$$\Sigma M_{pc}^* = M_{pcu}^* + M_{pcl}^* + \frac{\Sigma M_{pb}^*}{(H_u + H_l)} d \quad (10.8-2)$$

where

M_{pcu}^* = plastic moment nominal strength of the column above the node, about the axis under consideration considering simultaneous axial loading and loading about the transverse axis, kip-in. (N-mm)

M_{pcl}^* = plastic moment nominal strength of the column below the node, about the axis under consideration considering simultaneous axial loading and loading about the transverse axis, kip-in. (N-mm)

H_u = height of the story above the node, in. (mm)

H_l = height of the story below the node, in. (mm)

For sections with equal properties about both axes, It shall be permitted to take M_{pcu}^* and M_{pcl}^* as:

$$M_{pcu}^* = M_{pcl}^* = 0.67 Z_c F_y \left(1 - \frac{P_u}{A_s F_y + 0.85 A_c f'_c} \right) \quad (10.8-3)$$

where

A_c = area of concrete in the column, in.² (mm²)

A_s = area of steel in the column, in.² (mm²)

f'_c = specified compressive strength of the concrete fill, ksi (MPa)

P_u = axial load acting on the column at the section under consideration in accordance with the applicable load combination specified by the building code, but not considering amplified seismic load, kips (N)

Z_c = plastic section modulus of the column about either axis, in.³ (mm³)

Step 4. Compute the moment at the collar bolts for each beam:

$$M_{bolts} = M_{pr} + V_h s_{bolts} \quad (10.8-4)$$

where

M_{bolts} = moment at collar bolts, kip-in. (N-mm)

s_{bolts} = distance from center of plastic hinge to the centroid of the collar bolts, in. (mm) as given by the equations:

$$s_{bolts} = \frac{t_{collar}}{2} + a + \frac{b}{2} \quad (\text{for RBS beams}) \quad (10.8-5)$$

$$s_{bolts} = \frac{t_{collar}}{2} + \frac{d}{2} \quad (\text{for non-RBS beams}) \quad (10.8-6)$$

where

a = distance from the outside face of the collar to the RBS cut, in. (mm)

b = length of the RBS cut, in. (mm)

t_{collar} = distance from the face of the column to the outside face of the collar, taken as 7¹/₈ in. (181 mm) as illustrated in Figure 10.9

Step 5. Verify that the beam flange force does not exceed the available tensile strength of the bolts at the flange connection. The following relationship shall be satisfied for the collar bolts tensile strength:

$$\frac{r_{ut}}{\phi_d R_{pt}} = \frac{r_{ut}}{102} \leq 1.0 \quad (10.8-7)$$

$$\frac{r_{ut}}{\phi_d R_{pt}} = \frac{r_{ut}}{454,000} \leq 1.0 \quad (\text{S.I.}) \quad (10.8-7\text{M})$$

where

r_{ut} = required collar bolt tension strength, kips (N)

$$= \frac{M_{bolts}}{n_{cf} d \sin 45^\circ} = 0.177 \frac{M_{bolts}}{d} \quad (10.8-8)$$

n_{cf} = number of collar bolts per collar flange
= 8

R_{pt} = minimum bolt pretension, kips (N)

Step 6: Compute V_{bolts} , the probable maximum shear at the collar bolts, equal to the shear at the plastic hinge, V_h , plus any additional gravity loads between the plastic hinge and center of the collar flange, using the load combination of Step 2. Confirm that V_{bolts} is less than the slip critical, Class A bolt available slip resistance in accordance with the AISC *Specification* and using a resistance factor, ϕ , of unity.

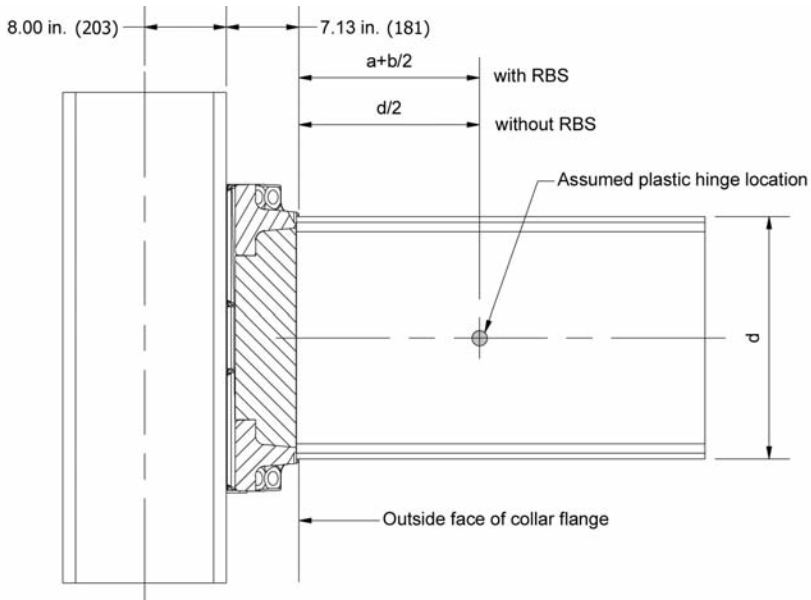


Fig. 10.9. Assumed plastic hinge location.

User Note: Note that for 1¹/₄ in. (31.8 mm) ASTM A574 bolts the value of T_b is the same as for 1¹/₄ in. (31.8 mm) ASTM A490 bolts and has a value of 102 kips (454 kN).

Step 7: Compute V_{cf} , the probable maximum shear at the face of collar flange, equal to the shear at the plastic hinge, V_h , plus any additional gravity loads between the plastic hinge and the outside face of the collar flange using the load combination of Step 2.

Check the design shear strength of the beam according to the requirements of the AISC *Specification* against V_{cf} .

Step 8: Determine required size of the fillet weld connecting the beam web to the collar web extension (CWX) using the following relationship:

$$t_f^{CWX} \geq \frac{\sqrt{2}V_{cf}}{\phi_n F_w I_w^{CWX}} \quad (10.8-9)$$

where

t_f^{CWX} = fillet weld size required to join each side of the beam web to the CWX, in. (mm)

F_w = nominal weld design strength per the AISC *Specification*
= 0.60 F_{EXX} , ksi (MPa)

I_w^{CWX} = total length of available fillet weld at CWX, in. (mm), taken as 54 in. (1370 mm) for W30 (W760) sections; 48 in. (1220 mm) for W27 (W690) sections; 42 in. (1070 mm) for W24 (W610) sections; 36 in. (914 mm) for W21 (W530) sections; and 30 in. (762 mm) for W18 (W460) sections

Step 9: Compute V_f , the probable maximum shear at the face of column, equal to the shear at the plastic hinge, V_h , plus any additional gravity loads between the plastic hinge and the face of the column using the load combination of Step 2.

Determine size of fillet weld connecting collar corner assemblies to column using the following relationship:

$$t_f^{CC} \geq \frac{\sqrt{2}V_f}{\phi_n F_w I_w^{CC}} \quad (10.8-10)$$

where

t_f^{CC} = fillet weld size required to join collar corner assembly to column, in. (mm)

I_w^{CC} = total length of available fillet weld at collar corner assembly, in. (mm), taken as 72 in. (1830 mm) for W30 (W760) sections; 66 in. (1680 mm) for W27 (W690) sections, 60 in. (1520 mm) for W24 (W610) sections; 54 in. (1370 mm) for W21 (W530) sections, and 48 in. (1220 mm) for W18 (W460) sections

Step 10: Determine the required shear strength of the column panel zone, R_p^c , using the following relationship:

$$R_u^{pz} = \frac{\sum(M_{pr} + V_h s_f)}{d} - V_{col} \quad (10.8-11)$$

where

$$\begin{aligned} V_{col} &= \text{column shear, kips (N)} \\ &= \frac{\sum(M_{pr} + V_h s_h)}{H} \end{aligned} \quad (10.8-12)$$

R_u^{pz} = required panel zone shear strength, kips (N)

$$\begin{aligned} s_f &= \text{distance from center of plastic hinge to face of column, in. (mm)} \\ &= t_{collar} + a + \frac{b}{2} \quad (\text{RBS beam}) \end{aligned} \quad (10.8-13)$$

$$= t_{collar} + \frac{d}{2} \quad (\text{non-RBS beam}) \quad (10.8-14)$$

s_h = distance from the center of plastic hinge to center of column, in. (mm), given by the equations:

$$= \frac{d_{col}}{2} + t_{collar} + a + \frac{b}{2} \quad (\text{RBS beam}) \quad (10.8-15)$$

$$= \frac{d_{col}}{2} + t_{collar} + \frac{d}{2} \quad (\text{non-RBS beam}) \quad (10.8-16)$$

$$H = \frac{H_u + H_l}{2} \quad (10.8-17)$$

d_{col} = depth of the column, in. (mm)

Step 11: Determine the nominal design panel zone shear strength, ϕR_n^{pz} , using the following relationship:

$$\phi R_n^{pz} = \phi_d 0.6 F_y A_{pz} \quad (10.8-18)$$

where

$$A_{pz} = 2d_{col}t_{col} + 4(d_{leg}^{CC}t_{leg}^{CC}) \quad (10.8-19)$$

d_{leg}^{CC} = effective depth of the collar corner assembly leg, taken as 3¹/₂ in. (89 mm)

t_{col} = wall thickness of HSS or built-up box column, in. (mm)

t_{leg}^{CC} = effective thickness of the collar corner assembly leg, taken as 1/2 in. (12 mm)

User Note: If required strength exceeds available strength the designer may increase the column section and/or decrease the beam section strength assuring that all other design criteria are met.

10.9 PART DRAWINGS

Figures 10.10 through 10.15 provide indicate the dimensions of the various components of the ConXtech ConXL moment connection.

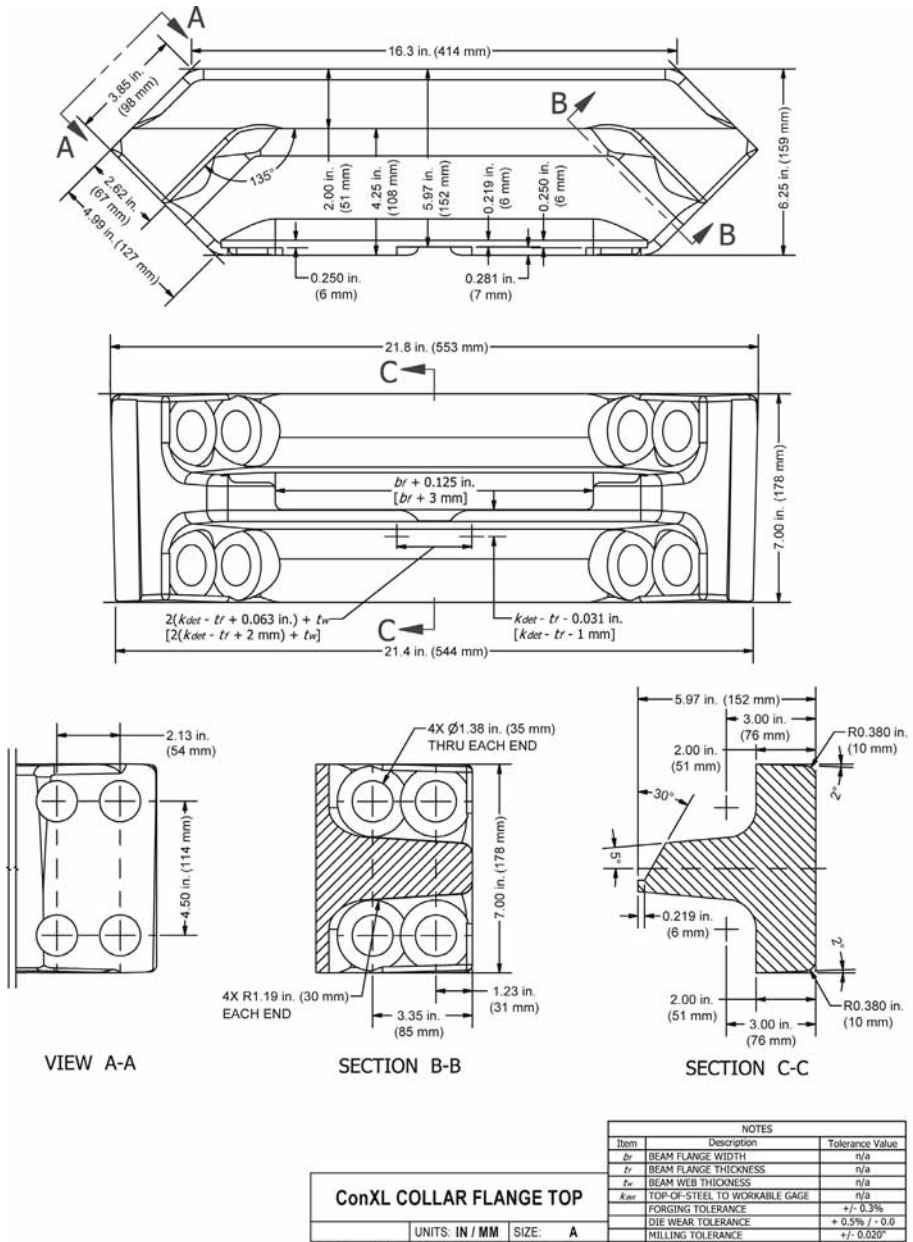


Fig. 10.10. Collar flange top (CFT).

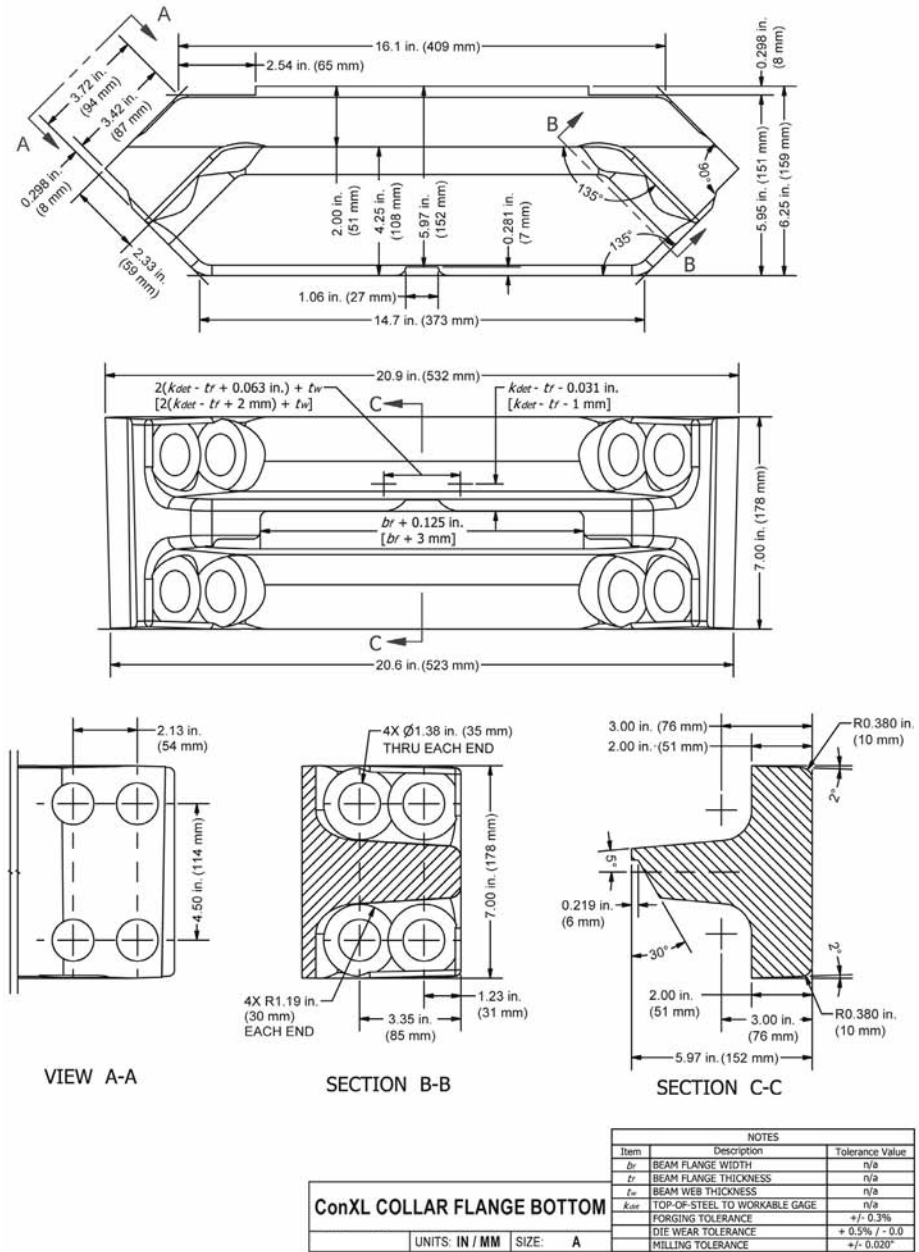
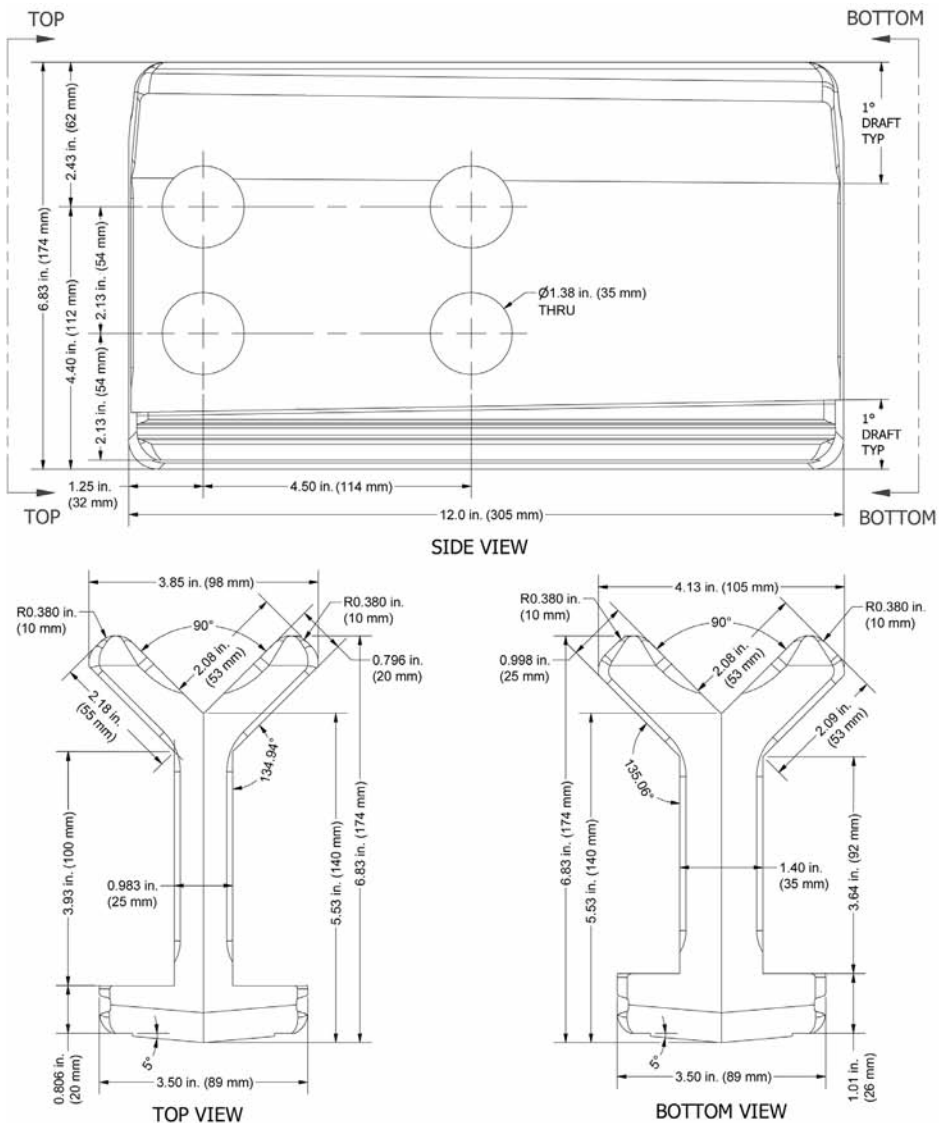
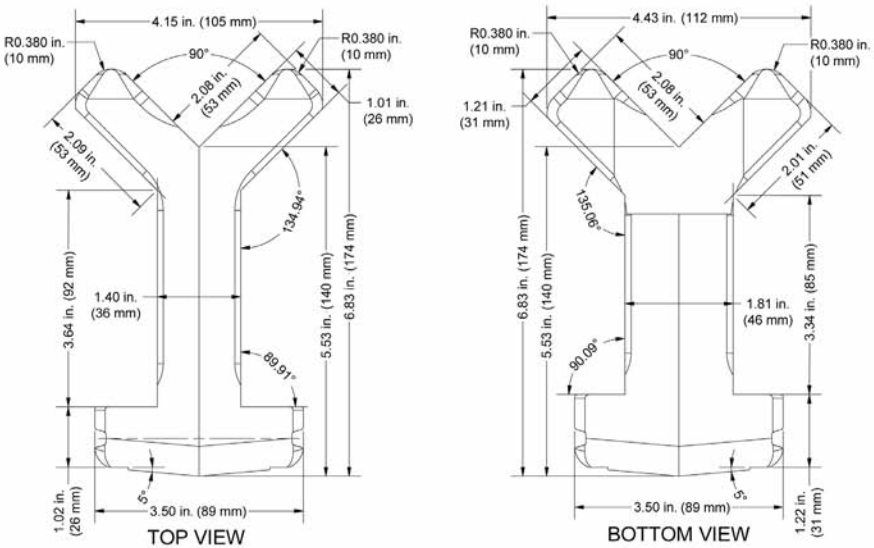
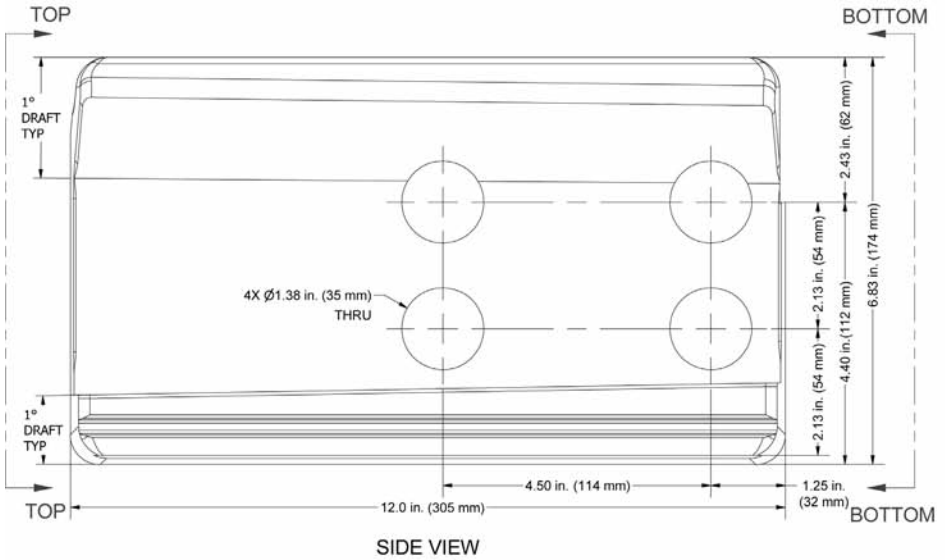


Fig. 10.11. Collar flange bottom (CFB).



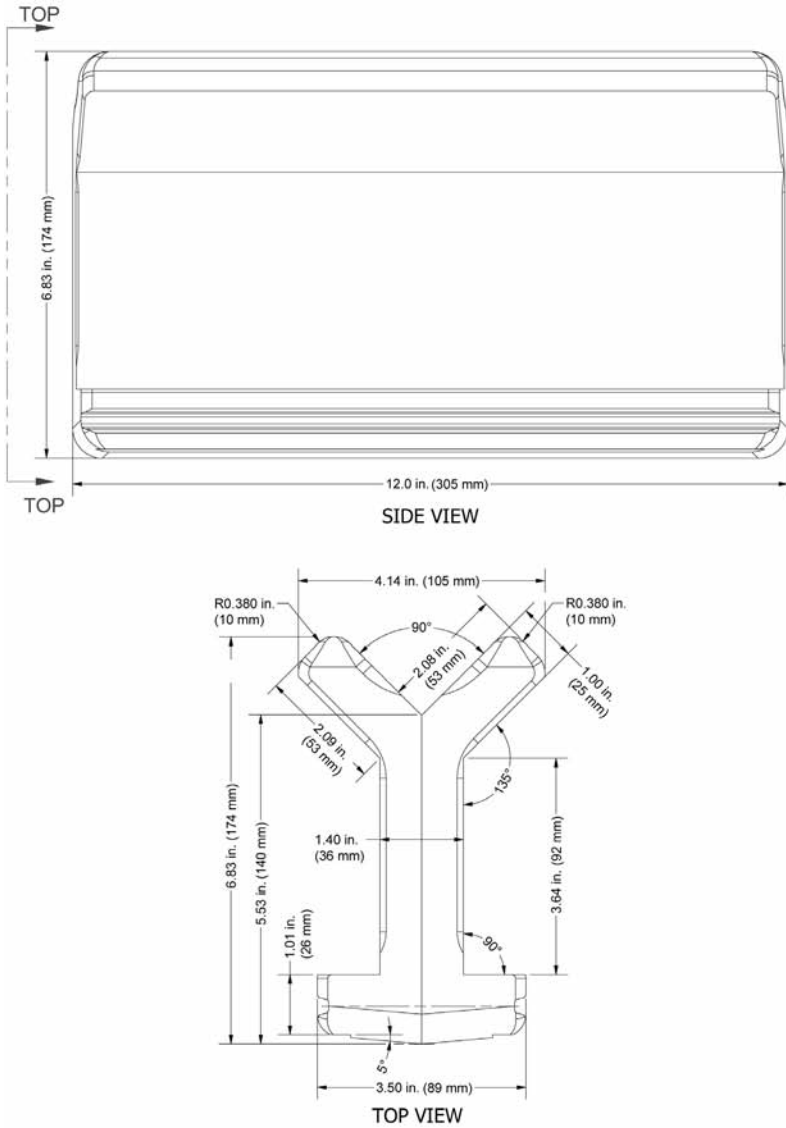
ConXL COLLAR CORNER TOP		NOTES	
		Description	Tolerance Value
UNITS: IN / MM		FORGING TOLERANCE	+/- 0.3%
SIZE: A		DIE WEAR TOLERANCE	+ 0.5% / - 0.0
		MILLING TOLERANCE	+/- 0.020"

Fig. 10.12. Collar corner top (CCT).



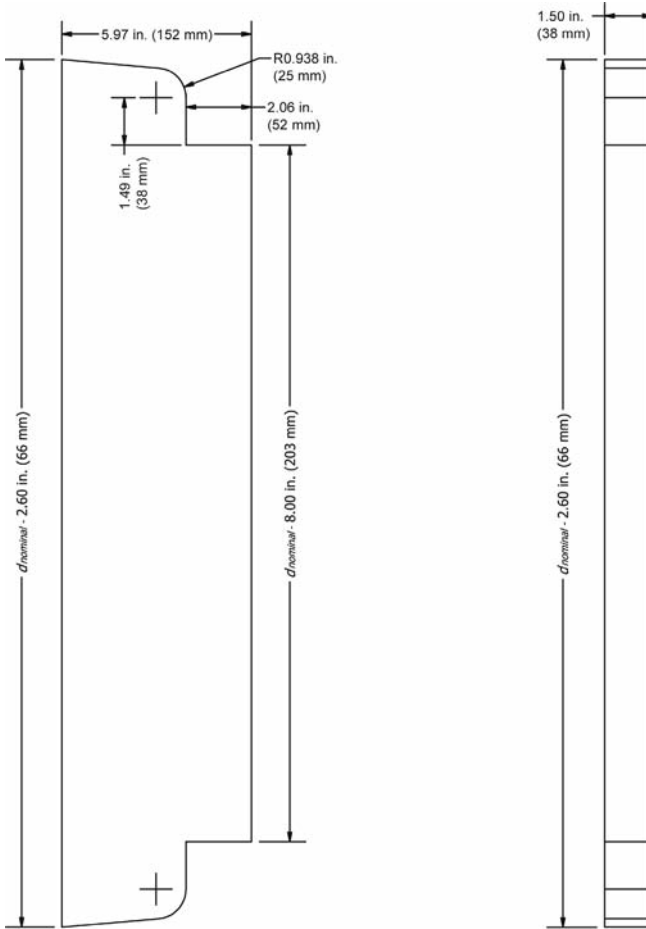
ConXL COLLAR CORNER BOTTOM		NOTES	
		Description	Tolerance Value
		FORGING TOLERANCE	± 0.3%
		DIE WEAR TOLERANCE	+ 0.5% / - 0.0
		MILLING TOLERANCE	± 0.020"
UNITS: IN / MM	SIZE: A		

Fig. 10.13. Collar corner bottom (CCB).



ConXL COLLAR CORNER MIDDLE		NOTES	
		Description	Tolerance Value
UNITS:	IN	FORGING TOLERANCE	+/- 0.3%
SIZE:	A	DIE WEAR TOLERANCE	+ 0.5% / - 0.0
		MILLING TOLERANCE	+/- 0.020"

Fig. 10.14. Collar corner middle (CCM).



ConXL COLLAR WEB EXTENSION		NOTES	
Item	Description	Tolerance Value	
d	BEAM FLANGE DEPTH	n/a	
	CUT TOLERANCE	+ 0.0 / - 0.030"	

UNITS: IN SIZE: A

Fig. 10.15. Collar web extension (CWX).

APPENDIX A

CASTING REQUIREMENTS

A1. CAST STEEL GRADE

Cast steel grade shall be in accordance with ASTM A958/A958M Grade SC8620 class 80/50.

A2. QUALITY CONTROL (QC)

1. Inspection and Nondestructive Testing Personnel

Visual inspection and nondestructive testing shall be conducted by the manufacturer in accordance with a written practice by qualified inspectors. The procedure and qualification of inspectors is the responsibility of the manufacturer. Qualification of inspectors shall be in accordance with ASNT-TC-1a or an equivalent standard. The written practice shall include provisions specifically intended to evaluate defects found in cast steel products. Qualification shall demonstrate familiarity with inspection and acceptance criteria used in evaluation of cast steel products.

2. First Article Inspection (FAI) of Castings

The first article is defined as the first production casting made from a permanently mounted and rigged pattern. FAI shall be performed on the first casting produced from each pattern. The first article casting dimensions shall be measured and recorded. FAI includes visual inspection in accordance with Section A2.3, nondestructive testing in accordance with Section A2.4, tensile testing in accordance with Section A2.6, and Charpy V-notch testing in accordance with Section A2.7.

3. Visual Inspection of Castings

Visual inspection of all casting surfaces shall be performed to confirm compliance with ASTM A802/A802M and MSS SP-55 with a surface acceptance Level I.

4. Nondestructive Testing (NDT) of Castings

4a. Procedures

Radiographic testing (RT) shall be performed by quality assurance (QA) according to the procedures prescribed in ASTM E446 and ASTM E186 with an acceptance Level III or better.

Ultrasonic testing (UT) shall be performed by QA according to the procedures prescribed by ASTM A609/A609M Procedure A with an acceptance Level 3, or better.

Magnetic particle testing (MT) shall be performed by QA according to the procedures prescribed by ASTM E709 with an acceptance Level V, or better, in accordance with ASTM A903/A903M.

4b. Required NDT

(1) First Article

RT and MT shall be performed on the first article casting.

(2) Production Castings

UT shall be performed on 100% of the castings.

MT shall be performed on 50% of the castings.

(3) Reduction of Percentage of UT

The UT rate is permitted to be reduced if approved by the engineer of record and the authority having jurisdiction. The UT rate may be reduced to 25%, provided the number of castings not conforming to Section A2.4a is demonstrated to be 5% or less. A sampling of at least 40 castings shall be made for such reduction evaluation. This reduction is not permitted for castings with weld repairs.

(4) Reduction of Percentage of MT

The MT rate is permitted to be reduced if approved by the engineer of record and the authority having jurisdiction. The MT rate may be reduced to 10%, provided the number of castings not conforming to Section A2.4a is demonstrated to be 5% or less. A sampling of at least 20 castings shall be made for such reduction evaluation. This reduction is not permitted for castings with weld repairs.

5. Weld Repair Procedures

Castings with discontinuities that exceed the requirements of Section A2.4a shall be weld repaired. Weld repair of castings shall be performed in accordance with ASTM A488/A488M. The same testing method that discovered the discontinuities shall be repeated on repaired castings to confirm the removal of all discontinuities that exceed the requirements of Section A2.4a.

6. Tensile Requirements

Tensile tests shall be performed for each heat in accordance with ASTM A370 and ASTM 781/A781M.

7. Charpy V-Notch (CVN) Requirements

CVN testing shall be performed in accordance with ASTM A370 and ASTM 781/A781M. Three notched specimens shall be tested with the first heat, and with each subsequent 20th ton (18,100 kg) of finished material. The specimens shall have a minimum CVN toughness of 20 ft-lb (27 J) at 70 °F (21 °C).

8. Casting Identification

The castings shall be clearly marked with the pattern number and a unique serial number for each individual casting providing traceability to heat and production records.

A3. MANUFACTURER DOCUMENTS

1. Submittal to Patent Holder

The following documents shall be submitted to the patent holder, prior to the initiation of production as applicable:

- (1) Material chemical composition report
- (2) First article inspection report

2. Submittal to Engineer of Record and Authority Having Jurisdiction

The following documents shall be submitted to the engineer of record and the authority having jurisdiction, prior to, or with shipment as applicable:

- (1) Production inspection and NDT reports
- (2) Tensile and CVN test reports
- (3) Weld repair reports
- (4) Letter of approval by the patent holder of the manufacturer's FAI report

APPENDIX B

FORGING REQUIREMENTS

B1. FORGED STEEL GRADE

Raw material shall conform to the requirements of ASTM A572/A572M, Gr. 50 (345). Forging process shall conform to the requirements of ASTM A788 and ASTM A668. Mechanical properties shall conform to the requirements of Table B1.1.

B2. BAR STOCK

Bar stock shall be cut to billets appropriate to the part being forged. All billets shall be marked with heat number.

B3. FORGING TEMPERATURE

Billets shall be forged at a minimum temperature of 2150 °F (1180 °C) and a maximum temperature of 2250 °F (1230 °C).

B4. HEAT TREATMENT

Immediately following impression forging, part the part being forged shall be normalized for one hour at 1650 °F (900 °C) then air cooled.

B5. FINISH

Finished forgings shall have shot blast finish, clean of mill scale.

B6. QUALITY ASSURANCE

One sample of bar stock from each heat shall be cut to a length of 6 in. (152 mm) and forged to a 5 in. by 2 in.-thick bar (127 mm by 50 mm). Samples shall be marked with longitudinal and transverse directions. Chemistry and physical properties per Table B1.1 shall be verified to ASTM A572/A572M Gr. 50 (345) for both longitudinal and transverse direction on each sample.

TABLE B1.1
Required Mechanical Properties

Yield strength	50 ksi (345 MPa) minimum
Tensile strength	65 ksi (450 MPa) minimum
Elongation in 2 in. (50 mm)	22% minimum
Reduction of area	38% minimum
Charpy V-notch toughness	20 ft-lb at 70 °F (27 J at 21 °C)

Magnetic particle testing shall be conducted on the initial 12 pieces from each run to verify tooling and forging procedures. Cracks shall not be permitted. If cracks are found, the tooling or forging procedure shall be modified and an additional 12 initial pieces shall be tested. This process shall be repeated until 12 crack-free samples are obtained prior to production.

B7. DOCUMENTATION

Laboratory test data documenting chemistry, strength, elongation, reduction of area, and Charpy requirements for the samples tested in accordance with Section B6 shall be submitted.

Inspection reports documenting satisfactory performance of magnetic particle tests per Section B6 shall be submitted.

Certification of conformance with the requirements of this Appendix shall be submitted to the purchaser.

COMMENTARY

on Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications

Including Supplement No. 1

(The Commentary is not part of ANSI/AISC 358-10, *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications*, or ANSI/AISC 358s1-11, *Supplement No. 1* to ANSI/AISC 358-10, but is included for informational purposes only.)

INTRODUCTION

The Standard is intended to be complete for normal design usage.

The Commentary furnishes background information and references for the benefit of the design professional seeking further understanding of the basis, derivations and limits of the Standard.

The Standard and Commentary are intended for use by design professionals with demonstrated engineering competence.

CHAPTER 1

GENERAL

1.1. SCOPE

Design of special moment frames (SMF) and intermediate moment frames (IMF) in accordance with the AISC *Seismic Provisions* and applicable building codes includes an implicit expectation that they will experience substantial inelastic deformations when subjected to design-level earthquake ground shaking, generally concentrated at the moment-resisting beam-to-column connections. In the 1994 Northridge earthquake, a number of steel moment frame buildings were found to have experienced brittle fractures that initiated at the welded beam flange-to-column flange joints of moment connections. These brittle fractures were unexpected and were quite different from the anticipated behavior of ductile beam flexural yielding in plastic hinge zones. Where they occurred, these brittle fractures prevented the formation of ductile plastic hinge zones and resulted in frame behavior substantially different from that upon which the design requirements for these systems were based.

Following this discovery, the Federal Emergency Management Agency (FEMA) provided funding to a coalition of universities and professional associations, known as the SAC Joint Venture. Over a period of six years, the SAC Joint Venture, with participation from AISC, AISI, AWS and other industry groups, conducted extensive research into the causes of the damage that had occurred in the Northridge earthquake and effective means of reducing the possibility of such damage in future earthquakes.

Numerous issues were identified in the SAC studies as contributing causes of these brittle fractures. This Standard specifically addresses the following four causes that were identified in the SAC study:

- (1) Connection geometries that resulted in large stress concentrations in regions of high triaxiality and limited ability to yield;
- (2) Use of weld filler metals with low inherent notch toughness and limited ductility;
- (3) High variability in the yield strengths of beams and columns resulting in unanticipated zones of weakness in connection assemblies; and
- (4) Welding practice and workmanship that fell outside the acceptable parameters of the AWS D1.1/D1.1M *Structural Welding Code* at that time.

A more complete listing of the causes of damage sustained in the Northridge earthquake may be found in a series of publications (FEMA 350, FEMA 351, FEMA 352, FEMA 353, FEMA 355C, and FEMA 355D) published in 2000 by the SAC Joint Venture that presented recommendations for design and construction of moment resisting frames designed to experience substantial inelastic deformation

during design ground shaking. These recommendations included changes to material specifications for base metals and welding filler metals, improved quality assurance procedures during construction and the use of connection geometries that had been demonstrated by testing and analysis to be capable of resisting appropriate levels of inelastic deformation without fracture. Most of these recommendations have been incorporated into the AISC *Seismic Provisions for Structural Steel Buildings* (AISC, 2010) as well as into AWS D1.8/D1.8M *Structural Welding Code—Seismic Supplement* (AWS, 2009).

Following the SAC Joint Venture recommendations, the AISC *Seismic Provisions* require that moment connections used in special or intermediate steel moment frames be demonstrated by testing to be capable of providing the necessary ductility. Two means of demonstration are acceptable. One means consists of project-specific testing in which a limited number of full-scale specimens, representing the connections to be used in a structure, are constructed and tested in accordance with a protocol prescribed in Chapter K of the AISC *Seismic Provisions*. Recognizing that it is costly and time consuming to perform such tests, the AISC *Seismic Provisions* also provide for prequalification of connections consisting of a rigorous program of testing, analytical evaluation and review by an independent body, the Connection Prequalification Review Panel (CPRP). Connections contained in this Standard have met the criteria for prequalification when applied to framing that complies with the limitations contained herein and when designed and detailed in accordance with this Standard.

1.2. REFERENCES

References for this Standard are listed at the end of the Commentary.

1.3. GENERAL

Connections prequalified under this Standard are intended to withstand inelastic deformation primarily through controlled yielding in specific behavioral modes. To obtain connections that will behave in the indicated manner, proper determination of the strength of the connection in various limit states is necessary. The strength formulations contained in the LRFD method are consistent with this approach.

CHAPTER 2

DESIGN REQUIREMENTS

2.1. SPECIAL AND INTERMEDIATE MOMENT FRAME CONNECTION TYPES

Limitations included in this Standard for various prequalified connections include specification of permissible materials for base metals, mechanical properties for weld filler metals, member shape and profile, and connection geometry, detailing and workmanship. These limitations are based on conditions, demonstrated by testing and analytical evaluation, for which reliable connection behavior can be attained. It is possible that these connections can provide reliable behavior outside these limitations; however, this has not been demonstrated. When any condition of base metal, mechanical properties, weld filler metals, member shape and profile, connection geometry, detailing or workmanship falls outside the limitations specified herein, project-specific qualification testing should be performed to demonstrate the acceptability of connection behavior under these conditions.

Limited testing of connections of wide-flange beams to the webs of I-shaped columns had been conducted prior to the Northridge earthquake by Tsai and Popov (1986, 1988). This testing demonstrated that these “minor-axis” connections were incapable of developing reliable inelastic behavior even at a time when major axis connections were thought capable of developing acceptable behavior. No significant testing of such minor axis connections following the Northridge earthquake has been conducted. Consequently, such connections are not currently prequalified under this Standard.

Similarly, although there has been only limited testing of connections in assemblies subjected to biaxial bending of the column, the judgment of the CPRP was that as long as columns are designed to remain essentially elastic and inelastic behavior is concentrated within the beams, it would be possible to obtain acceptable behavior of beam-column connection assemblies subjected to biaxial loading. Flanged cruciform section columns, built-up box columns, and boxed wide-flange columns are permitted to be used in assemblies subjected to bi-axial loading for those connections types where inelastic behavior is concentrated in the beam, rather than in the column. It should be noted that the strong column—weak beam criteria contained in AISC 341 are valid only for planar frames. When both axes of a column participate in a moment frame, columns should be evaluated for the ability to remain essentially elastic while beams framing to both column axes undergo flexural hinging.

2.3. MEMBERS

2. Built-up Members

The behavior of built-up I-shaped members has been extensively tested in bolted end-plate connections and has been demonstrated to be capable of developing the

necessary inelastic deformations. These members have not generally been tested in other prequalified connections; however, the conditions of inelastic deformation imposed on the built-up shapes in these other connection types are similar to those tested for the bolted end-plate connections.

2b. Built-up Columns

Four built-up column cross section shapes are covered by this Standard. These are illustrated in Figure C-2.1 and include:

- (1) I-shaped welded columns that resemble standard rolled wide-flange shapes in cross section shape and profile.
- (2) Cruciform W-shape columns, fabricated by splitting a wide-flange section in half and welding the webs on either side of the web of an unsplit wide-flange section at its mid-depth to form a cruciform shape, each outstanding leg of which terminates in a rectangular flange.
- (3) Box columns, fabricated by welding four plates together to form a closed box-shaped cross section.
- (4) Boxed W-shape columns constructed by adding side plates to the sides of an I-shaped cross section.

The preponderance of connection tests reviewed as the basis for prequalifications contained in this Standard consisted of rolled wide-flange beams connected to the flanges of rolled wide-flange columns. A limited number of tests of connections of wide-flange beams to built-up box section columns were also reviewed.

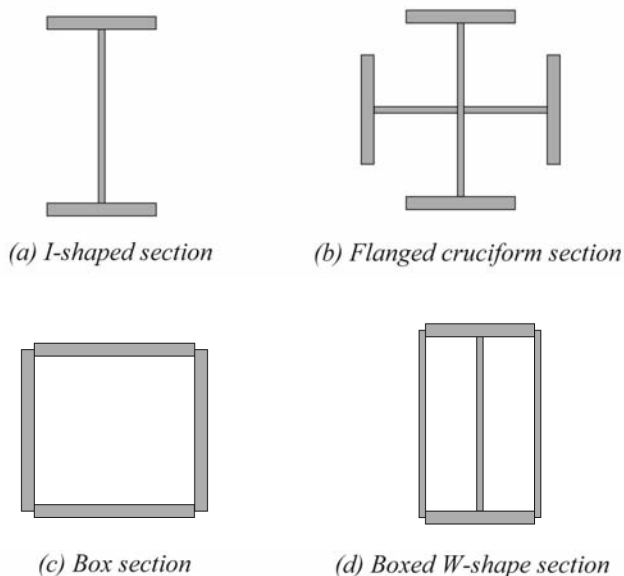


Figure C-2.1. Column shapes. Plate preparation and welds are not shown.

The flanged cruciform column and boxed wide-flange columns have not specifically been tested. However, it was the judgment of the CPRP that as long as such column sections met the limitations for I-shaped sections and box-shaped sections, respectively, and connection assemblies are designed to ensure that most inelastic behavior occurred within the beam as opposed to the column, the behavior of assemblies employing these sections would be acceptable. Therefore, prequalification has been extended to these cross sections for connection types where the predominant inelastic behavior is in the beam rather than the column.

2.4. CONNECTION DESIGN PARAMETERS

1. Resistance Factors

A significant factor considered in the formulation of resistance factors is the occurrence of various limit states. Limit states that are considered brittle (non-ductile) and subject to sudden catastrophic failure are typically assigned lower resistance factors than those that exhibit yielding (ductile) failure. Because, for the prequalified connections, design demand is determined based on conservative estimates of the material strength of weak elements of the connection assembly, and materials, workmanship and quality assurance are more rigorously controlled than for other structural elements, resistance factors have been set somewhat higher than those traditionally used. It is believed that these resistance factors, when used in combination with the design, fabrication, erection and quality-assurance requirements contained in the Standard, will provide reliable service in the prequalified connections.

2. Plastic Hinge Location

This Standard specifies the presumed location of the plastic hinge for each prequalified connection type. In reality, inelastic deformation of connection assemblies is generally distributed to some extent throughout the connection assembly. The plastic hinge locations specified herein are based on observed behavior during connection assembly tests and indicate the locations of most anticipated inelastic deformation in connection assemblies conforming to the particular prequalified type.

3. Probable Maximum Moment at Plastic Hinge

The probable plastic moment at the plastic hinge is intended to be a conservative estimate of the maximum moment likely to be developed by the connection under cyclic inelastic response. It includes consideration of likely material overstrength and strain hardening.

4. Continuity Plates

Beam flange continuity plates serve several purposes in moment connections. They help to distribute beam flange forces to the column web, they stiffen the column web to prevent local crippling under the concentrated beam-flange forces and they minimize stress concentrations that can occur in the joint between the beam flange and column due to nonuniform stiffness of the attached elements.

Almost all connection assembly testing has been conducted on specimens that include a significant length (typically one half story height) of column above and below the beam or beams framing into the column. Thus, the condition that typically exists in a structure's top story, where the column terminates at the level of the beam top flange has not specifically been tested to demonstrate acceptable detailing. A cap plate detail similar to that illustrated in Figure C-2.2 is believed to be capable of providing reliable performance when connection elements do not extend above the beam top flange. In some connections, e.g. extended end plate and Kaiser bolted bracket connections, portions of the connection assembly extend above the column top flange. In such cases, the column should be extended to a sufficient height above the beam flange to accommodate attachment and landing of those connection elements. In such cases, stiffener plates should be placed in the column web, opposite the beam top flange, as is done at intermediate framing levels.

The attachment of continuity plates to column webs is designed to be capable of transmitting the maximum shear forces that can be delivered to the continuity plate. This may be limited by the beam-flange force, the shear strength of the continuity plate itself, or the welded joint between continuity plate and column flange.

The AISC *Seismic Provisions* require that continuity plates be attached to column flanges with CJP groove welds so the strength of the beam flange can be properly developed into the continuity plate. For single-sided connections in which a moment-connected beam attaches to only one of the column flanges, it is generally not necessary to use CJP groove welds to attach the continuity plate to the column flange

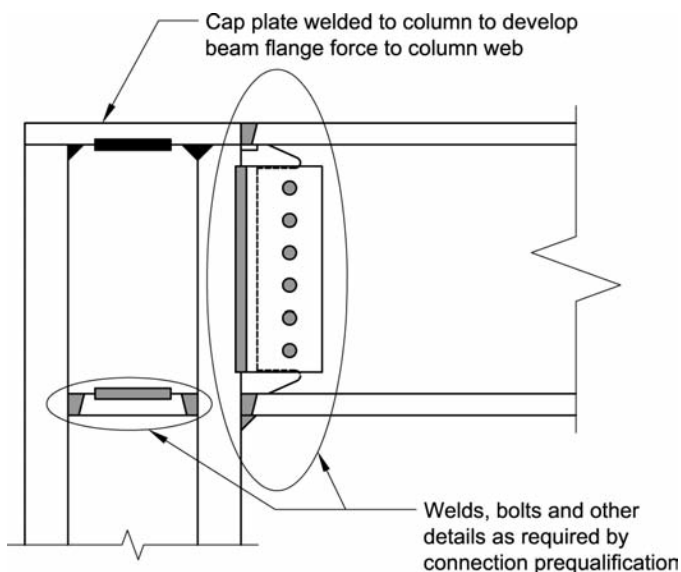


Figure C-2.2. Example cap plate detail at column top for RBS connection.

that does not have a beam attached. In such cases, acceptable performance can often be obtained by attaching the continuity plate to the column with a pair of minimum-size fillet welds.

When beams are moment connected to the side plates of boxed wide-flange column sections, continuity plates or cap plates should always be provided opposite the beam flanges, as is required for box section columns.

CHAPTER 3

WELDING REQUIREMENTS

3.3. BACKING AT BEAM-TO-COLUMN AND CONTINUITY PLATE-TO-COLUMN JOINTS

At the root of groove welds between beam flanges or continuity plates and column flanges, the inherent lack of a fusion plane between the left-in-place steel backing and the column flange creates a stress concentration and notch effect, even when the weld has uniform and sound fusion at the root. Further, when ultrasonic testing is performed, this left-in-place backing may mask significant flaws that may exist at the weld root. These flaws may create a more severe notch condition than that caused by the backing itself (Chi et al., 1997).

1. Steel Backing at Continuity Plates

The stress and strain level at the groove weld between a continuity plate and column flange is considerably different than that at the beam flange-to-column flange connection; therefore it is not necessary to remove the backing. The addition of the fillet weld beneath the backing makes the inherent notch at the interface an internal notch, rather than an external notch, reducing the notch effect. When backing is removed, the required reinforcing fillet weld reduces the stress concentration at the right-angle intersection of the continuity plate and the column flange.

2. Steel Backing at Beam Bottom Flange

The removal of backing, whether fusible or nonfusible, followed by backgouging to sound weld metal, is required so that potential root defects within the welded joint are detected and eliminated, and the stress concentration at the weld root is eliminated.

The influence of left-in-place steel backing is more severe on the bottom flange, as compared to the top flange, because at the bottom flange, the stress concentration from the backing occurs at the point of maximum applied and secondary tensile stresses in the groove weld, at the weld root, and at the outer fiber of the beam flange.

A reinforcing fillet weld with a $5/16$ -in. (8-mm) leg on the column flange helps to reduce the stress concentration at the right-angle intersection of the beam flange and column flange, and is placed at the location of maximum stress. The fillet weld's horizontal leg may need to be larger than $5/16$ in. (8 mm) to completely cover the weld root area, eliminating the potential for multiple weld toes at the root that serve as small stress concentrations and potential fracture initiation points. When grinding the weld root and base metal area, previously deposited weld toe regions and their associated fracture initiation sites are removed, and the horizontal leg of the fillet weld need not be extended to base metal.

3. Steel Backing at Beam Top Flange

Because of differences in the stress and strain conditions at the top and bottom flange connections, the stress/strain concentration and notch effect created by the backing/column interface at the top flange is at a lower level, compared to that at the bottom flange. Therefore, backing removal is not required. The addition of the reinforcing fillet weld makes the inherent notch at the interface an internal notch, rather than an external notch, further reducing the effect. Because backing removal, backgouging and backwelding would be performed through an access hole beneath the top flange, these operations should be avoided whenever possible.

4. Prohibited Welds at Steel Backing

Tack welds for beam flange-to-column connections should be made within the weld groove. Tack welds or fillet welds to the underside of beam at the backing would direct stress into the backing itself, increasing the notch effect at the backing/column flange interface. In addition, the weld toe of the tack weld or fillet weld on the beam flange would act as a stress concentration and a potential fracture initiation site.

Proper removal of these welds is necessary to remove the stress concentration and potential fracture initiation site. Any repair of gouges and notches by filling with weld metal must be made using filler metals with the required notch toughness.

5. Nonfusible Backing at Beam Flange-to-Column Joints

After nonfusible backing is removed, backgouging to sound metal removes potential root flaws within the welded joint. A reinforcing fillet weld with a $5/16$ -in. (8-mm) leg on the column flange helps reduce the stress concentration at the right-angle intersection of the beam flange and column flange.

The fillet weld's horizontal leg may need to be larger than $5/16$ in. (8 mm) to completely cover the weld root area, eliminating the potential for small stress concentrations and potential fracture initiation points. When grinding the weld root and base metal area, previously deposited weld toe regions and their associated fracture initiation sites are removed, therefore the horizontal leg of the fillet weld need not be extended to base metal.

3.4. DETAILS AND TREATMENT OF WELD TABS

Weld tabs are used to provide a location for initiation and termination of welds outside the final weld location, improving the quality of the final weld. The removal of weld tabs is performed to remove the weld discontinuities and defects that may be present at these start and stop locations. Because weld tabs are located at the ends of welds, any remaining weld defects at the weld-end removal areas may act as external notches and fracture initiation sites and are therefore removed. A smooth transition is needed between base metal and weld to minimize stress concentrations.

3.5. TACK WELDS

Tack welds outside weld joints may create unintended load paths and may create stress concentrations that become crack initiation sites when highly strained. By placing tack welds within the joint, the potential for surface notches and hard heat affected zones (HAZs) is minimized. When placed within the joint, the HAZ of a tack weld is tempered by the subsequent passes for the final weld.

Tack welds for beam flange-to-column connections are preferably made in the weld groove. Tack welds of backing to the underside of beam flanges would be unacceptable, and any tack welds between weld backing and beam flanges are to be removed in accordance with Section 3.3.4. Steel backing may be welded to the column under the beam flange, where a reinforcing fillet is typically placed.

When tack welds for the attachment of weld tabs are placed within the weld joint, they become part of the final weld.

3.6. CONTINUITY PLATES

The rotary straightening process used by steel rolling mills to straighten rolled sections cold works the webs of these shapes in and near the k -area. This cold working can result in an increase in hardness, yield strength, ultimate tensile strength, and yield-to-tensile ratio; and a decrease in notch toughness. In some instances, Charpy V-notch toughness has been recorded to be less than 2 ft-lb at 70 °F [3 J at 20 °C] (Barsom and Korvink, 1998). These changes do not negatively influence the in-service behavior of uncracked shapes. However, the potential for post-fabrication k -area base metal cracking exists in highly restrained joints at the weld terminations for column continuity plates, web doublers, and thermal cut coped beams.

When the minimum clip dimensions are used along the member web, the available continuity plate length must be considered in the design and detailing of the welds to the web. For fillet welds, the fillet weld should be held back one to two weld sizes from each clip. For groove welds, weld tabs should not be used in the k -area since they could cause base metal fracture from the combination of weld shrinkage, the stress concentration/notch effect at the weld end, and the low notch-toughness web material.

When the maximum clip dimensions are used along the member flange, the width, hence the capacity, of the continuity plate is not reduced substantially. Care must be used in making quality weld terminations near the member radius, as the use of common weld tabs is difficult. If used, their removal in this region may damage the base metal, necessitating difficult repairs. The use of cascaded ends within the weld groove may be used within the dimensional limits stated. Because of the incomplete filling of the groove, the unusual configuration of the weld, and the relatively low level of demand placed upon the weld at this location, nondestructive testing of *cascaded weld ends* in groove welds at this location are not required.

3.7. QUALITY CONTROL AND QUALITY ASSURANCE

Chapter J of the AISC *Seismic Provisions* specifies the minimum requirements for a quality assurance plan for the seismic load resisting system. It may be appropriate to supplement the Chapter J provisions with additional requirements for a particular project based on the qualifications of the contractor(s) involved and their demonstrated ability to produce quality work. Contract documents are to define the quality control (QC) and quality assurance (QA) requirements for the project.

QC includes those tasks to be performed by the contractor to ensure that their materials and workmanship meet the project's quality requirements. Routine welding QC items include personnel control, material control, preheat measurement, monitoring of welding procedures, and visual inspection.

QA includes those tasks to be performed by an agency or firm other than the contractor. QA includes monitoring of the performance of the contractor in implementing the contractor's QC program, ensuring that designated QC functions are performed properly by the contractor on a routine basis. QA may also include specific inspection tasks that are included in the contractor's QC plan, and may include nondestructive testing of completed joints.

CHAPTER 4

BOLTING REQUIREMENTS

4.1. FASTENER ASSEMBLIES

ASTM F1852 twist-off type tension-control fastener assemblies are appropriate equivalents for ASTM A325 bolts. ASTM F2280 twist-off type tension control fastener assemblies are appropriate substitutes for ASTM A490. Such assemblies are commonly produced and used, and are addressed by the RCSC *Specification* (RCSC, 2009).

4.2. INSTALLATION REQUIREMENTS

Section D2 of the AISC *Seismic Provisions* designates all bolted joints to be pretensioned joints, with the additional requirement that the joint's faying surfaces meet Class A conditions for slip-critical joints. Some connection types designate the bolted joint to be designed as slip-critical, and others waive the faying surface requirements of the AISC *Seismic Provisions*.

4.3. QUALITY CONTROL AND QUALITY ASSURANCE

See Commentary Section 3.7.

CHAPTER 5

REDUCED BEAM SECTION (RBS) MOMENT CONNECTION

5.1. GENERAL

In a reduced beam section (RBS) moment connection, portions of the beam flanges are selectively trimmed in the region adjacent to the beam-to-column connection. In an RBS connection, yielding and hinge formation are intended to occur primarily within the reduced section of the beam, and thereby limit the moment and inelastic deformation demands developed at the face of the column.

A large number of RBS connections have been tested under a variety of conditions by different investigators at institutions throughout the world. A listing of relevant research is presented in the references at the end of this document. Review of available test data indicates that RBS specimens, when designed and constructed according to the limits and procedures presented herein, have developed interstory drift angles of at least 0.04 rad under cyclic loading on a consistent basis. Tests on RBS connections show that yielding is generally concentrated within the reduced section of the beam and may extend, to a limited extent, to the face of the column. Peak strength of specimens is usually achieved at an interstory drift angle of approximately 0.02 to 0.03 rad. Specimen strength then gradually reduces due to local and lateral-torsional buckling of the beam. Ultimate failure typically occurs at interstory drift angles of approximately 0.05 to 0.07 rad, by low cycle fatigue fracture at local flange buckles within the RBS.

RBS connections have been tested using single-cantilever type specimens (one beam attached to column), and double-sided specimens (specimen consisting of a single column, with beams attached to both flanges). Tests have been conducted primarily on bare-steel specimens, although some testing is also reported on specimens with composite slabs. Tests with composite slabs have shown that the presence of the slab provides a beneficial effect by helping to maintain the stability of the beam at larger interstory drift angles.

Most RBS test specimens were tested pseudo-statically, using a loading protocol in which applied displacements are progressively increased, such as the loading protocol specified in ATC-24 (ATC, 1992) and the loading protocol developed in the FEMA/SAC program and adopted in Chapter K of the AISC *Seismic Provisions*. Two specimens were tested using a loading protocol intended to represent near-source ground motions that contain a large pulse. Several specimens were also tested dynamically. Radius-cut RBS specimens have performed well under all of these loading conditions. See Commentary Section 5.7 for a discussion of other shapes of RBS cuts.

5.2. SYSTEMS

Review of the research literature presented in the reference section at the end of this document and summarized in Commentary Section 5.1 indicates that the radius-cut RBS connection meets the prequalification requirements in Chapter K, Section K1 of the AISC *Seismic Provisions* for special and intermediate moment frames.

5.3. PREQUALIFICATION LIMITS

1. Beam Limitations

A wide range of beam sizes has been tested with the radius-cut RBS. The smallest beam size reported in the literature was a Canadian W530×82, roughly equivalent to a W21×50. The heaviest beam reported was a W36×300 (W920×446) (FEMA, 2000e), no longer produced. Although the AISC *Seismic Provisions* permit limited increases in beam depth and weight compared to the maximum sections tested, the prequalification limits for maximum beam depth and weight were established based on the test data for W36×300 (W920×446). It was the judgment of the CPRP that for the purposes of establishing initial prequalification limits, adherence to the maximum tested specimen would be appropriately conservative. There is no evidence that modest deviations from the maximum tested specimen would result in significantly different performance, and the limit on maximum flange thickness is approximately 4% thicker than the 1.68 in. (43 mm) flange in a W36×300 (W920×446).

Beam depth and beam span-to-depth ratio are significant in the inelastic behavior of beam-to-column connections. For the same induced curvature, deep beams will experience greater strains than shallower beams. Similarly, beams with shorter span-to-depth ratio will have a sharper moment gradient across the beam span, resulting in reduced length of the beam participating in plastic hinging and increased strains under inelastic rotation demands. Most of the beam-to-column assemblies that have been tested had configurations approximating beam spans of about 25 ft (7.6 m) and beam depths varying from W30 (W760) to W36 (W920) so that beam span-to-depth ratios were typically in the range of eight to ten (FEMA, 2000e). Given the degree to which most specimens significantly exceeded the minimum interstory drift demands, it was judged reasonable to set the minimum span-to-depth ratio at seven for SMF and five for IMF.

Local buckling requirements for members subjected to significant inelastic rotation are covered in the AISC *Seismic Provisions*. For the purposes of calculating the width-to-thickness ratio, it is permitted to take the flange width at the two-thirds point of the RBS cut. This provision recognizes that the plastic hinge of the beam forms within the length of the RBS cut where the width of the flange is less than at the uncut section. This provision will result in a lower width-to-thickness ratio when taken at the RBS cut compared to that at the uncut section. Many of the RBS tests conducted as a part of the FEMA/SAC program used a W30×99 (W760×147) beam that does not quite satisfy the flange width-to-thickness ratio at the uncut section.

Nevertheless, the tests were successful. For these reasons, it was judged reasonable to permit the calculation of the width-to-thickness ratio a reasonable distance into the RBS cut.

In developing this prequalification, the CPRP also reviewed lateral bracing requirements for beams with RBS connections. Some concerns were raised in the past that the presence of the RBS flange cuts might make the beam more prone to lateral-torsional buckling and that supplemental lateral bracing should be provided at the RBS. The issue of lateral bracing requirements for beams with RBS connections was subsequently investigated in both experimental and analytical studies (FEMA, 2000f; Yu et al., 2000). These studies indicated that for bare steel specimens (no composite slab), interstory drift angles of 0.04 rad can be achieved without a supplemental lateral brace at the RBS, as long as the normal lateral bracing required for beams in SMF systems is provided, per Section D1.2b of the AISC *Seismic Provisions*.

Studies also indicated that although supplemental bracing is not required at the RBS to achieve 0.04 rad interstory drift angles, the addition of a supplemental brace can result in improved performance. Tests on RBS specimens with composite slabs indicated that the presence of the slab provided a sufficient stabilizing effect that a supplemental brace at the RBS is not likely to provide significantly improved performance (FEMA, 2000f; Engelhardt, 1999; Tremblay et al., 1997). Based on the available data, beams with RBS connections that support a concrete structural slab are not required to have a supplemental brace at the RBS.

In cases where a supplemental brace is provided, the brace should not be connected within the reduced section (protected zone). Welded or bolted brace attachments in this highly strained region of the beam may serve as fracture initiation sites. Consequently, if a supplemental brace is provided, it should be located at or just beyond the end of the RBS that is farthest from the face of the column.

The protected zone is defined as shown in Figure 5.1 and extends from the face of the column to the end of the RBS farthest from the column. This definition is based on test observations that indicate yielding typically does not extend past the far end of the RBS cut.

2. Column Limitations

Nearly all tests of RBS connections have been performed with the beam flange welded to the column flange (i.e., strong-axis connections). The limited amount of weak-axis testing has shown acceptable performance. In the absence of more tests, the CPRP recommended limiting prequalification to strong-axis connections only.

The majority of RBS specimens were constructed with W14 (W360) columns. However, a number of tests have also been conducted using deeper columns, including W18, W27 and W36 (W460, W690 and W920) columns. Testing of deep-column RBS specimens under the FEMA/SAC program indicated that stability problems may occur when RBS connections are used with deep columns (FEMA, 2000f). In FEMA 350 (FEMA, 2000b), RBS connections were only prequalified for W12 (W310) and W14 (W360) columns.

The specimens in the FEMA/SAC tests conducted showed a considerable amount of column twisting (Gilton et al., 2000). However, two of the three specimens tested achieved 0.04-rad rotation, albeit with considerable strength degradation. The third specimen just fell short of 0.04-rad rotation and failed by fracture of the column web near the k -area. Subsequent study attributed this fracture to column twisting.

Subsequent to the FEMA/SAC tests, an analytical study (Shen et al., 2002) concluded that boundary conditions used in these tests may not be representative of what would be found in an actual building. Consequently, the large-column twisting (and presumably resultant k -area column fracture) seen in the FEMA/SAC tests would not be expected in real buildings. The study also concluded that deep columns should not behave substantially different from W14 (W360) columns and that no special bracing is needed when a slab is present. This was followed by a more extensive analytical and large-scale experimental investigation on RBS connections with columns up to W36 (W920) in depth (Ricles et al., 2004). This investigation showed that good performance can be achieved with deep columns when a composite slab is present or when adequate lateral bracing is provided for the beam and/or column in the absence of a slab. Based on a review of this recent research, the prequalification of RBS connections is extended herein to include W36 (W920) columns.

The behavior of RBS connections with cruciform columns is expected to be similar to that of a rolled wide-flange column because the beam flange frames into the column flange, the principal panel zone is oriented parallel to that of the beam and the web of the cut wide-flange column is to be welded with a CJP groove weld to the continuous web one foot above and below the depth of the frame girder. Given these similarities and the lack of evidence suggesting behavioral limit states different from those associated with rolled wide-flange shape, cruciform column depths are limited to those imposed on wide-flange shapes.

Successful tests have also been conducted on RBS connections with built-up box columns. The largest box column for which test data was available was 24 in. by 24 in. (610 mm by 610 mm). Consequently, RBS connections have been prequalified for use with built-up box columns up to 24 in. (610 mm). Limits on the width-to-thickness ratios for the walls of built-up box columns are specified in Section 2.3.2b(3) and were chosen to reasonably match the box columns that have been tested.

The use of box columns participating in orthogonal moment frames, that is, with RBS connections provided on orthogonal beams, is also prequalified. Although no data were available for test specimens with orthogonal beams, this condition should provide ostensibly the same performance as single-plane connections, since the RBS does not rely on panel zone yielding for good performance, and the column is expected to remain essentially elastic for the case of orthogonal connections.

Based on successful tests on wide-flange columns and on built-up box columns, boxed wide-flange columns would also be expected to provide acceptable performance. Consequently, RBS connections are prequalified for use with boxed wide-flange columns. When moment connections are made only to the flanges of the wide-flange portion of the boxed wide-flange, the column may be up to W36 in

depth. When the boxed wide-flange column participates in orthogonal moment frames, then neither the depth nor the width of the column is allowed to exceed 24 in. (610 mm), applying the same limits as for built-up boxes.

5.4. COLUMN-BEAM RELATIONSHIP LIMITATIONS

Column panel zone strength provided on RBS test specimens has varied over a wide range. This includes specimens with very strong panel zones (no yielding in the panel zone), specimens with very weak panel zones (essentially all yielding in the panel zone and no yielding in the beam), and specimens where yielding has been shared between the panel zone and the beam. Good performance has been achieved for all levels of panel zone strength (FEMA, 2000f), including panel zones that are substantially weaker than permitted in Section E3.6e of the AISC *Seismic Provisions*. However, there are concerns that very weak panel zones may promote fracture in the vicinity of the beam-flange groove welds due to “kinking” of the column flanges at the boundaries of the panel zone. Consequently, the minimum panel zone strength specified in Section E3.6e of the AISC *Seismic Provisions* is required for prequalified RBS connections.

5.5. BEAM FLANGE-TO-COLUMN FLANGE WELD LIMITATIONS

Complete-joint-penetration groove welds joining the beam flanges to the column flanges provided on the majority of RBS test specimens have been made by the self-shielded flux cored arc welding process (FCAW-S) using electrodes with a minimum specified Charpy V-notch toughness. Three different electrode designations have commonly been used in these tests: E71T-8, E70TG-K2 and E70T-6. Further, for most specimens, the bottom flange backing was removed and a reinforcing fillet added, top flange backing was fillet welded to the column, and weld tabs were removed at both the top and bottom flanges.

Test specimens have employed a range of weld access-hole geometries, and results suggest that connection performance is not highly sensitive to the weld access-hole geometry. Consequently, prequalified RBS connections do not require specific access-hole geometry. Weld access holes should satisfy the requirements of Section 6.10 of AWS D1.8/D1.8M (AWS, 2009). The alternative geometry for weld access holes specified in Section 6.10.1.2 of AWS D1.8/D1.8M is not required for RBS connections.

5.6. BEAM WEB-TO-COLUMN CONNECTION LIMITATIONS

Two types of web connection details have been used for radius-cut RBS test specimens: a welded and a bolted detail. In the welded detail, the beam web is welded directly to the column flange using a complete-joint-penetration groove weld. For the bolted detail, pretensioned high-strength bolts are used. Specimens with both types of web connections have achieved at least 0.04-rad interstory drift angles, and consequently both types of web connection details were permitted for RBS connections in FEMA 350 (2000b).

Previous test data (Engelhardt et al., 2000) indicate that beyond an interstory drift angle of 0.04 rad, specimens with bolted web connections show a higher incidence of fracture occurring near the beam-flange groove welds, as compared to specimens with welded web connections. Thus, while satisfactory performance is possible with a bolted web connection, previous test data indicate that a welded web is beneficial in reducing the vulnerability of RBS connections to fracture at the beam-flange groove welds.

Subsequent to the SAC/FEMA testing on RBS connections, a test program (Lee et al., 2004) was conducted that directly compared nominally identical RBS connections except for the web connection detail. The RBS specimens with welded web connections achieved 0.04-rad interstory drift angle, whereas RBS specimens with bolted web connections failed to achieve 0.04 rad.

Thus, while past successful tests have been conducted on RBS connections with bolted web connections, recent data has provided contradictory evidence, suggesting bolted web connections may not be suitable for RBS connections when used for SMF applications. Until further data is available, a welded web connection is required for RBS connections prequalified for use in SMF. For IMF applications, bolted web connections are acceptable.

The beam web-to-plate CJP groove weld is intended to extend the full distance between the weld access holes to minimize the potential for crack-initiation at the ends of the welds, hence the requirement for the plate to extend from one weld access hole to the other. All specimens were tested with the full-depth weld configuration.

5.7. FABRICATION OF FLANGE CUTS

Various shapes of flange cutouts are possible for RBS connections, including a constant cut, a tapered cut, and a radius cut. Experimental work has included successful tests on all of these types of RBS cuts. The radius cut avoids abrupt changes of cross section, reducing the chances of a premature fracture occurring within the reduced section. Further, the majority of tests reported in the literature used radius-cut RBS sections. Consequently, only the radius-cut RBS shape is prequalified.

An issue in the fabrication of RBS connections is the required surface finish and smoothness of the RBS flange cuts. No research data was found that specifically addressed this issue. Consequently, finish requirements for RBS cuts were chosen by the CPRP based on judgment and are consistent with those specified in FEMA 350 (2000b).

5.8. DESIGN PROCEDURE

Dimensions of the RBS cuts for the test specimens reported in the literature vary over a fairly small range. The distance from the face of the column to the start of the RBS radius cut (designated as a in Figure 5.1) ranged from 50 to 75% of the beam-flange width. The length of the cuts (designated as b in Figure 5.1) varied from

approximately 75 to 85% of the beam depth. The amount of flange width removed at the minimum section of the RBS varied from about 38 to 55%. Flange removal for prequalified RBS connections is limited to a maximum of 50%, to avoid excessive loss of strength or stiffness.

The design procedure presented herein for prequalified RBS connections is similar to that presented in FEMA 350 (2000b). The overall basis for sizing the RBS radius cut in this design procedure is to limit the maximum beam moment that can develop at the face of the column to the actual plastic moment (based on expected yield stress) of the beam when the minimum section of the RBS is fully yielded and strain hardened. Test data indicate that connecting the beam at the face of the column in accordance with the requirements herein allows the connection to resist this level of moment while minimizing the chance of fracture at the beam-flange groove welds.

Step 4 of the design procedure requires computation of the shear force at the center of the RBS radius cut. This shear force is a function of the gravity load on the beam

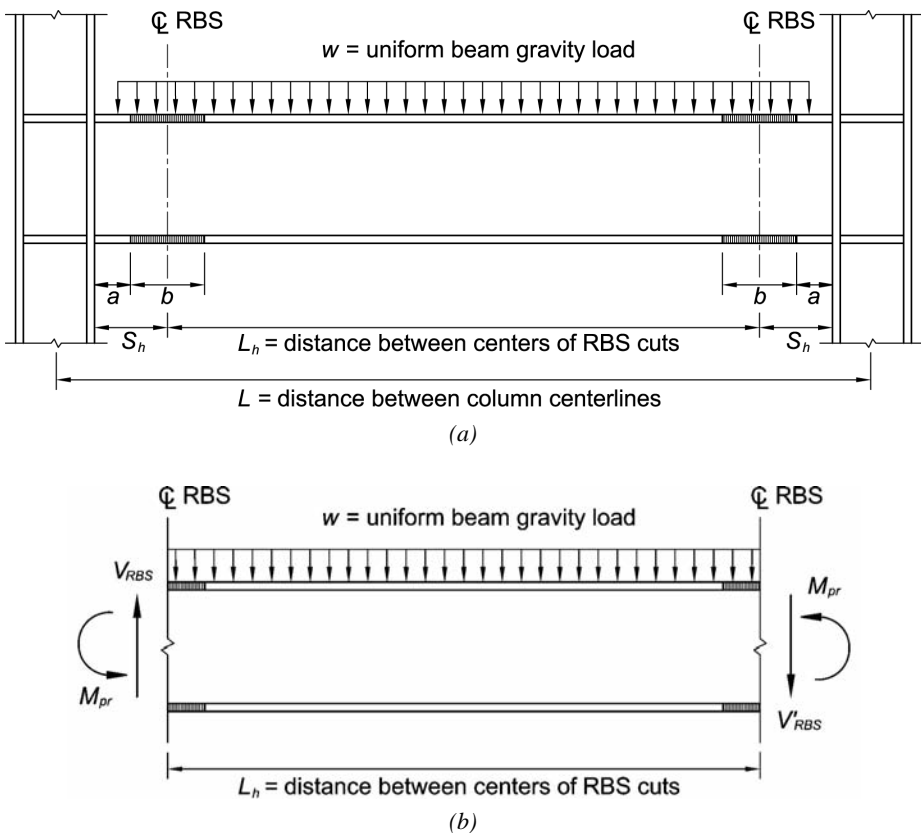


Figure C-5.1. Example calculation of shear at center of RBS cuts.

(a) Beam with RBS cuts and uniform gravity load;

(b) Free-body diagram of beam between RBS cuts and calculation of shear at RBS.

and the plastic moment capacity of the RBS. An example calculation is shown in Figure C-5.1 for the case of a beam with a uniformly distributed gravity load.

For gravity load conditions other than a uniform load, the appropriate adjustment should be made to the free-body diagram in Figure C-5.1 and to Equations C-5.8-1 and C-5.8-2.

$$V_{RBS} = \frac{2M_{pr}}{L_h} + \frac{wL_h}{2} \quad (\text{C-5.8-1})$$

$$V'_{RBS} = \frac{2M_{pr}}{L_h} - \frac{wL_h}{2} \quad (\text{C-5.8-2})$$

Equations C-5.8-1 and C-5.8-2 assume that plastic hinges will form at the RBS at each end of the beam. If the gravity load on the beam is very large, the plastic hinge at one end of the beam may move toward the interior portion of the beam span. If this is the case, the free-body diagram in Figure C-5.1 should be modified to extend between the actual plastic hinge locations. To determine whether Equations C-5.8-1 and C-5.8-2 are valid, the moment diagram for the segment of the beam shown in Figure C-5.1(b)—that is, for the segment of the beam between the centers of the RBS cuts—is drawn. If the maximum moment occurs at the ends of the span, then Equations C-5.8-1 and C-5.8-2 are valid. If the maximum moment occurs within the span and exceeds M_{pe} of the beam (see Equation 5.8-7), then the modification described above will be needed.

CHAPTER 6

BOLTED UNSTIFFENED AND STIFFENED EXTENDED END-PLATE MOMENT CONNECTIONS

6.1. GENERAL

The three extended end-plate moment configurations currently addressed in this chapter are the most commonly used end-plate connection configurations in steel moment frames. AISC Design Guide 4, *Extended End-Plate Moment Connections, Seismic and Wind Applications* (Murray and Sumner, 2003) provides background, design procedures, and complete design examples for the three configurations. The guide was developed before this Standard was written, and there are small differences between the design procedures in the guide and in Commentary Section 6.10. The primary differences are in the resistances factors. The Standard supersedes the design guide in all instances.

Prequalification test results for the three extended end-plate moment connections are found in FEMA (1997); Meng (1996); Meng and Murray (1997); Ryan and Murray (1999); Sumner et al. (2000a); Sumner et al. (2000b); Sumner and Murray (2001); and Sumner and Murray (2002). Results of similar testing but not used for prequalification are found in Adey et al. (1997); Adey et al. (1998); Adey et al. (2000); Castellani et al. (1998); Coons (1999); Ghobarah et al. (1990); Ghobarah et al. (1992); Johnstone and Walpole (1981); Korol et al. (1990); Popov and Tsai (1989); and Tsai and Popov (1990).

The intent of the design procedure in Section 6.10 is to provide an end-plate moment connection with sufficient strength to develop the strength of the connected flexural member. The connection does not provide any contribution to inelastic rotation. All inelastic deformation for an end-plate connection is achieved by beam yielding and/or column panel zone deformation.

The design procedure in Section 6.10 is based on Borgsmiller and Murray (1995) and is similar to the “thick plate” procedure in AISC Design Guide 16 (Murray and Shoemaker, 2002). The procedure is basically the same as that in FEMA 350 (2000b), but with much clarification. Applicable provisions in FEMA 353 (2000d) are incorporated into the procedure as well.

6.2. SYSTEMS

The three extended end-plate moment connections in Figure 6.1 are prequalified for use in IMF and SMF systems, except in SMF systems where the beam is in direct contact with concrete structural slabs. The exception applies only when shear studs are used to attach the concrete slab to the connected beam and is because of the lack

of test data to date. Prequalification testing has generally been performed with bare steel specimens. Sumner and Murray (2002) performed one test in which a slab was present. In this test, headed studs were installed from near the end-plate moment connection to the end of the beam, and the concrete was in contact with the column flanges and web. The lower bolts failed prematurely by tension rupture because of the increase in the distance from the neutral axis due to the presence of the composite slab. In later testing, Murray repeated this test but placed a flexible material between the vertical face of the end plate and the slab to inhibit slab participation in transfer of load to the column. This specimen performed acceptably and resulted in provisions for using concrete structural slabs when such flexible material is placed between the slab and the plate.

6.3. PREQUALIFICATION LIMITS

The parametric limitations in Table 6.1 were determined from reported test data in the prequalification references. Only connections that are within these limits are prequalified.

Beams may be either hot-rolled or built-up. If built-up sections are used, the web-to-flange weld may be a one-sided fillet weld, except within the beam, depth, or three times the flange width of the face of the end-plate. Within this length, fillet welds on both sides are required of a size at least $\frac{1}{4}$ in. (6 mm) for constructability or 0.75 times the beam-flange web thickness to develop the web material, whichever is greater. Complete-joint-penetration (CJP) groove welds may be used in lieu of fillet welds.

For tapered members, the depth of the beam at the connection is used to determine the limiting span-to-depth ratio.

6.4. BEAM LIMITATIONS

The beam size limitations in Table 6.1 are directly related to connection testing. Since many of the tested beam sections were built-up members, the limitations are in cross section dimensions instead of rolled-beam designations. There is no evidence that modest deviations from these dimensions will result in significantly different performance.

Similar to RBS testing, most of the tested beam-column assemblies had configurations approximating beam span-to-depth ratios in the range of eight to ten. However, it was judged reasonable to set the minimum span-to-depth ratio at 7 for SMF and 5 for IMF.

The protected zone is based on test observations.

6.5. COLUMN LIMITATIONS

Extended end-plate moment connections may be used only with rolled or built-up I-shaped sections and must be flange connected. There are no other specific column requirements for extended end-plate moment connections.

6.6. COLUMN-BEAM RELATIONSHIP LIMITATIONS

There are no specific column-to-beam relationship limitations for extended end-plate moment connections.

6.7. CONTINUITY PLATES

Continuity plate design must conform to the requirements of Section 2.4.4. The design procedure in Section 6.10 contains provisions specific to extended end-plate moment connections, and the procedure is discussed generally in AISC Design Guide 13, *Wide-Flange Column Stiffening at Moment Connections* (Carter, 1999).

6.8. BOLTS

Prequalification tests have been conducted with both pretensioned ASTM A325 and A490 bolts. Bolt length should be such that at least two complete threads are between the unthreaded portion of the shank and the face of the nut after the bolt is pretensioned. Slip-critical connection provisions are not required for end-plate moment connections.

6.9. CONNECTION DETAILING

Maximum gage, that is, the horizontal distance between outer bolt columns, is limited to the width of the beam flange to ensure a stiff load path. Monotonic tests have shown that the stiffness and strength of an end-plate moment connection are decreased when the bolt gage is wider than the beam flange.

Inner bolt pitch, the distance between the face of the beam flange and the first row of inside or outside bolts, must be sufficient to allow bolt tightening. The minimum pitch values specified have been found to be satisfactory. An increase in pitch distance can significantly increase the required end-plate thickness.

The end-plate can be wider than the beam flange, but the width used in design calculations is limited to the beam flange width plus 1 in. (25 mm). This limitation is based on the CPRP's assessment of unpublished results of monotonic tests of end-plate connections.

The requirements for the length of beam-flange-to-end-plate stiffeners are established to ensure a smooth load path. The 30° angle is the same as used for determining the Whitmore section width in other types of connections. The required 1-in. (25-mm) land is needed to ensure the quality of the vertical and horizontal weld terminations.

Tests have shown that the use of finger shims between the end-plate and the column flange do not affect the performance of the connection (Sumner et al., 2000a).

Design procedures are not available for connections of beams with composite action at an extended end-plate moment connection. Therefore, careful composite slab detailing is necessary to prevent composite action that may increase tension forces in the lower bolts. Welded steel stud anchors are not permitted within 1½ times the

beam depth, and compressible material is required between the concrete slab and the column face (Sumner and Murray, 2002; Yang et al., 2003).

Cyclic testing has shown that use of weld access holes can cause premature fracture of the beam flange at extended end-plate moment connections (Meng and Murray, 1997). Short to long weld access holes were investigated with similar results. Therefore, weld access holes are not permitted for extended end-plate moment connections.

Strain gage measurements have shown that the web plate material in the vicinity of the inside tension bolts generally reaches the yield strain (Murray and Kukreti, 1988). Consequently, it is required that the web-to-end-plate weld(s) in the vicinity of the inside bolts be sufficient to develop the strength of the beam web.

The beam-flange-to-end-plate and stiffener weld requirements equal or exceed the welding that was used to prequalify the three extended end-plate moment connections. Because weld access holes are not permitted, the beam-flange-to-end plate weld at the beam web is necessarily a partial-joint-penetration (PJP) groove weld. The prequalification testing has shown that these conditions are not detrimental to the performance of the connection.

6.10. DESIGN PROCEDURE

The design procedure in this section, with some modification, was used to design the prequalification test specimens. The procedure is very similar to that in the AISC Design Guide 4 (Murray and Sumner, 2003) except that different resistance factors are used. Example calculations are found in the design guide. Column stiffening example calculations are found in AISC Design Guide 13 (Carter, 1999).

CHAPTER 7

BOLTED FLANGE PLATE (BFP) MOMENT CONNECTION

7.1. GENERAL

The bolted flange plate (BFP) connection is a field-bolted connection. The fundamental seismic behaviors expected with the BFP moment connection include:

- (1) initial yielding of the beam at the last bolt away from the face of the column
- (2) slip of the flange plate bolts, which occurs at similar resistance levels to the initial yielding in the beam flange, but the slip does not contribute greatly to the total deformation capacity of the connection
- (3) secondary yielding in the column panel zone, which occurs as the expected moment capacity and strain hardening occur
- (4) limited yielding of the flange plate, which may occur at the maximum deformations

This sequence of yielding has resulted in very large inelastic deformation capacity for the BFP moment connection, but the design procedure is somewhat more complex than some other prequalified connections.

The flange plates and web shear plate are shop-welded to the column flange and field-bolted to the beam flanges and web, respectively. ASTM A490 or A490M bolts with threads excluded from the shear plane are used for the beam flange connections because the higher shear strength of the A490 or A490M bolts reduces the number of bolts required and reduces the length of the flange plate. The shorter flange plates that are therefore possible reduce the seismic inelastic deformation demands on the connection and simplify the balance of the resistances required for different failure modes in the design procedure. Flange plate connections with A325 or A325M bolts may be possible, but will be more difficult to accomplish because of the reduced bolt strength, greater number of bolts, and longer flange plates required. As a result, the connection is not prequalified for use with A325 or A325M bolts.

Prequalification of the BFP moment connection is based upon 20 BFP moment connection tests under cyclic inelastic deformation (FEMA, 2000e; Schneider and Teeraparbwong, 1999; Sato, Newall and Uang, 2008). Additional evidence supporting prequalification is derived from bolted T-stub connection tests (FEMA, 2000e; Swanson et al., 2000), since the BFP moment connection shares many yield mechanisms, failure modes, and connection behaviors with the bolted T-stub connection. The tests were performed under several deformation-controlled test protocols, but most use variations of the ATC-24 (ATC, 1992) or the SAC steel protocol (Krawinkler et al., 2000), which are both very similar to the prequalification test protocol of Chapter K of the AISC *Seismic Provisions* (AISC 2010a). The 20

BFP tests were performed on connections with beams ranging in depth from W8 (W200) to W36 (W920) sections, and the average total demonstrated ductility capacity exceeded 0.057 rad. Hence, the inelastic deformation capacity achieved with BFP moment connections is among the best achieved from seismic testing of moment frame connections. However, the design of the connection is relatively complex because numerous yield mechanisms and failure modes must be considered in the design process. Initial and primary yielding in the BFP moment connection is flexural yielding of the beam near the last row of bolts at the end of the flange plate. However, specimens with the greatest ductility achieve secondary yielding through shear yielding of the column panel zone and limited tensile yielding of the flange plate. Hence, a balanced design that achieves yielding from multiple yield mechanisms is encouraged.

Most past tests have been conducted on specimens with single-sided connections, and the force-deflection behavior is somewhat pinched as shown in Figure C-7.1. Because plastic hinging at the end of the flange plate is the controlling yield mechanism, the expected plastic moment at this location dominates the connection design. The pinching is caused by a combination of bolt slip and the sequence of yielding and strain hardening encountered in the connection. Experiments have shown that the expected peak moment capacity at the plastic hinge is typically on the order of 1.15 times the expected M_p of the beam, as defined in the AISC *Seismic Provisions*, and the expected moment at the face of the column is on the order of 1.3 to 1.5 times the expected M_p of the beam depending upon the span length, number of bolts, and length of the flange plate. The stiffness of this connection is usually slightly greater than 90% of that anticipated with a truly rigid, fully restrained (FR) connection. This reduced stiffness is expected to result in elastic deflection no more than 10% larger than computed with an FR connection, and so elastic calculations with rigid connections are considered to be adequate for most practical design purposes.

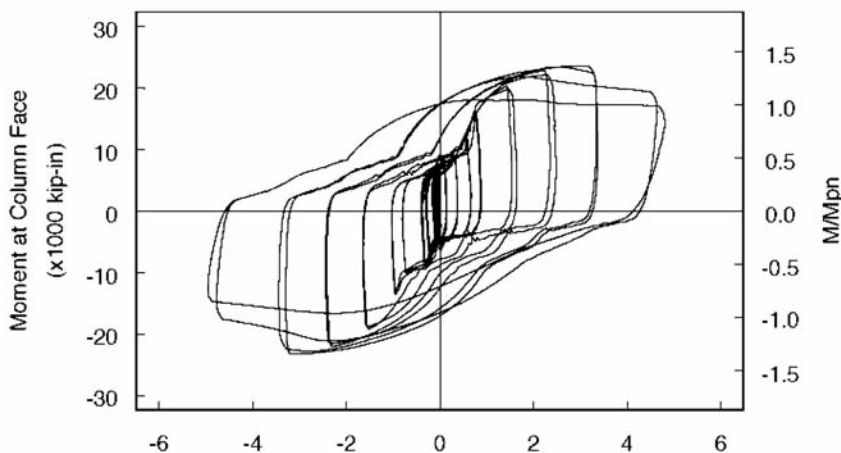


Fig. C-7.1. Moment at face of column vs. total connection rotation for a BFP moment connection with a W30×108 (W760×161) beam and a W14×233 (W360×347) column.

7.2. SYSTEMS

Review of the research literature shows that BFP moment connections meet the qualifications and requirements of both SMF and IMF frames. However, no test data are available for BFP moment connections with composite slabs, and so the BFP moment connection is not prequalified with reinforced concrete structural slabs that contact the face of the columns. Reinforced concrete structural slabs that make contact with the column may:

- significantly increase the moment at the face of the column;
- cause significant increases of the force and strain demands in the bottom flange plate; and
- result in reduced inelastic deformation capacity of the connection.

Therefore, prequalification of the BFP moment connection is restricted to the case where the concrete structural slab has a minimum separation or isolation from the column. In general, isolation is achieved if steel stud anchors are not included in the protected zone and if the slab is separated from all surfaces of the column by an open gap or by use of compressible foam-like material.

7.3. PREQUALIFICATION LIMITS

1. Beam Limitations

The SMF prequalification limits largely reflect the range of past testing of the BFP moment connection. Limits for IMF connections somewhat exceed these limits because 18 of the past 20 tests used to prequalify the connection developed plastic rotations larger than those required to qualify as a SMF connection, and all 20 tests greatly exceed the rotation required to qualify as an IMF connection.

BFP moment connections have been tested with beams as large as the W36×150 (W920×223) while achieving the ductility required for qualification as an SMF. Consequently, the W36 (W920) beam depth, 150 lb/ft weight limit (223 kg/m mass limit), and 1 in. (25 mm) flange thickness limits are adopted in this provision. Past tests have shown adequate inelastic rotation capacity to qualify as an SMF in tests with span-to-depth ratios less than 5 and greater than 16, and so lower bound span-to-depth ratio limits of 7 and 9 are conservatively adopted for the IMF and SMF applications, respectively. Inelastic deformation is expected for approximately one beam depth beyond the end of the flange plate, and limited yielding is expected in the flange plate. As a result, the protected zone extends from the column face to a distance equal to the depth of the beam beyond the bolt farthest from the face of the column.

Primary plastic hinging of the BFP moment connection occurs well away from the face of the column, and lateral-torsional deformation will occur as extensive yielding develops in the connection. As a result, lateral bracing of the beam is required at the end of the protected zone. The bracing is required within the interval between 1 and 1.5 beam depths beyond the flange bolts farthest from the face of the column. This permits some variation in the placement of the lateral support to allow economical

use of transverse framing for lateral support where possible. As with other moment frame connections, supplemental lateral bracing at the column flange connection can typically be accommodated by the stiffness of the diaphragm and transverse framing.

As for other prequalified connections, the BFP moment connection requires compact flanges and webs as defined by the AISC *Seismic Provisions*, and built-up I-shaped beams conforming to Section 2.3 are permitted. It should be noted, however, that the BFP and most other prequalified connections do not have specific seismic test data to document the prequalification of built-up beam sections. This prequalification is provided, because long experience shows that built-up steel sections provide similar flexural behavior as hot-rolled shapes with comparable materials and proportions.

2. Column Limitations

BFP moment connections have been tested with wide flange columns up to W14×233 (W360×347) sections. The SMF prequalification limits largely reflect the range of past testing of the BFP moment connection. All 20 tests were completed with strong axis bending of the column, and the prequalification of the BFP moment connections is limited to connections made to the column flange.

As with most other prequalified connections, the BFP moment connection has not been tested with columns deeper than W14 (W360) sections or with built-up column sections. It was the judgment of the CPRP that the BFP moment connection places similar or perhaps smaller demands on the column than other prequalified connections. The demands may be smaller because of the somewhat smaller strain-hardening moment increase achieved with the BFP moment connection as compared to the welded web-welded flange and other FR connections. The location of yielding of the BFP moment connection is somewhat analogous to the RBS connection, and therefore, prequalification limits for the column are comparable to those used for the RBS connection.

7.4. COLUMN-BEAM RELATIONSHIP LIMITATIONS

The BFP moment connection is expected to sustain primary yielding in the beam starting at the last flange plate bolt line away from the face of the column. Secondary yielding is expected in the column panel zone and very limited subsequent yielding is expected in the flange plate. Yielding in the column outside the connection panel zone is strongly discouraged. Therefore, the BFP moment connection employs a similar weak beam-strong column check and panel zone resistance check as used for other prequalified connections.

7.5. CONNECTION DETAILING

The BFP moment connection requires plate steel for the flange plate, shear plate, and possibly panel zone doubler plates. Past tests have been performed with plates fabricated both from ASTM A36/A36M and A572/A572M Grade 50 (Grade 345) steels. Therefore, the prequalification extends to both plate types. The designer should be aware of potential pitfalls with the material selection for the flange plate design. The flange plate must develop tensile yield strength over the gross section and ultimate tensile fracture resistance over the effective net section. A36/A36M steel has greater

separation of the nominal yield stress and the minimum tensile strength, and this may simplify the satisfaction of these dual requirements. However, variation in expected yield stress is larger for A36/ A36M steel, and design calculations may more accurately approximate actual flange plate performance with A572/A572M steel.

The flange plate welds are shop welds, and these welds are subject to potential secondary yielding caused by strain hardening at the primary yield location in the beam. As a result, the welds are required to be demand-critical complete-joint-penetration (CJP) groove welds. If backing is used, it must be removed and the weld must be backgouged to sound material and back welded to assure that the weld can sustain yielding of the flange plate. Since the welds are shop welds, considerable latitude is possible in the selection of the weld process as long as the finished weld meets the demand critical weld requirements stipulated in the AISC *Seismic Provisions*. In the test specimens used to prequalify this connection, electroslag, gas shielded metal arc, and flux cored arc welding have been used.

The BFP moment connection places somewhat less severe demands on the web connection than most FR connections, because of the somewhat greater flexibility of the bolted flange connection. As a result, the shear plate may be welded with CJP groove welds or partial-joint-penetration (PJP) groove welds or fillet welds.

Bolts in the flange plate are limited to two rows of bolts, and the bolt holes must be made by drilling or sub-punching and reaming. These requirements reflect testing used to prequalify the BFP moment connection, but they also reflect practical limitations in the connection design. Net section rupture is a clear possibility in the beam flange and flange plates, and it is very difficult to meet the net section rupture criteria if more than two rows of bolts are employed.

A single row of bolts causes severe eccentricity in the connection and would lead to an excessively long connection. Punched bolt holes without reaming are not permitted, because punching may induce surface roughness in the hole that may initiate cracking of the net section under high tensile stress. As noted earlier, the connection is prequalified only for A490 or A490M bolts with threads excluded from the shear plane. Bolt diameter is limited to a maximum of 1¹/₈ in. (28 mm), because larger bolts are seldom used and the 1¹/₈ in. (28 mm) diameter is the maximum used in past BFP tests. The bolt diameter must be selected to ensure that flange yielding over the gross area exceeds the net section capacity of the beam flange.

Oversized bolt holes were included in some past tests, because the oversized holes permit easier alignment of the bolts and erection of the connection and resulted in good performance of the connection. Further, the beam must fit between two welded flange plates with full consideration of rolling and fabrication tolerances. As a result, shims may be used to simplify erection while ensuring a tight connection fit.

7.6. DESIGN PROCEDURE

The BFP moment connection is somewhat more complex than some other connections, because a larger number of yield locations and failure modes are encountered

with this connection. **Step 1** of this procedure defines the maximum expected moment, M_{pr} , at the last bolt away from the face of the column in the flange plate. The beam flange must have greater net section fracture resistance than its yield resistance, because tensile yield of the flange is a ductile mechanism and net section rupture is a brittle failure. **Step 2** establishes the maximum bolt diameter that can meet this balanced criterion. While this requirement is rational, it should be noted that net section rupture of the beam flange has not occurred in any past BFP tests, since the beam web clearly reduces any potential for flange rupture.

The shear strength of the flange bolts is the smallest strength permitted by bolt shear with threads excluded from the shear plane, the bolt bearing on the flange plate, bolt bearing on the beam flange and block shear considerations. **Step 3** provides this evaluation. **Step 4** is an approximate evaluation of the number of bolts needed to develop the BFP moment connection. The moment for the bolts is larger than M_{pr} because the centroid of the bolt group is at a different location than the primary hinge location. However, this moment cannot be accurately determined until the geometry of the flange plate and bolt spacing are established. The 1.25 factor is used as an empirical increase in this moment to provide this initial estimate for the number of bolts required. The bolts are tightened to meet slip-critical criteria, but the connection is not slip-critical: the bolts are designed as bearing bolts.

Once the required number of bolts is established, bolt spacing and an initial estimate of the flange plate length can be established. This geometry is illustrated and summarized in Figure 7.1, and **Step 5** defines critical dimensions of this geometry for later design checks.

Step 6 is similar to other connection types in that the shear force at the plastic hinge is based upon the maximum shear achieved with maximum expected moments at the plastic hinges at both ends of the beam plus the shear associated with appropriate gravity loads on the beam.

Step 7 uses the geometry established in Step 5 and the maximum shear force established in Step 6 to determine the maximum expected moment at the face of the column flange, M_f . The maximum expected force in the flange plate, F_{pr} , is determined from M_f in **Step 8**.

The flange plate bolts cannot experience a tensile force larger than F_{pr} , and so **Step 9** checks the actual number of bolts required in the connection. If this number is larger or smaller than that estimated in Step 4, it may be necessary to change the number of bolts and repeat Steps 5 through 9 until convergence is achieved.

Steps 10 and 11 check the flange plate width and thickness to ensure that tensile yield strength and tensile rupture strength, respectively, exceed the maximum expected tensile force in the flange. The net section rupture check of Step 11 employs the nonductile resistance factor, while the flange yielding check of Step 10 employs the ductile resistance factor; this check also allows limited yielding in the flange plate and ensures ductility of the connection. **Step 12** checks block shear of the bolt group in the flange plate, and **Step 13** checks the flange plate for buckling, when F_{pr} is in

compression. Both block shear and buckling of the flange plate are treated as non-ductile behaviors.

Step 14 is somewhat parallel to Step 6 except that the beam shear force at the face of the column is established, and this shear force is then used to size and design the single shear plate connection is **Step 15**.

Continuity plates and panel zone shear strength are checked in **Steps 16 and 17**, respectively. These checks are comparable to those used for other prequalified connections.

As previously noted, the BFP moment connection has provided quite large inelastic rotational capacity in past research. It has done this by attaining primary yielding in the beam at the end of the flange plate away from the column and through secondary yielding as shear yielding in the column panel zone and tensile yielding in the flange plate. Bolt slip occurs but does not contribute greatly to connection ductility. This rather complex design procedure attempts to achieve these goals by balancing the resistances for different yield mechanisms and failure modes in the connection and by employing somewhat greater conservatism for brittle behaviors than for ductile behaviors.

CHAPTER 8

WELDED UNREINFORCED FLANGE-WELDED WEB (WUF-W) MOMENT CONNECTION

8.1. GENERAL

The welded unreinforced flange-welded web (WUF-W) moment connection is an all-welded moment connection, wherein the beam flanges and the beam web are welded directly to the column flange. A number of welded moment connections that came into use after the 1994 Northridge earthquake, such as the reduced beam section and connections provided with beam flange reinforcement, were designed to move the plastic hinge away from the face of the column. In the case of the WUF-W moment connection, the plastic hinge is not moved away from the face of the column. Rather, the WUF-W moment connection employs design and detailing features that are intended to permit the connection to achieve SMF performance criteria without fracture. Key features of the WUF-W moment connection that are intended to control fracture are as follows:

- The beam flanges are welded to the column flange using CJP groove welds that meet the requirements of demand critical welds in the AISC *Seismic Provisions*, along with the requirements for treatment of backing and weld tabs and welding quality control and quality assurance requirements, as specified in Chapter 3 of this Standard.
- The beam web is welded directly to the column flange using a CJP groove weld that extends the full-depth of the web—that is, from weld access hole to weld access hole. This is supplemented by a single-plate connection, wherein a single plate is welded to the column flange and is then fillet welded to the beam web. Thus, the beam web is attached to the column flange with both a CJP groove weld and a welded single-plate connection. The single-plate connection adds stiffness to the beam web connection, drawing stress toward the web connection and away from the beam flange to column flange connections. The single plate also serves as backing for the CJP groove weld connecting the beam web to the column flange.
- Instead of using a conventional weld access hole detail as specified in Section J1.6 of the AISC *Specification* (AISC, 2010b), the WUF-W moment connection employs a special seismic weld access hole with requirements on size, shape and finish that reduce stress concentrations in the region around the access hole detailed in AWS D1.8/D1.8M (AWS, 2009).

Prequalification of the WUF-W moment connection is based on the results of two major research and testing programs. Both programs combined large-scale tests with extensive finite element studies. Both are briefly described herein.

The first research program on the WUF-W moment connection was conducted at Lehigh University as part of the SAC-FEMA program. Results are reported in several publications (Ricles et al., 2000, 2002). This test program formed the basis of prequalification of the WUF-W moment connection in FEMA 350 (FEMA, 2000e). As part of the Lehigh program, tests were conducted on both interior and exterior type specimens. The exterior specimens consisted of one beam attached to a column. The interior specimens consisted of a column with beams attached to both flanges. One of the interior specimens included a composite floor slab. All specimens used W36×150 (W920×223) beams. Three different column sizes were used: W14×311, W14×398 and W27×258 (W360×463, W360×592 and W690×384). All WUF-W moment connection specimens tested in the Lehigh program satisfied the rotation criteria for SMF connections (± 0.04 rad total rotation). Most specimens significantly exceeded the qualification criteria. Considering that the interior type specimens included two WUF-W moment connections each, 12 successful WUF-W moment connections were tested in the Lehigh program. This research program included extensive finite element studies that supported the development of the special seismic weld access hole and the details of the web connection.

The second major research program on the WUF-W moment connection was conducted at the University of Minnesota. The purpose of this research program was to examine alternative doubler plate details, continuity plate requirements, and effects of a weak panel zone. All test specimens used the WUF-W moment connection. Results are reported in several publications (Lee et al., 2002, 2005a, 2005b). Six interior type specimens were tested in the Minnesota program. All specimens used W24×94 beams. Three column sizes were used: W14×283, W14×176 and W14×145. All specimens were designed with panel zones weaker than permitted by the AISC *Seismic Provisions*. Two of the test specimens, CR1 and CR4, were inadvertently welded with low-toughness weld metal. This resulted in premature weld failure in specimen CR4 (failure occurred at about 0.015 rad rotation). With the exception of CR4, all specimens achieved a total rotation of ± 0.04 rad, and sustained multiple cycles of loading at ± 0.04 rad prior to failure. All successful specimens exhibited substantial panel zone yielding, due to the weak panel zone design. This test program was also supported by extensive finite element studies.

Considering the WUF-W moment connection research programs at both Lehigh and the University of Minnesota, WUF-W moment connection specimens have shown excellent performance in tests. There is only one reported failed test, due to the inadvertent use of low-toughness weld metal for beam flange CJP groove welds (Minnesota Specimen CR4). Of all of the WUF-W moment connection specimens that showed good performance (achieved rotations of at least ± 0.04 rad), approximately one-half had panel zones weaker than permitted by the AISC *Seismic Provisions*. The other half satisfied the panel zone strength criteria of the AISC *Seismic Provisions*. This suggests that the WUF-W moment connection performs well for both strong and weak panel zones; therefore the connection is not highly sensitive to panel zone strength.

The protected zone for the WUF-W moment connection is defined as the portion of the beam extending from the face of the column to a distance d from the face of the column, where d is the depth of the beam. Tests on WUF-W moment connection specimens show that yielding in the beam is concentrated near the face of the column, but extends to some degree over a length of the beam approximately equal to its depth.

8.3. PREQUALIFICATION LIMITS

The WUF-W moment connection is prequalified for beams up to W36 (W920) in depth, up to 150 lb/ft in weight (223 kg/m mass limit), and up to a beam flange thickness of 1 in. (25 mm). This is based on the fact that a W36×150 (W920×223) is the deepest and heaviest beam tested with the WUF-W moment connection. The 1-in. (25-mm) flange thickness limitation represents a small extrapolation of the 0.94-in. (23.9-mm) flange thickness for the W36×150 (W920×223). Limits are also placed on span-to-depth ratio based on the span-to-depth ratios of the tested connections and based on judgment of the CPRP.

Beam lateral bracing requirements for the WUF-W moment connection are identical to those for the RBS moment connection. The effects of beam lateral bracing on cyclic loading performance have been investigated more extensively for the RBS moment connection than for the WUF-W moment connection. However, the available data for the WUF-W moment connection suggests that beams are less prone to lateral-torsional buckling than with the RBS moment connections. Consequently, it is believed that lateral bracing requirements established for the RBS moment connection are satisfactory, and perhaps somewhat conservative, for the WUF-W moment connection.

Column sections used in WUF-W moment connection test specimens were W14 (W360) and W27 (W690) sections. However, column limitations for the WUF-W moment connection are nearly the same as for the RBS moment connection, which includes wide-flange shapes up to W36 (W920) and box columns up to 24 in. by 24 in. (610 mm by 610 mm). A primary concern with deep columns in moment frames has been the potential for twisting and instability of the column driven by lateral-torsional buckling of the beam. Because beams with WUF-W moment connections are viewed as somewhat less prone to lateral-torsional buckling than beams with RBS moment connections, the column limitations established for the RBS moment connection were judged as appropriate for the WUF-W moment connection.

8.4. COLUMN-BEAM RELATIONSHIP LIMITATIONS

WUF-W moment connection test specimens have shown good performance with a range of panel zone shear strengths, ranging from very weak to very strong panel zones. Tests conducted at the University of Minnesota (Lee et al., 2005b) showed excellent performance on specimens with panel zones substantially weaker than required in the AISC *Seismic Provisions*. However, there are concerns that very weak panel zones may contribute to premature connection fracture under some circumstances, and it is believed further research is needed before weak panel zone designs

can be prequalified. Consequently, the minimum panel zone strength required in Section E3.6e of the AISC *Seismic Provisions* is required for prequalified WUF-W moment connections for SMF. For IMF systems, the AISC *Seismic Provisions* have no special panel zone strength requirements, beyond the AISC *Specification*. This may lead to designs in which inelastic action is concentrated within the panel zone. As described earlier, based on successful tests on WUF-W moment connection specimens with weak panel zones, this condition is not viewed as detrimental for IMF systems.

8.5. BEAM FLANGE-TO-COLUMN FLANGE WELDS

Beam flanges are required to be connected to column flanges with CJP groove welds. The welds must meet the requirements of demand critical welds in the AISC *Seismic Provisions*, as well as the detailing and quality control and quality assurance requirements specified in Chapter 3 of this Standard. These beam flange-to-column flange weld requirements reflect the practices used in the test specimens that form the basis for prequalification of the WUF-W moment connection and reflect what are believed to be best practices for beam flange groove welds for SMF and IMF applications.

A key feature of the WUF-W moment connection is the use of a special weld access hole. The special seismic weld access hole has specific requirements on the size, shape and finish of the access hole. This special access hole was developed in research on the WUF-W moment connection (Ricles et al., 2000, 2002) and is intended to reduce stress concentrations introduced by the presence of the weld access hole. The size, shape and finish requirements for the special access hole are specified in AWS D1.8/D1.8M, Section 6.10.1.2 (AWS, 2009).

8.6. BEAM WEB-TO-COLUMN CONNECTION LIMITATIONS

The beam web is connected to the column flange with a single plate that is welded to the column flange and fillet welded to the beam web and with a full-depth (weld access hole to weld access hole) CJP groove weld. The single plate serves as backing for the beam web CJP groove weld. The use of the CJP groove weld combined with the fillet-welded single plate is believed to increase the stiffness of the beam web connection. The stiffer beam web connection serves to draw stress away from the beam flanges and therefore reduces the demands on the beam flange groove welds.

Most of the details of the beam web-to-column connection are fully prescribed in Section 8.6; thus few design calculations are needed for this connection. An exception to this is the connection of the single plate to the column. This connection must develop the shear strength of the single plate, as specified in Section 8.6(2). This can be accomplished by the use of CJP groove welds, PJP groove welds, fillets welds or combinations of these welds. The choice of these welds is left to the discretion of the designer. In developing the connection between the single plate and the column flange, designers should consider the following issues:

- The use of a single-sided fillet weld between the single plate and the column flange should be avoided. If the single plate is inadvertently loaded or struck in the out-of-plane direction during erection, the fillet weld may break and may lead to erection safety concerns.
- The end of the beam web must be set back from the face of the column flange a specified amount to accommodate the web CJP root opening dimensional requirements. Consequently, the single plate-to-column weld that is placed in the web CJP root opening must be small enough to fit in that specified root opening. For example, if the CJP groove weld is detailed with a $1/4$ -in. (6-mm) root opening, a fillet weld between the single plate and the column flange larger than $1/4$ in. (6 mm) will cause the root of the CJP groove weld to exceed $1/4$ in. (6 mm).
- Placement of the CJP groove weld connecting the beam web to the column flange will likely result in intermixing of weld metal, with the weld attaching the single plate to the column flange. Requirements for intermix of filler metals specified in AWS D1.8/D1.8M (AWS, 2009) should be followed in this case.

The CJP groove weld connecting the beam web to the column flange must meet the requirements of demand critical welds. Note that weld tabs are permitted, but not required, at the top and bottom ends of this weld. If weld tabs are used, they should be removed after welding according to the requirements of Section 3.4. If weld tabs are not used, the CJP groove weld should be terminated in a manner that minimizes notches and stress concentrations, such as with the use of cascaded ends.

The fillet weld connecting the beam web to the single plate should be terminated a small distance from the weld access hole, as shown in Figure 8.3. This is to avoid introducing notches at the edge of the weld access hole.

8.7. DESIGN PROCEDURE

For the WUF-W moment connection, many of the details of the connection of the beam to the column flange are fully prescribed in Sections 8.5 and 8.6. Consequently, the design procedure for the WUF-W moment connection largely involves typical checks for continuity plates, panel zone shear strength, column-beam moment ratio and beam shear strength.

With the WUF-W moment connection, yielding of the beam (i.e., plastic hinge formation) occurs over the portion of the beam extending from the face of the column to a distance of approximately one beam depth beyond the face of the column. For purposes of the design procedure, the location of the plastic hinge is taken to be at the face of the column. That is, $S_h = 0$ for the WUF-W moment connection. It should be noted that the location of the plastic hinge for design calculation purposes is somewhat arbitrary, since the plastic hinge does not occur at a single point but instead occurs over some length of the beam. The use of $S_h = 0$ is selected to simplify the design calculations. The value of C_{pr} was calibrated so that when used with $S_h = 0$, the calculated moment at the column face reflects values measured in experiments.

Note that the moment in the beam at the column face is the key parameter in checking panel zone strength, column-beam moment ratio, and beam shear strength.

The value of C_{pr} for the WUF-W moment connection is specified as 1.4, based on an evaluation of experimental data. Tests on WUF-W moment connections with strong panel zones (Ricles et al., 2000) showed maximum beam moments, measured at the face of the column, as high as $1.49M_p$, where M_p was based on measured values of F_y . The average maximum beam moment at the face of the column was $1.33M_p$. Consequently, strain hardening in the beam with a WUF-W moment connection is quite large. The value of C_{pr} of 1.4 was chosen to reflect this high degree of strain hardening. Combining the value of $C_{pr} = 1.4$ with $S_h = 0$ results in a moment at the face of the column, $M_f = M_{pr} = 1.4R_y F_y Z$, that reasonably reflects maximum column face moments measured in experiments.

CHAPTER 9

KAISER BOLTED BRACKET (KBB) MOMENT CONNECTION

9.1. GENERAL

The Kaiser bolted bracket (KBB) moment connection is designed to eliminate field welding and facilitate frame erection. Depending on fabrication preference, the brackets can be either fillet welded (W-series) or bolted (B-series) to the beam. The B-series can also be utilized to improve the strength of weak or damaged connections, although it is not prequalified for that purpose. Information on the cast steel and the process used to manufacture the brackets is provided in Appendix A.

The proprietary design of the brackets is protected under U.S. patent number 6,073,405 held by Steel Cast Connections LLC. Information on licensing rights can be found at <http://www.steelcastconnections.com>. The connection is not prequalified when brackets of an unlicensed design and/or manufacture are used.

Connection prequalification is based on 21 full-scale bolted bracket tests representing both new and repaired applications (Kasai and Bleiman, 1996; Gross et al., 1999; Newell and Uang, 2006; and Adan and Gibb, 2009). These tests were performed using beams ranging in depth from W16 to W36 (W410 to W920) and columns using W12, W14 and W27 (W310, W360 and W690) sections. Built-up box columns have also been tested. The test subassemblies have included both single cantilever and double-sided column configurations. Concrete slabs were not present in any tests. During testing, inelastic deformation was achieved primarily through the formation of a plastic hinge in the beam. Some secondary yielding was also achieved in the column panel zone. Peak strength typically occurred at an interstory drift angle between 0.025 and 0.045 rad. Specimen strength then gradually decreased with additional yielding and deformation. In the KBB testing reported by Adan and Gibb (2009), the average specimen maximum interstory drift angle exceeded 0.055 rad.

9.2. SYSTEMS

Review of the research literature and testing referenced in this document indicates that the KBB moment connection meets the prequalification requirement for special and intermediate moment frames.

The exception associated with concrete structural slab placement at the column and bracket flanges is based on testing conducted on the stiffened extended end-plate moment connection (Seek and Murray, 2008). While bolted bracket testing has been conducted primarily on bare-steel specimens, some limited testing has also been performed on specimens with a concrete structural slab. In these tests, the presence of

the slab provided a beneficial effect by maintaining the stability of the beam at larger interstory drift angles (Gross et al., 1999; Newell and Uang, 2006). However, in the absence of more comprehensive testing with a slab, the placement of the concrete is subject to the exception.

9.3. PREQUALIFICATION LIMITS

1. Beam Limitations

A wide range of beam sizes was tested with bolted brackets. The lightest beam size reported in the literature was a W16×40 (W410×60). The heaviest beam reported was a W36×210 (W920×313). In the W36×210 test, the specimen met the requirements, but subsequently experienced an unexpected nonductile failure of the bolts connecting the bracket to the column. The next heaviest beams reported to have met the requirements were W33×130 and W36×150 (W840×193 and W410×60). Based on the judgment of the CPRP, the maximum beam depth and weight was limited to match that of the W33×130 (W840×193). The maximum flange thickness was established to match a modest increase above that of the W36×150 (W410×60).

The limitation associated with minimum beam flange width is required to accommodate fillet weld attachment of the W-series bracket and to prevent beam flange tensile rupture when using the B-series bracket.

Bolted bracket connection test assemblies used configurations approximating beam spans between 24 and 30 ft (7310 and 9140 mm). The beam span-to-depth ratios were in the range of 8 to 20. Given the degree to which most specimens significantly exceeded the requirement, it was judged reasonable to set the minimum span-to-depth ratio at 9 for both SMF and IMF systems.

As with other prequalified connections, beams supporting a concrete structural slab are not required to have a supplemental brace near the expected plastic hinge. If no floor slab is present, then a supplemental brace is required. The brace may not be located within the protected zone.

2. Column Limitations

Bolted bracket connection tests were performed with the brackets bolted to the column flange (i.e., strong-axis connections). In the absence of additional testing with brackets bolted to the column web (weak-axis connections), the prequalification is limited to column flange connections.

Test specimen wide flange column sizes ranged from a W12×65 to a W27×281 (W310×97 to W690×418). Testing performed by Ricles et al. (2004) of deep-column RBS connections demonstrated that deep columns do not behave substantially different from W14 (W360) columns when a slab is present or when adequate lateral bracing is provided for the beam and/or column in the absence of a slab. Based on the similarity in performance to that of the RBS connection, the KBB is prequalified to include column sizes up to W36 (W920).

The behavior of a flanged cruciform column in KBB connections is expected to be similar to that of a rolled wide-flange. Therefore, flanged cruciform columns are prequalified, subject to the limitations imposed on rolled wide-flange shapes.

Two of the tests were successfully conducted using a built-up box column. In the first box column test, connections were made on two opposing column faces. Then, in the second test, a connection was made to the orthogonal face of the same column. These two tests were intended to prequalify a box column participating in orthogonal moment frames. The tested box column was 15⁵/₈ in. (397 mm) square (Adan and Gibb, 2009). Consequently, bolted bracket connections are prequalified for use with built-up box columns up to 16 in. (406 mm) square.

Based on both successful wide-flange and built-up box column testing, acceptable performance would also be expected for boxed wide-flange columns. Therefore, the use of boxed wide-flange columns is also prequalified. When moment connections are made only to the flanges of the wide-flange portion of the boxed wide-flange, subject to the bracing limitations mentioned previously, the column may be as deep as a W36 (W920). When the boxed wide-flange column participates in orthogonal moment frames, neither the depth nor the width of the column is allowed to exceed 16 in. (406 mm), applying the same limit as a built-up box.

3. Bracket Limitations

The ASTM cast steel material specification used to manufacture the brackets is based on recommendations from the Steel Founders' Society of America (SFSA).

The cast brackets are configured and proportioned to resist applied loads in accordance with the limit states outlined by Gross et al. (1999). These limit states include column flange local buckling, bolt prying action, combined bending and axial loading on the bracket, shear, and for the B-series, bolt bearing deformation and block shear rupture.

In tests representing new applications, the bracket column bolt holes were cast vertically short-slotted. The vertically slotted holes provide field installation tolerance. In tests representing a repair application, the holes were cast standard diameter. There has been no difference in connection performance using either type of cast hole (Adan and Gibb, 2009).

9.4. COLUMN-BEAM RELATIONSHIP LIMITATIONS

The reduction of column axial and moment strength due to the column bolt holes need not be considered when checking column-beam moment ratios. Research performed by Masuda et al. (1998) indicated that a 30 to 40% loss of flange area due to bolt holes showed only a corresponding 10% reduction in the yield moment strength.

9.5. BRACKET-TO-COLUMN FLANGE CONNECTION LIMITATIONS

In the prequalification tests, fasteners joining the bracket to the column flange were pretensioned ASTM A490 or A490M bolts. The column bolt head can be positioned

on either the column or bracket side of the connection. Where possible, the column bolts are tightened prior to the bolts in the web shear tab.

When needed, finger shims between the bracket and column face allow for fit between the bracket and column contact surfaces. Tests indicated that the use of finger shims does not affect the performance of the connection.

Because the flanges of a box column are stiffened only at the corners, tightening of the column bolts can cause excessive local flange bending. Therefore, as shown in Figure C-9.1, a washer plate is required between the box column flange and the bracket.

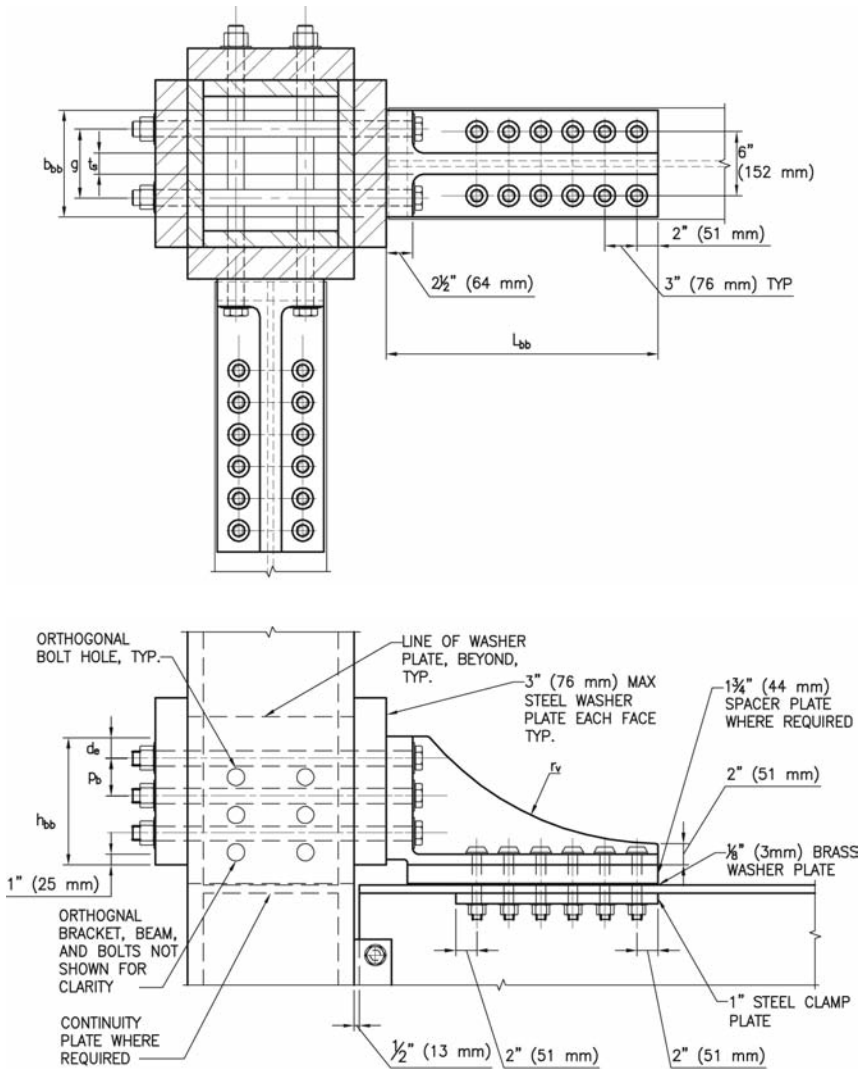


Fig. C-9.1. Box column connection detailing for KBB.

As shown in Figure C-9.1, orthogonally connected beams framing into a box column are raised one-half of the column bolt spacing distance to avoid overlapping the column bolts.

9.6. BRACKET-TO-BEAM FLANGE CONNECTION LIMITATIONS

The cast steel brackets are not currently listed as a prequalified material in AWS D1.1/D1.1M (AWS, 2010). Therefore, the weld procedure specification (WPS) for the fillet weld joining the bracket to the beam flange is required to be qualified by test with the specific cast material.

Bolts joining the bracket to the beam flange in prequalification tests have been conducted with pretensioned ASTM A490 or A490M bolts with the threads excluded from the shear plane. The beam bolt head can be positioned on either the beam or bracket side of the connection. Given the beam bolt pattern and hole size, it is necessary to use the bracket as a template when drilling the beam bolt holes. The holes must be aligned to permit insertion of the bolts without undue damage to the threads.

The brass washer plate prevents abrading of the beam and bracket contact surfaces. In the initial developmental stages of the connection, several specimens configured without the brass plate experienced flange net section rupture through the outermost bolt holes. Observation of the failed specimens indicated that fracture likely initiated at a notch created by the abrading contact surfaces near the hole. Furthermore, energy released through the beam-bracket slip-stick mechanism caused loud, intermittent bursts of noise, particularly at high levels of inelastic drift (Kasai and Bleiman, 1996). To overcome these problems, the brass plate was inserted between the bracket and the beam flange. The idea is based on the use of a brass plate as a special friction-based seismic energy dissipator (Grigorian et al., 1992). Although not intended to dissipate energy in the bolted bracket connection, the brass plate provides a smooth slip mechanism at the bracket-to-beam interface.

When bolting the bracket to a beam flange, a steel washer or clamp plate is positioned on the opposite side of the connected flange. The restraining force of the clamp plate prevents local flange buckling from occurring near the outermost bolt holes. In tests performed without the clamp plates, flange distortion increased the strains near the holes. The increased strain caused necking and fracture through the flange net area. In similar tests performed with the clamp plates, yielding and fracture occurred outside the connected region through the flange gross area (Kasai and Bleiman, 1996).

9.7. BEAM WEB-TO-COLUMN CONNECTION LIMITATIONS

All of the bolted bracket connection tests were performed with a bolted web connection where pretensioned high-strength bolts were used. Therefore, the KBB is prequalified for a bolted beam web-to-column connection.

9.8. CONNECTION DETAILING

Both Figures 9.4 and 9.5 show the connection configured with continuity plates where required. The use of continuity plates is dictated by the need to satisfy

prescribed limit states for the flange and web of the column. In a bolted connection, the configuration of the fasteners can impede the ability of the continuity plates to effectively address these limit states. The design intent for the KBB is to satisfy the prescribed limit states without continuity plates. In tests of wide flange columns without continuity plates, the absence of the continuity plates did not appear to promote local flange bending or lead to other detrimental effects (Adan and Gibb, 2009). However, in the absence of additional tests on deeper column sections, prequalification without continuity plates is limited to W12 and W14 sections.

9.9. DESIGN PROCEDURE

The design procedure for prequalified KBB connections is intended to develop the probable maximum moment capacity of the connecting beam. Test data indicate that connecting the brackets to the column and beam in accordance with the requirements herein allows the connection to resist this level of moment.

Tables C-9.1, C-9.1M, C-9.2, and C-9.2M can be used as a guide in selecting trial bracket-beam combinations in conjunction with **Steps 1 and 3**. The tables are based on beams that satisfy the limitations of Section 9.3.1 for ASTM A992/A992M or A572/A572M Grade 50 (Grade 345) wide flange shapes.

Step 4 of the procedure requires computation of the shear force at the expected plastic hinge. This shear force is a function of the gravity load on the beam and the plastic moment strength. A calculation similar to that for the RBS moment connection is required for the case of a beam with a uniformly distributed gravity load as shown in Figure C-5.1. For the KBB, L_h is the distance between the expected plastic hinge locations and S_h is the distance from the face of the column to the hinge. The explanation associated with Equations C-5.8-1 and C-5.8-2 also applies to the KBB.

Step 6 is based on the limit state of bolt tensile rupture as defined in Section J3.6 of the AISC *Specification* (AISC, 2010b), where the required bolt tensile strength is determined in Equation 9.9-3.

Steps 7 and 11 of the procedure apply to rolled or built-up shapes with flange holes, proportioned based on flexural strength of the gross section. The flexural strength is limited in accordance with the limit state of flange tensile rupture as defined in Section F13.1(a) of the AISC *Specification*. When the flange width is adequate, the tensile rupture limit state does not apply.

Step 8 of the procedure requires a column flange prying action check as outlined in Chapter 9 of the AISC *Manual*. The computations include provisions from the research performed by Kulak, Fisher and Struik (1987).

Step 9 of the procedure is based on the limit state of column flange local bending as defined in Section J10.1 of the AISC *Specification*. The limit state determines the strength of the flange using a simplified yield line analysis. Yield line analysis is a method that determines the flexural load at which a collapse mechanism will form in a flat plate structure and employs the principle of virtual work to develop an upper bound solution for plate strength. Given the bolted bracket configuration, the

TABLE C-9.1
Recommended W-Series
Bracket-Beam Combinations

Bracket Designation	Beam Designations
W1.0	W33×130, W30×124, W30×116, W24×131, W21×122, W21×111
W2.1	W30×108, W27×114, W27×102, W24×103, W21×93, W18×106, W18×97
W2.0	W27×94, W24×94, W24×84, W24×76, W21×83, W21×73, W21×68, W21×62, W18×86, W18×71, W18×65
W3.1	W24×62, W24×55, W21×57, W18×60, W18×55, W16×57
W3.0	W21×50, W21×44, W18×50, W18×46, W18×35, W16×50, W16×45, W16×40, W16×31

TABLE C-9.1M
Recommended W-Series
Bracket-Beam Combinations

Bracket Designation	Beam Designations
W1.0	W840×193, W760×185, W760×173, W610×195, W530×182, W530×165
W2.1	W760×161, W690×170, W690×152, W610×153, W530×138, W460×158, W460×144
W2.0	W690×140, W610×140, W610×125, W610×113, W530×123, W530×109, W530×101, W530×92, W460×128, W460×106, W460×97
W3.1	W610×92, W610×82, W530×85, W460×89, W460×82, W410×85
W3.0	W530×74, W530×66, W460×74, W460×68, W460×52, W410×75, W410×67, W410×60, W410×46.1

TABLE C-9.2
Recommended B-Series
Bracket-Beam Combinations

Bracket Designation	Beam Designations
B1.0	W33×130, W30×124, W30×116, W24×131, W21×122, W21×111
B2.1	W30×108, W27×114, W27×102, W27×94, W18×106, W18×97

TABLE C-9.2M
Recommended B-Series
Bracket-Beam Combinations

Bracket Designation	Beam Designations
B1.0	W840×193, W760×185, W760×173, W610×195, W530×182, W530×165
B2.1	W760×161, W690×170, W690×152, W690×140, W460×158, W460×144

solution can be simplified to determine the controlling yield line pattern that produces the lowest failure load. Because a continuity plate would interfere with the installation of the connecting bolts, the procedure requires that the column flange thickness adequately satisfies the limit state without the requirement to provide continuity plates.

Although Step 9 requires a flange thickness that will adequately satisfy the column flange local bending limit state, the limit states of web local yielding, web crippling, and web compression buckling as defined in Sections J10.2, J10.3 and J10.5 of the *AISC Specification*, respectively, may also be applicable. In shallow seismically compact W12 (W310) and W14 (W360) sections these additional limit states will not control. However, in some deeper sections, the additional limit states may govern. Therefore, **Step 10** requires continuity plates in the deeper sections to adequately address the limit states and to stabilize deep column sections. The plates are positioned at the same level as the beam flange as shown in Figures 9.4 and 9.5.

Step 12 of the procedure is based on the limit state of bolt shear rupture as defined in Section J3.6 of the *AISC Specification*. When this connection first appeared in the 2009 Supplement No. 1 to AISC 358-05, a bolt shear overstrength factor of 1.1 was

included in the denominator of Equation 9.9-9 based on research subsequently reported by Tide (2010). The 2010 AISC *Specification* has since incorporated that factor into the tabulated shear strengths of bolts, necessitating its removal here.

The procedure outlined in Step 12 omits a bolt-bearing limit state check per Section J3.10 of the AISC *Specification* because the provisions of Sections 9.3.1(5) and 9.3.1(7) preclude the use of beams where the bolt bearing would limit the strength of the connection.

Step 14 of the procedure is based on the limit state of weld shear rupture as defined in Section J2.4 of the AISC *Specification*. The procedure assumes a linear weld group loaded through the center of gravity.

Step 18 of the procedure is supplemental if the column is a built-up box configuration. The procedure is based on the limit state of yielding (plastic moment) as defined in Section F11.1 of the AISC *Specification*. The design assumes a simply supported condition with symmetrical point loads applied at the bolt locations.

CHAPTER 10

CONXTECH CONXL MOMENT CONNECTION

10.1. GENERAL

The ConXtech® ConXL™ moment connection is designed to provide robust cost effective moment framing, while eliminating field welding and facilitating fast frame erection. The patented ConXL fabrication and manufacturing process utilizes forged parts, welding fixtures and robotic welders to produce a standardized connection.

The collars and collar assemblies illustrated, and methodologies used in their fabrication and erection, are covered by one or more of the U.S. and foreign patents shown at the bottom of the first page of Chapter 10. Additional information on the ConXL connection can also be found at <http://www.conxtech.com>.

Prequalification of the ConXL moment connection is based on the 17 qualifying cyclic tests listed in Table C10.1, as well as nonlinear finite element modeling of the connection. The test database includes five bi-axial moment connection tests. These unprecedented bi-axial moment connection tests subjected the framing in the orthogonal plane to a constant shear creating a moment across the column-beam joint equivalent to that created by the probable maximum moment at the plastic hinge of the primary beams, while the framing in the primary plane was simultaneously subjected to the qualifying cyclic loading specified by AISC 341-05 Appendix S until failure occurred. Tests were conducted using a variety of column to beam strength ratios. Many tests were conducted with an intentionally reinforced column, consisting of a concrete-filled HSS with an embedded W12 (W310) inside the HSS, forcing all inelastic behavior out of the column. In one of the biaxial tests, simultaneous flexural yielding of the column was initiated during cycling. Typically, failures consist of low-cycle fatigue of a beam flange in the zone of plastic hinging, following extensive rotation and local buckling deformation.

The ConXL connection is a true bi-axial moment connection capable of moment-connecting up to four beams to a column. All moment-connected columns require a full set of four collar flange top (CFT) pieces and four collar flange bottom (CFB) pieces at every beam-column moment connected joint, even if a column face has no beam present. Each column face with either a moment-connected beam or simply supported beam will have the full collar flange assembly [CFT, CFB and collar web extension (CWX)] with the simply connected beam connected to the CWX with a standardized bolted connection.

Unlike more conventional moment frame design, which focuses on keeping the number of moment-resisting frames to a minimum for reasons of economy, the efficient ConXL system distributes the bi-axial moment connection to nearly every beam-column-beam joint throughout the structure creating a distributed moment-resisting space frame. Thus, instead of a less redundant structure with more concentrated

TABLE C10.1
Summary of ConXL Tests

Test No.	Test Condition	Column Size	Primary Axis Beam	Secondary Axis Beam	Rotation (radians)
1101	Planar	HSS 16×16× ⁵ / ₈ *	W18×76 RBS	N/A	0.05
1102	Planar	HSS 16×16× ⁵ / ₈ *	W18×119	N/A	0.05
1103	Planar	HSS 16×16× ⁵ / ₈ *	W24×84 RBS	N/A	0.06
1104	Planar	HSS 16×16× ⁵ / ₈ *	W24×104	N/A	0.05
1105	Planar	HSS 16×16× ⁵ / ₈ *	W24×117×6 [†]	N/A	0.04
1106	Planar	HSS 16×16× ⁵ / ₈ *	W24×117×9 [†]	N/A	0.04
1107	Planar	HSS 16×16× ⁵ / ₈	W21×62 RBS	N/A	0.04
1108	Planar	HSS 16×16× ⁵ / ₈	W21×62 RBS	N/A	0.06
1201	Planar	HSS 16×16× ⁵ / ₈ *	W30×108 RBS	N/A	0.05
1202	Planar	HSS 16×16× ⁵ / ₈ *	W30×108 RBS	N/A	0.05
1203	Planar	HSS 16×16× ⁵ / ₈ *	W30×90	N/A	0.04
1204	Planar	HSS 16×16× ⁵ / ₈ *	W30×90	N/A	0.04
2102	Bi-Axial	BU 16×16×1.25	W30×108 RBS	W30×148	0.05
2103	Bi-Axial	BU 16×16×1.25	W30×108 RBS	W30×148	0.06
2105	Bi-Axial	HSS 16×16× ¹ / ₂	W21×55 RBS	W21×83	0.06
2106	Bi-Axial	BU 16×16×1.25	W30×108 RBS	W30×148	0.05
2107	Bi-Axial	BU 16×16×1.25	W30×108 RBS	W30×148	0.05

* Column consisted of HSS 16 with supplementary W12×136 housed within concrete fill.
[†] Beam flanges were trimmed to the indicated width in order to test the ability of the collar to withstand (a) narrow-flange beams [6 in. (150 mm) flange] and (b) maximum forces [9 in. (230 mm) flange].
 BU indicates built-up box section columns.

lateral force resistance, all or almost all beam-column connections are moment-resisting creating extensive redundancy. The distribution of moment connections throughout the structure also allows for reduced framing sizes and provides excellent floor vibration performance due to fixed-fixed beam end conditions. The highly distributed lateral force resistance also provides for reduced foundation loads and an inherently robust resistance to progressive collapse.

Finite element models of tested beam-column assemblies confirm that the contribution of concrete column fill can be accounted for using the gross transformed properties of the column. Beams and columns should be modeled without rigid end offsets. Prescriptive reductions in beam stiffness to account for reduced beam section (RBS) property reductions are conservative for ConXL framing, as the RBS is

located farther away from the column centerline than is typical of standard RBS connections. Therefore, modeling of ConXL assemblies employing RBS beams should model the reduced beam sections explicitly, rather than using prescriptive reductions in stiffness to account for the beam flange reduction.

Because ConXL systems have their lateral force resistance distributed throughout the structure, torsional resistance can be less than structures with required lateral force resistance concentrated on exterior lines. It is possible to minimize this effect by selecting stiffer members towards the building perimeter, to increase the torsional inertia.

10.2. SYSTEMS

The ConXL moment connection is unique in that it meets the prequalification requirements for special and intermediate moment frames in orthogonal intersecting moment-resisting frames. It can also be used in more traditional plane frame applications. These requirements are met with a single standardized connection.

The exception associated with concrete structural slab placement at the column and collar assembly is based on testing conducted on the stiffened extended end-plate moment connection (Seek and Murray, 2005). Early testing by Murray of a bolted-end-plate specimen with a concrete slab in place failed by tensile rupture of the bolts. This was postulated to be the result of composite action between the beam and slab, resulting in increased beam flexural strength and increased demands on the bolt relative to calculated demands neglecting composite effects. Later testing referenced above demonstrated that placement of a flexible material in the slab adjacent to the column sufficiently reduced this composite action and protected the bolts. Although ConXL connections have not been tested with slabs present, it is believed that the same protective benefits of the flexible material apply to this connection.

ConXL's highly distributed lateral force resistance reduces the need for metal deck/concrete fill to act as a diaphragm and drag forces to a limited number of moment resisting frames. Each moment-resisting column and connected beams resist a tributary lateral load and typically minimal concrete reinforcement or deck attachment is required.

10.3. PREQUALIFICATION LIMITS

1. Beam Limitations

Minimum beam depth is controlled by the collar dimensions and is 18 in. (460 mm). Maximum beam depth is controlled by strong-column weak-beam considerations and is limited to 30 in. (760 mm) for practical purposes. The flange width and thickness requirements are limited by the ability of the collar flange to accommodate the beam flange weld and also by the strength of the bolts. A key ConXL requirement for allowable beam sections is limiting the force delivered by the beam to the bolts connecting the collar flange/beam to the collar corner assemblies/column so as to not

overcome the pretension load applied to the bolts. This requirement is covered in detail in Section 10.8.

ConXL connections have been successfully tested without reduced beam section reductions in flange width and are qualified for use without such reductions. However, RBS cuts in beam flanges can be a convenient way to achieve strong column weak beam limitations without increasing column weight.

Lateral bracing of beams is per the AISC *Seismic Provisions*. During the bi-axial moment connection tests, the test beams (W30×108 with 50% RBS, W21×55 with 50% RBS) were not braced at the RBS and were braced at the beam ends, 10 ft. (3050 mm) from the column center.

All moment-connected beams are required to meet seismic compaction requirements of the AISC *Seismic Provisions*, if RBS beams are used, the width-thickness ratio is taken within its reduced flange width as permitted for RBS connections (Section 5.3.1(6)).

2. Column Limitations

The key requirement for ConXL moment columns is a square sectional dimension of 16 in. (406 mm). Section type (built-up box or HSS) can vary, as can steel strength and wall thickness. All columns used in ConXL moment connections are concrete-filled with either normal or lightweight concrete, having minimum compressive strength of 3,000 psi (21 MPa). Columns are typically filled with concrete at the job site, after erection and bolting is complete. The concrete is pumped to the top of column and allowed to free-fall the full height of column, using the column as a tremie. There are no obstructions, stiffener plates, etc. within the column, thus the column is similar to a tremie-pipe allowing the concrete an unobstructed path to its placement with excellent consolidation (Suprenant, 2001).

3. Collar Limitations

Appendix B describes the forged steel material specification used to manufacture the collars. The forging process produces an initial collar (blank collar) slightly larger than the final overall dimensions. The collar is then machined to their manufacturing dimensions within the required tolerances.

10.4. COLLAR CONNECTION LIMITATIONS

The collars are the key elements of the ConXL connection. They are standardized components and no further design or sizing of these components are required. The same components are used for all beams and columns. The same is true for the collar bolts, where the specification, size and number of bolts always remain the same. The design procedure ensures that column-beam combinations used in the ConXL connection fall within the code requirements of these standard connection components.

The bolts used in the ConXL connection are 1¹/₄ in. diameter ASTM A574 bolts. These bolts are similar in chemistry and mechanical properties to ASTM A490 bolts, but have

socket heads to accommodate their use in this connection. Metric bolts conforming to ASTM A574M have not been tested and are not prequalified for use in this connection. Pretensioning is performed to the requirements for 1¹/₄ in. diameter ASTM A490 bolts [102 kips (454 kN) per Table J3.1 of the 2010 AISC *Specification*].

10.5. BEAM WEB-TO-COLLAR CONNECTION LIMITATIONS

The collar web extension (CWX) is 1¹/₂ in. (38 mm) thick, thus the minimum sized fillet weld between the CWX and beam web is a ⁵/₁₆ in. (8 mm) fillet weld. This weld size for a two-sided fillet weld (each side of the web) should be sufficient for all allowable beams; this should be confirmed during the design procedure calculations.

10.6. BEAM FLANGE-TO-COLLAR FLANGE WELDING LIMITATIONS

Weld access holes are not permitted in the ConXL connection. Welding of the beam flange to the collar flange is performed in a proprietary ConXtech beam weld fixture, which rotates the beam to allow access to the bottom flange for welding in the flat position. The beam weld fixture enables the manufacturing of the moment beam within ConXL tolerances.

10.7. COLUMN-BEAM RELATIONSHIP LIMITATIONS

The ConXL moment connection is a bi-axial connection. Strong-column weak beam requirements specified by the AISC *Seismic Provisions* were formulated considering the typical planar framing prevalent in moment-frame construction following the 1994 Northridge earthquake. Because the ConXL connection is primarily used in intersecting moment frames, with biaxial behavior an inherent part of the design, the committee felt that it was imperative to require that columns have sufficient strength to develop expected simultaneous flexural hinging in beams framing into all column faces. The bi-axial calculation considers all moment beams attached to the column. This calculation is covered in detail in Section 10.8.

10.8. DESIGN PROCEDURE

Step 1. As with other connections, the first step in the design procedure is to compute the probable maximum moment at the plastic hinge. Note that differing C_{pr} factors are applied for RBS and non-RBS beams. The factor for non-RBS beams is compatible with the standard requirements in the AISC *Seismic Provisions* while that for RBS beams is compatible with the requirements of this standard for RBS connections.

Step 2. As with other connections, the equation given for computation of shear forces has to include consideration of gravity loads that are present. The equations presented in the design procedure assume uniform gravity loading. Modifications to these equations are necessary for cases with concentrated loads present. These modifications must satisfy static equilibrium requirements.

Step 3. The ConXL moment connection is a true bi-axial moment connection, thus the committee determined that columns must be sufficiently strong to permit simultaneous development of flexural hinging in all beams framing to a column, not just beams along a single plane. This bi-axial column-beam moment evaluation is more conservative than current AISC *Seismic Provisions* requirements which considers plastic hinging of beams in a single plane only, even though columns supporting moment frames in orthogonal directions are possible with other connections using built-up box sections or other built-up column sections. In calculating the ConXL bi-axial column-beam moment ratio it is permitted to take the actual yield strength of the column material in lieu of the specified minimum yield stress, F_y , and to consider the full composite behavior of the column for axial load and flexural action (inter-story drift analysis). The default formula for column strength provided in the design procedure assumes that equal strength beams are present on all faces of the connection. When some beams framing to a column are stronger than others, it is permitted to use basic principals of structural mechanics to compute the actual required flexural strength.

The design procedure also considers the critical beam strength as it relates to the column strength at locations just above the beam's top flange and just below the beam's bottom flange, where flexural demand on the columns are greatest. Flexural demand on the column within the panel zone is less than at these locations.

Step 5. The available tensile strength for the bolts used in the ConXL connection is specified as the minimum bolt pretension load. The purpose of assigning the minimum pretension load as the available bolt tensile strength is to prevent overcoming of bolt pretension, at least up to the bolt loading subjected by the probable maximum moment. The minimum bolt pretension load is 102 kips (454 kN). Bolts are checked for tension only because the frictional force developed by the bolt pretension will resist beam shear (see Steps 6 and 7).

Steps 6 and 7. Beam shear is resisted by the friction developed between the collar flanges and the collar corners. The collar flanges are clamped against the collar corner assemblies and column when the collar bolts are pretensioned. This pretension clamping force creates friction between the machined surfaces of the collar flanges and collar corners. The machined surfaces are classified as a Class B Surface (unpainted blast-cleaned steel surfaces). The design frictional resistance per bolt is:

$$R_n = \mu D_u h_{sc} T_b N_s$$

$$\phi = 0.85$$

$$\mu = 0.5$$

$$D_u = 1.13$$

$$h_{sc} = 1.0$$

$$T_b = 102 \text{ kips (454 kN)}$$

$$N_s = 1$$

$$\phi R_n = 0.85 \times 0.5 \times 1.13 \times 1.0 \times 102 \times 1 = 49.0 \text{ kips/bolt (218 kN/bolt)}$$

There are 16 bolts per beam end providing a total of 784 kips (3487 kN) of frictional resistance against shear. This frictional force is significantly greater than any beam shear developed by an allowable beam.

Steps 8 and 9. The available length of weld for the collar web extension and collar corner assemblies allow for minimum sized fillet welds to resist beam shear.

Steps 10 and 11. The collar corner assemblies provide additional strength to the column walls to resist panel zone shear. Without taking into consideration the contribution of the concrete fill, the column section along with the collar corner assemblies should provide sufficient strength for anticipated panel zone shear; this should be confirmed during the design procedure calculations.

APPENDIX A

CASTING REQUIREMENTS

A1. CAST STEEL GRADE

The cast steel grade is selected for its ability to provide ductility similar to that of rolled steel. The material has a specified yield and tensile strength of 50 ksi (354 MPa) and 80 ksi (566 MPa), respectively. The ASTM specification requires the castings be produced in conjunction with a heat treatment process that includes normalizing and stress relieving. It also requires each heat of steel meet strict mechanical properties. These properties include the specified tensile and yield strengths, as well as elongation and area reduction limitations.

A2. QUALITY CONTROL (QC)

See Commentary Section 3.7.

2. First Article Inspection (FAI) of Castings

The intent of this section is that at least one casting of each pattern undergo FAI. When a casting pattern is replaced or when the rigging is modified, FAI is to be repeated.

3. Visual Inspection of Castings

All casting surfaces shall be free of adhering sand, scales, cracks, hot tears, porosity, cold laps, and chaplets. All cored holes in castings shall be free of flash and raised surfaces. The ASTM specification includes acceptance criteria for the four levels of surface inspection. Level I is the most stringent criteria. The Manufacturers Standardization Society (MSS) specification includes a set of reference comparators for the visual determination of surface texture, surface roughness and surface discontinuities.

4. Nondestructive Testing (NDT) of Castings

These provisions require the use of nondestructive testing to verify the castings do not contain indications that exceed the specified requirements.

Radiographic testing (RT) is capable of detecting internal discontinuities and is specified only for the FAI. The ASTM specifications contain referenced radiographs and five levels of RT acceptance. The lower acceptance levels are more stringent and are typically required on high-performance aerospace parts such as jet engine turbine blades or on parts that may leak such as valves or pumps. Level III is considered the industry standard for structurally critical components.

Ultrasonic testing (UT) is also capable of detecting internal discontinuities and is specified for production castings. The ASTM specification includes seven levels of

UT acceptance. The lower acceptance levels are more stringent and are typically reserved for machined surfaces subject to contact stresses such as gear teeth. Level 3 is considered the industry standard for structurally critical components.

The areas to be covered by RT or UT are those adjacent to the junctions of:

- (1) The vertical flange and the horizontal flange
- (2) The vertical flange and the vertical stiffener
- (3) The horizontal flange and the vertical stiffener

Magnetic particle testing (MT) is required to detect other forms of discontinuities on or near the surface of the casting. The ASTM specification includes five levels of MT acceptance. The lower levels are more stringent and are typically reserved for pressure vessels. Level V is considered the industry standard for structurally critical components.

Shrinkage is one of the more commonly occurring internal discontinuities and is a result of metal contraction in the mold during solidification. Shrinkage is avoided using reservoirs of molten metal known as risers that compensate for the volumetric contraction during solidification. Numerical modeling of solidification and prediction of shrinkage have been the focus of a number of investigations performed in conjunction with the Steel Founders' Society of America (SFSA). Niyama et al. (1982) developed a criterion that relates the casting temperature gradient and cooling rate. Based on the Niyama criterion, Hardin et al. (1999) developed a correlation between casting simulation and radiographic testing. Subsequently, Carlson et al. (2003) determined that variation in internal porosity (shrinkage) was related to the pattern and rigging of the casting mold.

Based on these conclusions, the provisions require RT and MT on the first article casting to verify that the pattern and rigging are capable of producing a satisfactory casting. Subsequent castings manufactured with the same pattern and rigging require UT and MT to verify production consistency.

Research performed by Briggs (1967) on the effect of discontinuities found that castings perform satisfactorily under loads in excess of service requirements even with discontinuities of considerable magnitude. Testing demonstrated fatigue and static failures occurred at the location of maximum stress regardless of the presence of discontinuities in other sections.

6. Tensile Requirements

Coupons or keel blocks for tensile testing shall be cast and treated from the same batch of representative castings. Each test specimen shall have complete documentation and traceability. If the specimens fail to meet required specifications, then all the castings they represent shall be rejected.

A3. MANUFACTURER DOCUMENTS

Submittal documents allow a thorough review on the part of the patent holder, engineer of record, the authority having jurisdiction and outside consultants, if required.

APPENDIX B

FORGING REQUIREMENTS

There is no Commentary for this Appendix.

REFERENCES

The following references have been reviewed as a basis for the prequalification of the connections described in this Standard. Although some references are not specifically cited in this Standard, they have been reviewed by the AISC Connection Prequalification Review Panel and are listed here to provide an archival record of the basis for this Standard in accordance with the requirements of Chapter K of the AISC *Seismic Provisions*.

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