TRANSMITTAL FORM

PENNON CONSTRUCTION COMPANY

9750 3rd Ave NE, Suite 250, Seattle, WA 98115
Phone: (206) 418-0235 FAX: (206) 418-0237

DATE:	7/25/2024	JOB NO:	24-011
ATTENTION:	**Matt Reeves**		
RE:	PSE Operational Training Center		

TO: **Zervas Group**
209 Prospect Street
Bellingham, WA, 98225

WE ARE SENDING YOU: ☒ Attached ☐ Under separate cover via _____ the following items:

☒ Shop Drawing ☐ Prints ☐ Plans ☐ Samples
☐ Copy of Letter ☐ Change Order ☐ Specifications ☐ Copies
☐ Submittal

COPIES	DATE	NO.	DESCRIPTION
1	7/25/2024	24-011-010	Brace Frame Submittal
			For Construction

DUE DATE: **N/A**

THESE ARE TRANSMITTED as checked below:

☐ For approval ☐ Approved as submitted ☐ Resubmit_____copies for approval
☒ For your use ☐ Approved as noted ☐ Submit_____copies for distribution
☐ As requested ☐ Returned for corrections ☐ Return_____signed contracts
☐ For review & comment ☐ _____
☐ FOR BIDS DUE ☐ RETURN PLANS TO PENNON OFFICE

REMARKS: _____

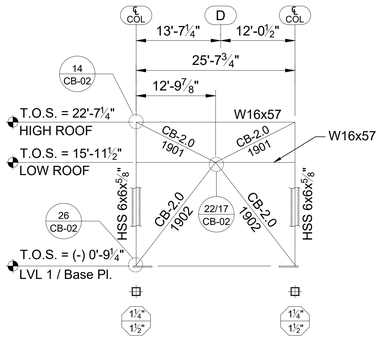
COPY TO _____ SIGNED **Simon Muhuga**

SHOP DRAWING / SUBMITTAL REVIEW

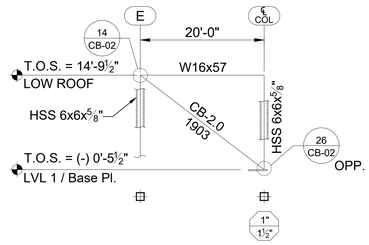
This review is for general conformance with the plans and specifications only. Approvals are subject to subcontractor's performance within the confines of the contract documents. Review of dimensions will not serve to relieve the subcontractor of contractual responsibility for any deviations from the contract requirements.

x Reviewed Without Comment	___ Reviewed as Noted
___ Field Measurement or Templates required prior to fabrication	___ Rejected - Revise & Resubmit
PCCI Project # **24-011**	Submittal # **010**
Reviewed By: **Simon Muhuga**	Date: **7/25/2024**
PENNON CONSTRUCTION COMPANY, INC.	9750 3rd Ave NE Suite 250 Seattle, WA 98115 P: 206-418-0235 - F: 206-418-0237

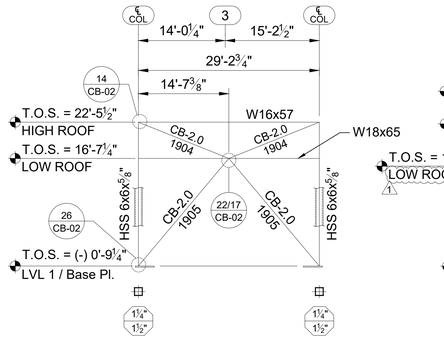
PRCNC20240216 - Revision 2 (Brace Frame)



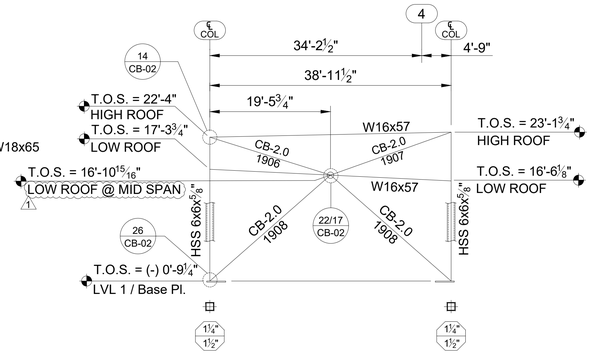
GRID 4.1
(BF-6)



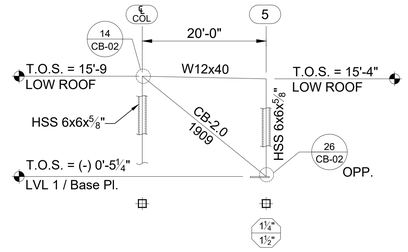
GRID 5
(BF-5)



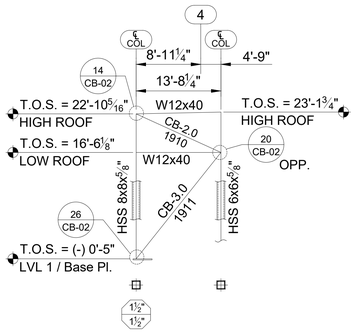
GRID C
(BF-4)



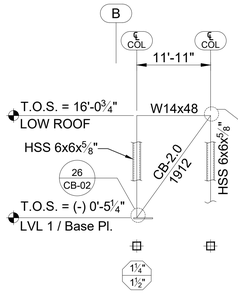
GRID C.2
(BF-3)



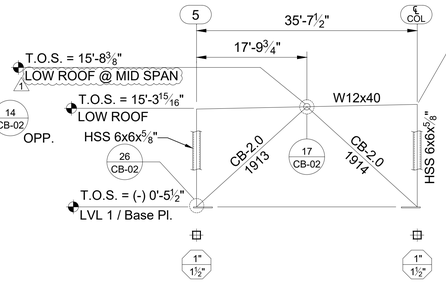
GRID E
(BF-2)



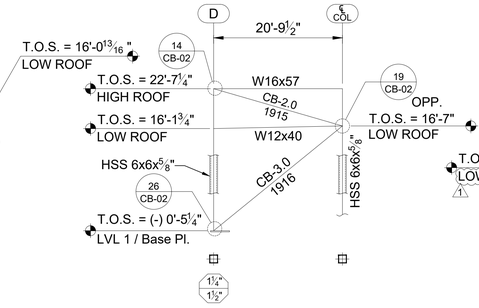
GRID E
(BF-1)



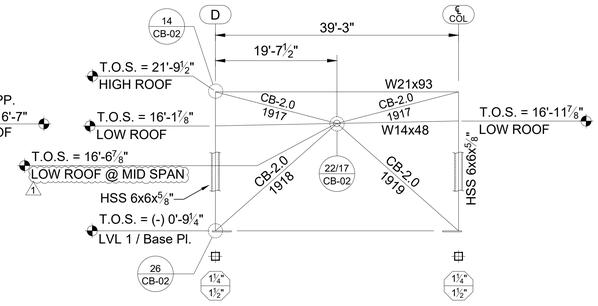
GRID 4
(BF-10)



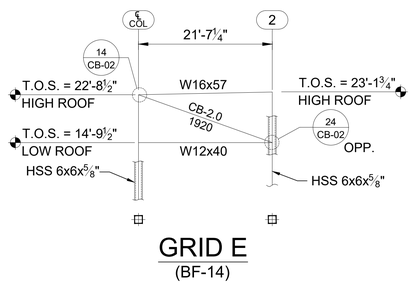
GRID B
(BF-9)



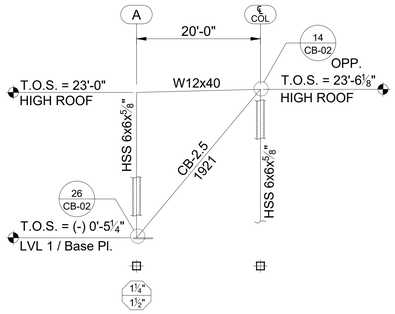
GRID 2
(BF-8)



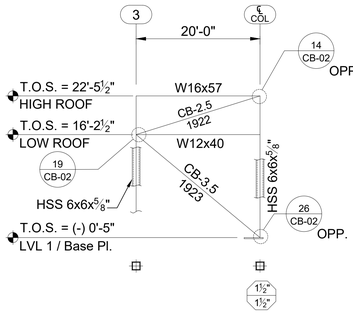
GRID 3.2
(BF-7)



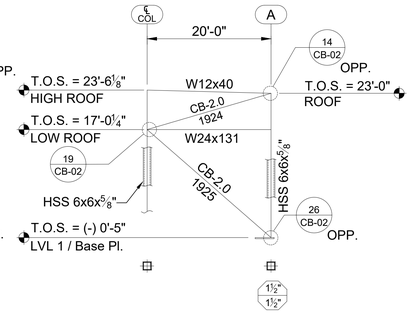
GRID E
(BF-14)



GRID 2
(BF-13)



GRID A
(BF-12)



GRID 3
(BF-11)

City of Puyallup
Development & Permitting Services
ISSUED PERMIT

Building	Planning
Engineering	Public Works
Fire	Traffic

KINGWORKS STRUCTURAL ENGINEERS

[X] REVIEWED [ ] REJECTED

[X] NO EXCEPTIONS TAKEN
[ ] NOTE MARKINGS & REVISE
[ ] NOTE MARKINGS, REVISE & RESUBMIT

Delegated Design / Deferred Submittal review by KW is limited to the component's conformance with design criteria, concept, and loads imposed on the primary structure. Structural performance of the supplier-designed components is the responsibility of the component's structural engineer. Corrections or comments made on the attached submittal do not relieve the Contractor from compliance with the Contract Documents unless specifically noted otherwise. Contractor is responsible for: confirming and correlating all quantities, dimensions, and elevations; selecting fabrication processes and techniques of construction; coordinating work with that of all other trades; and performing work in a safe and satisfactory manner. Where required to RESUBMIT, Contractor need only resubmit sheets that are affected by the marks or otherwise revised.

Date 8/14/24 By DL

City of Puyallup
Building
REVIEWED FOR COMPLIANCE
BSnowden
11/13/2024
2:43:55 PM

CITY OF PUYALLUP STATE OF WASHINGTON

CoreBrace 20 ANNIVERSARY 2002 - 2022 SUPERIOR SEISMIC PERFORMANCE
5789 W. Wells Park Rd.
West Jordan, Utah 84081
(801) 280-0701

© 2024 CoreBrace™, LLC This drawing is proprietary to CoreBrace™, LLC. Not to be duplicated or used without the express written consent of CoreBrace™, LLC. Moreover, CoreBrace™, LLC is not responsible for the use of this drawing by others without its knowledge and consent.

CoreBrace Engineering Design Responsibilities are limited to the following:
- Complete BRB design based on A_{sc} provided by E.O.R.
- Design connection of BRB to gusset.
- Design gusset connection to frame columns, beams and base plates.

General Notes:
1. See "Casing Buried in Concrete Detail" where concrete slab will interfere with required BRB stroke.
2. Structural steel detailer and erection team to consider erectability constraints when determining piece erection sequencing and field welding versus shop welding of stiffeners and gussets.
3. Detail callouts are typical at the given frame location, UNO. See "CB" sheets for typical details.
4. Single-line diagrams do not necessarily represent WP axis of members, see details.
5. Member sizes, dimensions, elevations, and work point locations on CB sheets are shown for coordination only. Project documents shall govern. Verify in field as necessary.
6. See project documents for additional information; more stringent requirements on project documents shall govern.

Abbreviations

Abt	About	DIA	Diameter	NTS	Not to Scale
Approx	Approximate	DIM	Dimension	PL	Plate
Asc	Area of Steel Core	dc	Depth of column	Req'd	Required
btb	Width of flange of beam	(E)	Existing	Sched	Schedule
bfc	Width of flange of column	EQ	Equal	SIM	Similar
Bldg	Building	FF	Finished Floor	SYM	Symetrical
Bm	Beam	FHG	Full-Height Gusset	Stiff	Stiffener
Bot	Bottom	Flng	Flange	tfb	Thickness of flange of beam
B.P.	Base Plate	Galv	Galvanized	tfc	Thickness of flange of column
BRB	Buckling-Restrained Brace	Gsst	Gusset	T&B	Top and Bottom
CB	CoreBrace	Info	Information	T.O.F.	Top of Footing
CJP	Complete Joint Penetration	LVL	Level	T.O.C	Top of Concrete
C_L	Centerline	MAX	Maximum	twb	Thickness of web of beam
Col	Column	MIN	Minimum	TYP	Typical
Conc	Concrete	N&FS	Near and Far Side	UNO	Unless Noted Otherwise
Conn	Connection	Nom	Nominal	WP	WORK POINT

Symbols Legend:

X = BASE PL THICKNESS
Y = GROUT THICKNESS
I INDICATES FRAMING OF GUSSET PL TO COLUMN WEB (WEAK AXIS)
H INDICATES FRAMING OF GUSSET PL TO COLUMN FLANGE (STRONG AXIS)
□ INDICATES FRAMING OF GUSSET PL TO HSS COLUMN (SLOT GUSSET THROUGH)

CB-XX INDICATES BRB WITH CORE AREA SIZE OF XX in^2
T.O.S. = X'-X" INDICATES TOP OF STEEL BEAM ELEVATION
19## BRACE MARK IDENTIFICATION

PROJECT:

PSE Operational Training Center

PUYALLUP, WA.

REV	DATE	DESCRIPTION
/0	2024-05-28	FOR APPROVAL
/1	2024-07-18	FOR FIELD USE

ADDITIONAL NOTES:

CoreBrace 20 ANNIVERSARY 2002 - 2022 SUPERIOR SEISMIC PERFORMANCE
5789 West Wells Park Rd.
West Jordan, Utah 84081
(801) 280-0701

SHEET TITLE:

COREBRACE BRB FRAME ELEVATIONS

DRAWN BY: BP	DATE: 2024-07-18
CHECKED BY: FH	REV #: 1
SCALE: NONE	PROJECT NUMBER: 5872
SHEET NUMBER: CB-01	

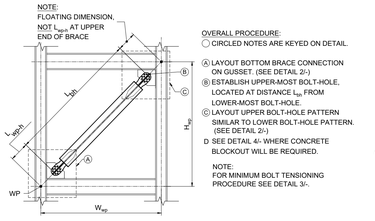
PRCNC20240216 - Revision 2 (Brace Frame)

NOTE:
FLOATING DIMENSION, NOT $L_{sys.ft}$ AT UPPER END OF BRACE

OVERALL PROCEDURE:
○ CIRCLED NOTES ARE KEYED ON DETAIL.

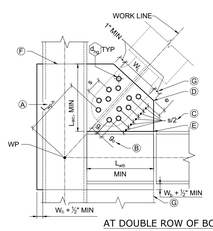
Ⓐ LAYOUT BOTTOM BRACE CONNECTION ON GUSSET. (SEE DETAIL 2/-)
Ⓑ ESTABLISH UPPER-MOST BOLT-HOLE, LOCATED AT DISTANCE L_{sh} FROM LOWER-MOST BOLT-HOLE.
Ⓒ LAYOUT UPPER BOLT-HOLE PATTERN SIMILAR TO LOWER BOLT-HOLE PATTERN. (SEE DETAIL 2/-)
D SEE DETAIL 4/- WHERE CONCRETE BLOCKOUT WILL BE REQUIRED.

NOTE:
FOR MINIMUM BOLT TENSIONING PROCEDURE SEE DETAIL 3/-

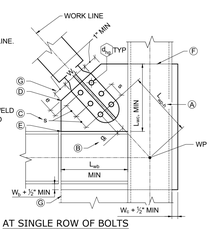


BOLTED GUSSET OVERALL LAYOUT PROCEDURE 1
SCALE: NTS

GUSSET LAYOUT PROCEDURE:
Ⓐ ESTABLISH LOCATION OF 1ST BOLT LINE ALONG WORK LINE.
Ⓑ ESTABLISH INNER AND OUTER (WHERE APPLICABLE) BOLT ROW OFFSETS WITH g_i AND g_o.
Ⓒ LAY OUT BOLT HOLE PATTERN USING HOLE SIZE (d_{sh}), SPACING (s), AND EDGE DISTANCE (e) AS SHOWN.
Ⓓ W_s + 2 x MIN RETURN, GUSSET EDGE WIDTH PERPENDICULAR TO WORK LINE.
Ⓔ RETURN TO BEAM AND/OR COLUMN AND VERIFY MIN WELD LENGTH (INCLUDING DEDUCTIONS FOR CLIP AND WELD START/STOP) IS MAINTAINED.
Ⓕ SLOT GUSSET THROUGH COLUMN. INDICATED WELD SIZE REQUIRED ON BOTH SIDES OF COLUMN AND BOTH SIDES OF GUSSET (4 TOTAL WELDS)
Ⓖ WHERE GUSSET PLATE CONTINUES THROUGH BEAM DEPTH, EXTEND EDGE OF GUSSET TO ALIGN WITH GUSSET ON OTHER SIDE OF BEAM.



AT DOUBLE ROW OF BOLTS



AT SINGLE ROW OF BOLTS

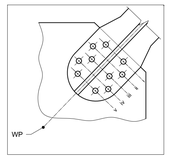
BOLTED FHG/HSS GUSSET LAYOUT PROCEDURE 2
SCALE: NTS

BOLT TENSIONING PROCEDURE
Bolts shall be torqued to achieve the appropriate bolt tension as set forth in the erector's approved procedures. As a minimum, the following items shall be adhered to:

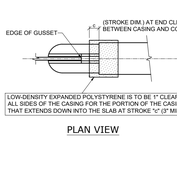
A. Starting with the most rigid part of the connection (Row '1') and continuing to the least rigid part of the connection (Row 'x'), bring all bolts to snug-tight condition.
B. Recheck snug-tight condition of bolts in rows '1' and 'ii', re-tighten as necessary.
C. Torque bolts in Row '1' to appropriate level of tension using approved procedure.
D. Re-check snug tight condition of bolt in row 'iii'.
E. Torque bolts in Row 'ii' to appropriate level using approved procedure.
F. Continue alternating check of snug tight condition of next-to-nearest row and torquing nearest row of untorged bolts as set forth in steps D & E until end of brace is reached and all bolts are at appropriate level of torque.
G. Repeat similar procedure at top end of brace.

GENERAL NOTES:
ALL BOLTED BRACE CONNECTIONS SHALL BE INSTALLED IN ACCORDANCE WITH THE ERECTOR'S APPROVED QUALITY ASSURANCE PLAN. AS A MINIMUM, THE FOLLOWING MUST BE MET:

- Tighten all slip-critical bolts and bolts installed in oversized holes by a method approved by the engineer of record. Provide hardened washers under all turned elements.
- Where ASTM F3125 Gr A490-SC/F2280-TC or stronger bolts are specified in the drawings, provide hardened washer between nut & gusset. Where required by AISC Specifications, provide washer between bolt head & gusset.
- Bolts must be long enough for the threads to be flush with the outside face of the nut after tightening. Thread stickout shall not exceed that allowed by structural drawings.
- Do not reuse bolts, nuts, or washers.



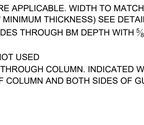
MINIMUM BOLT TENSIONING PROCEDURE 3
SCALE: NTS



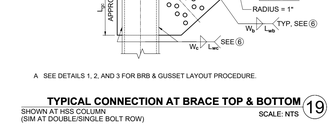
PLAN VIEW

INDICATED CLEARANCES REPRESENT BLOCKOUT CONDITIONS REQUIRED FOR FINAL INSTALLED STATE OF BRB. LARGER BLOCKOUTS MAY BE REQUIRED FOR INSTALLATION. LOW-DENSITY EXPANDED POLYSTYRENE PROVIDED BY OTHERS.

BRB CASING BURIED IN CONCRETE - TYPICAL DETAIL 4
SCALE: NTS

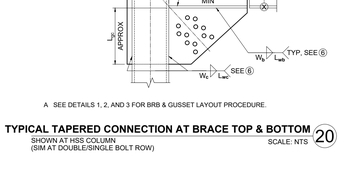


SECTION A-A



PLAN VIEW

TYPICAL CORE PLATE DETAIL 6
SCALE: NTS

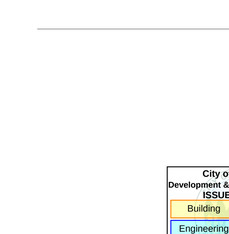


ELEVATION VIEW
DOUBLE BOLT ROW

TYPICAL END CONNECTION DETAIL 8
SCALE: NTS

NOTE: BOLT HOLES IN CONNECTION LUGS ARE STANDARD HOLES.

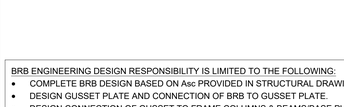
TYPICAL END CONNECTION DETAIL 10
SCALE: NTS



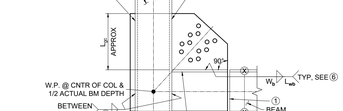
SHADED REGIONS INDICATE PROTECTED ZONES

BRB PROTECTED ZONES SHALL INCLUDE THE STEEL CORE AND CONNECTION ELEMENTS AND SHALL SATISFY THE REQUIREMENTS OF SECTION F4.5c OF AISC 341. ADDITIONALLY, ATTACHMENTS WHICH PENETRATE THE CASING (SCREWS, PAF, ETC) OR ANY ATTACHMENT SUPPORTING OVER 50 LBS SHALL BE APPROVED BY THE ENGINEER OF RECORD AND COREBRACE.

PROTECTED ZONES - AISC 341 13
SCALE: NTS



TYPICAL CORE AND CASING CONFIGURATION 5
SCALE: NTS



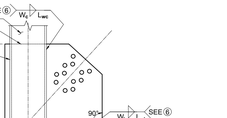
ELEVATION VIEW

TYPICAL CORE PLATE DETAIL 7
SCALE: NTS

ELEVATION VIEW
SINGLE BOLT ROW

TYPICAL END CONNECTION DETAIL 9
SCALE: NTS

NOTE: BOLT HOLES IN CONNECTION LUGS ARE STANDARD HOLES.



NOTES:
Ⓐ NOT USED
Ⓑ FOR STIFFENER THICKNESS REQUIREMENTS, SEE CONNECTION SCHEDULE
USE 5/16" FILLET WELD FOR THICKNESSES < 1.25", 3/8" FILLET WELD FOR THICKNESSES ≤ 2.0", UNO FOR STIFF PLATES > 2" CONTACT COREBRACE FOR FILLET WELD SIZE.

STIFF PL TO MEMBER 11
SCALE: NTS

PLAN VIEW

FLANGE PLATES TO HSS COLUMN CONNECTION 12
SCALE: NTS

GENERAL NOTES:
G1. SEE PROJECT DRAWINGS FOR ADDITIONAL INFORMATION
G2. DIMENSIONS AND WP LOCATIONS FROM PROJECT DRAWINGS GOVERN. CONTACT COREBRACE PRIOR TO DETAILING IF ANY DISCREPANCIES ARE NOTED.
G3. CORE PL A36 SPECIAL (FY RANGE PROVIDED ON COREBRACE SCHEDULE)
G4. CASING A500 GR B FOR HSS AND A53 GR B FOR PIPE
G5. BRB LUG PLATE (TRANSVERSE STIFFENER) A572 GR 50
G6. GUSSET PL, GUSSET STIFFENER AND REPAD PL A572 GR 50 U.N.O.
G7. ALL STIFFENERS AND DOUBLER PL TO MATCH BEAM AND COLUMN GRADE.
G8. USE ASTM F3125 GR A490-SC/F2280-TC OR ASTM F3148 TNA BOLTS. BOLT HOLES IN GUSSET ARE OVERSIZED. BOLT HOLES IN BRB ARE STANDARD. ***(BOLTS AND WASHERS ARE NOT PROVIDED BY COREBRACE)***
G9. CLASS A (TOOL CLEAN) ALL FAYING SURFACES.
G10. GALVANIZED FAYING SURFACES TO BE HAND WIRE BRUSHED PRIOR TO ERECTION OF BRB.
G11. THE GAP BETWEEN THE BOLTED CONNECTION PLATES AT THE END OF THE BRB SHALL NOT BE INCREASED EXCEPT IN INSTANCES WHERE SPECIFIC APPROVAL AND METHODOLOGY HAVE BEEN PROVIDED BY COREBRACE.

CONNECTION NOTES:
○ CIRCLED NOTES ARE KEYED ON CONNECTION DETAILS.

① SEE STRUCTURAL DRAWINGS FOR COLUMN/BEAM/BASE PLATE CONNECTION, TYP.
② SEE CONNECTION SCHEDULE FOR CONNECTION DIMENSIONS.
③ SEE COREBRACE SCHEDULE FOR BRB GEOMETRY DIMENSIONS.
④ MAIN STIFF PL EA SIDE AS REQ'D BY STRUCTURAL DRAWINGS OR AS INDICATED ON CONNECTION SCHEDULE. SEE DETAIL 11.
⑤ FIELD INSTALL STIFF PL AS NECESSARY FOR INSTALLATION OF BRACE.
⑥ WELD BOTH SIDES. WHERE AVAILABLE WELD LENGTH IS LONGER THAN REQ'D WELD LENGTH, PROVIDE WELD ALONG ENTIRE LENGTH TO WITHIN 3/4" OF EDGE OF PL.
⑦ TOP AND BOTTOM FLANGE LATERAL BRACING AS REQUIRED BY STRUCTURAL DRAWINGS.
⑧ THROUGH ⑩ NOT USED

⑪ STIFF PL TO EACH SIDE OF GUSSET OR SINGLE CONTINUOUS STIFF PL WHERE APPLICABLE. WIDTH TO MATCH BEAM AND COLUMN WIDTH. (L_{sh} + 1/4" MINIMUM THICKNESS) SEE DETAIL 12 AND NOTE 5.
⑫ WELD BOTH SIDES THROUGH BM DEPTH WITH $5/16"t_g$

⑬ THROUGH ⑭ NOT USED
⑮ SLOT GUSSET THROUGH COLUMN. INDICATED WELD SIZE REQUIRED ON BOTH SIDES OF COLUMN AND BOTH SIDES OF GUSSET (4 TOTAL WELDS).

BRB ENGINEERING DESIGN RESPONSIBILITY IS LIMITED TO THE FOLLOWING:
- COMPLETE BRB DESIGN BASED ON Asc PROVIDED IN STRUCTURAL DRAWINGS.
- DESIGN GUSSET PLATE AND CONNECTION OF BRB TO GUSSET PLATE.
- DESIGN CONNECTION OF GUSSET TO FRAME COLUMNS & BEAMS/BASE PLATES.

COREBRACE™
SUPERIOR SEISMIC PERFORMANCE

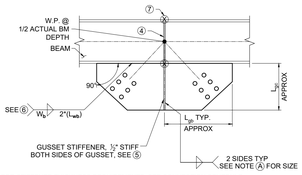
5789 W. Wells Park Rd.
West Jordan, Utah 84081
(801) 280-0701

A SEE DETAILS 1, 2, AND 3 FOR BRB & GUSSET LAYOUT PROCEDURE.

TYPICAL FHG CONNECTION AT BRACE TOP 14
SHOWN AT HSS COLUMN
SCALE: NTS

NOT USED 15
SCALE: NTS

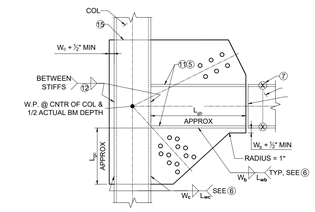
NOT USED 27
SCALE: NTS



Ⓐ FOR STIFFENER THICKNESS REQUIREMENTS, SEE CONNECTION SCHEDULE
USE 5/16" FILLET WELD FOR THICKNESSES < 1.25", 3/8" FILLET WELD FOR THICKNESSES ≤ 2.0", UNO FOR STIFF PLATES > 2" CONTACT COREBRACE FOR FILLET WELD SIZE.

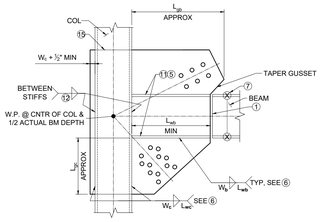
TYPICAL CONNECTION AT CHEVRON TOP 17
SHOWN WITH SINGLE BOLT ROW (SIM AT DOUBLE BOLT ROW)
SCALE: NTS

NOT USED 18
SCALE: NTS



A SEE DETAILS 1, 2, AND 3 FOR BRB & GUSSET LAYOUT PROCEDURE.

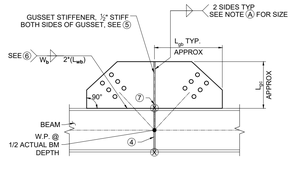
TYPICAL CONNECTION AT BRACE TOP & BOTTOM 19
SHOWN AT HSS COLUMN
(SIM AT DOUBLE/SINGLE BOLT ROW)
SCALE: NTS



A SEE DETAILS 1, 2, AND 3 FOR BRB & GUSSET LAYOUT PROCEDURE.

TYPICAL TAPERED CONNECTION AT BRACE TOP & BOTTOM 20
SHOWN AT HSS COLUMN
(SIM AT DOUBLE/SINGLE BOLT ROW)
SCALE: NTS

NOT USED 21
SCALE: NTS



Ⓐ FOR STIFFENER THICKNESS REQUIREMENTS, SEE CONNECTION SCHEDULE
USE 5/16" FILLET WELD FOR THICKNESSES < 1.25", 3/8" FILLET WELD FOR THICKNESSES ≤ 2.0", UNO FOR STIFF PLATES > 2" CONTACT COREBRACE FOR FILLET WELD SIZE.

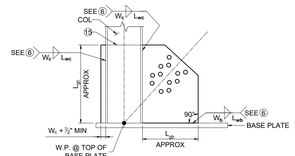
TYPICAL CONNECTION AT CHEVRON BOT 22
SHOWN WITH SINGLE BOLT ROW (SIM AT DOUBLE BOLT ROW)
SCALE: NTS

NOT USED 23
SCALE: NTS

A SEE DETAILS 1, 2, AND 3 FOR BRB & GUSSET LAYOUT PROCEDURE.

TYPICAL FHG CONNECTION AT BRACE BOTTOM 24
SHOWN AT HSS COLUMN
SHOWN WITH DOUBLE BOLT ROW (SIM AT SINGLE BOLT ROW)
SCALE: NTS

NOT USED 25
SCALE: NTS



A SEE DETAILS 1, 2, AND 3 FOR BRB & GUSSET LAYOUT PROCEDURE.

TYPICAL CONNECTION AT BASEPLATE 26
SHOWN AT HSS COLUMN
WP AT TOP OF BASE PLATE
SHOWN WITH DOUBLE BOLT ROW (SIM AT SINGLE BOLT ROW)
SCALE: NTS

City of Puyallup
Development & Permitting Services
ISSUED PERMIT

Building	Planning
Engineering	Public Works
Fire	Traffic

Welding to be completed by an individual or fabricator who is WABO certified or approved by the Building Official to perform the work. All welds must be inspected and approved by a WABO certified special inspector.

PROJECT:

PSE Operational Training Center

PUYALLUP, WA.

REV	DATE	DESCRIPTION
0	2024-05-28	FOR APPROVAL
1	2024-07-18	FOR FIELD USE

ADDITIONAL NOTES:

COREBRACE
SUPERIOR SEISMIC PERFORMANCE
20 YEARS ANNIVERSARY 2002 - 2022
5789 West Wells Park Rd.
West Jordan, Utah 84081
(801) 280-0701

SHEET TITLE:

COREBRACE BRACE AND GUSSET CONNECTION DETAILS

DRAWN BY: BP	DATE: 2024-07-18
CHECKED BY: FH	REV #: 1
SCALE: NONE	PROJECT NUMBER: 5872
SHEET NUMBER: CB-02	

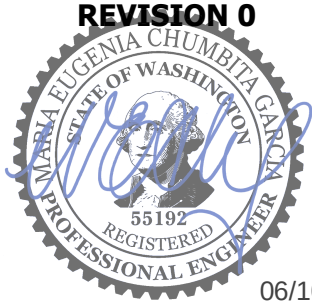
| | | | | | | | | | Casing | | | | | | | | |

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning
Engineering | Public Works
Fire | Traffic

PRCNC20240216 - Revision 2 (Brace Frame)

PSE Operational Training Center
CALCULATIONS
SUBMITTAL

REVISION 0



06/10/2024

May 29, 2024

CoreBrace Project #5872

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

www.CoreBrace.com

Calculations required to be provided by the Permittee on site for all Inspections

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building
Planning
Engineering
Public Works
Fire
Traffic

PSE Operational Training Center

Calculation Submittal Package

Description

Section 1 Strain, β, and ω Determination and Summary Tables

Section 2 Buckling Calculation and Summary Tables

Section 3 Brace End Connection Sample Calculation and Summary Tables

Section 4 Bottom Gusset Beam to Column Flange (Strong-Axis) Connection Sample Calculation and Summary Tables

Section 5 Not Used

Section 6 Chevron Gusset Connection Sample Calculation and Summary Tables

Section 7 Stiffness Sample Calculation and Summary Tables

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building
Planning
Engineering
Public Works
Fire
Traffic

PSE Operational Training Center

Calculation Submittal Package

Description

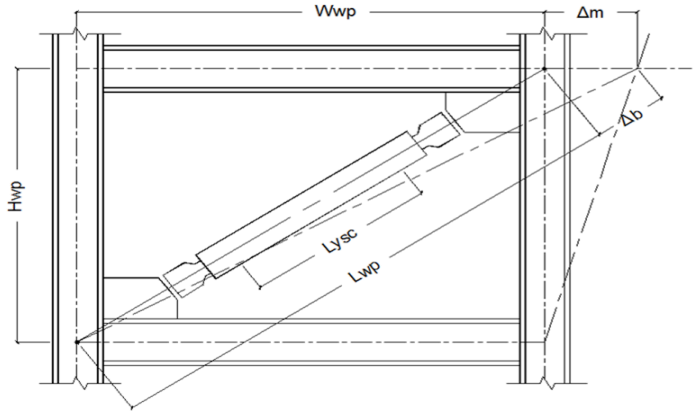
Section 1. Strain, β, and ω Determination and Submittal Tables

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning
Engineering | Public Works
Fire | Traffic

Strain and Overstrength Calculation

Example Mark #: 1901

Line 4.1, Grid D.3 to D(+), Level Low Roof



1.0 DESIGN CRITERIA

Width Between Workpoints	W_{wp}:	153.88 in	*(3908 mm)*
Height Between Workpoints	H_{wp}:	79.75 in	*(2026 mm)*
Yielding Core Length	L_{ysc}:	74.46 in	*(1891 mm)*
Workpoint Length Along Diagonal $L_{wp} = \sqrt{(W_{wp}^2+H_{wp}^2)}$	L_{wp}:	173.31 in	*(4402 mm)*
Yield Stress of Core Material for Establishing Area	$F_{y\text{-}min}$:	38 ksi	*(262 MPa)*
Maximum Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Modulus of Elasticity	E:	29000 ksi	*(199955 MPa)*
LRFD Resistance Factor	ϕ_{BRB}:	0.90	
Deflection Amplification Factor	C_d:	5.00	
Demand Capacity Ratio	DCR:	1.00	
Importance Factor	I_E:	1.00	
Redundancy Factor	ρ:	1.00	
Specified Story Drift to Consider (Typically 1.0% Minimum unless NLRHA)	SSD:	1.00%	
The displacements and strains assocaited with this value will later be multiplied by 2, so 2% minimum is typically being considered.			
Area of Yielding Steel Core	A_{sc}:	2.00 in²	*(1290 mm²)*

1.1 STRAIN CALCULATION

Minimum Yield Force in Steel Core $(F_{y\text{-}min}\cdot A_{sc})$	$P_{ysc,min}$:	76 kip	*(338 kN)*
Maximum yield Force in Steel Core $(F_{y\text{-}max}\cdot A_{sc})$	$P_{ysc,max}$:	92 kip	*(409 kN)*
Final Width Between Workpoints after Specified Story Drift			
$W_f = W_{wp}+(SSD\cdot H_{wp})$	W_f:	154.67 in	*(3929 mm)*
$\Delta_{mSSD} = W_f - W_{wp}$ (for reference only)	Δ_{mSSD}:	0.80 in	*(20 mm)*
Final WP Length Along Diagonal After Specified Story Drift			
$L_f = \sqrt{(W_f^2+H_{wp}^2)}$	L_f:	174.02 in	*(4420 mm)*
Yielding Core Elongation at Specified Story Drift $(L_f - L_{wp})$	Δ_{bSSD}:	0.71 in	*(18 mm)*
Core Strain at Considered Story Drift (Δ_{bSSD}/L_{ysc})	ε_{bSSD}:	0.95%	
Core Strain at Design Story Drift (Cd*Yield Strain)			
Force for Elastic Drift Determination $P_d=\phi P_{ysc,min}/(\rho\cdot I)\cdot DCR$	P_d:	68 kip	*(304 kN)*
Stiffness of Yeilding Core $K_{Lysc}=A_{sc}\cdot E/L_{ysc}$	K_{Lysc}:	779 k/in	*(136 kN/mm)*
Core Deformation at Yield $\Delta_{by}=P_d/K_{Lysc}$	Δ_{by}:	0.09 in	*(2 mm)*
Core Deformation at Design Story Drift $\Delta_{bCd}=\Delta_{by}\cdot C_d$	Δ_{bCd}:	0.44 in	*(11 mm)*
Core Strain at Design Story Drift $\varepsilon_{bCd} = \Delta_{bCd}/L_{ysc}$	ε_{bCd}:	0.59%	
Note, identical results are found by calculating the strain with the following equation,			
$\varepsilon_{bCd} = \phi\cdot C_d\cdot(F_y/E)\cdot DCR/(I_E\cdot\rho)$, and then backing out the deformation, $\Delta_{bCd} = \varepsilon_{bCd}\cdot L_{ysc}$			
$\Delta_{mCd} = \Delta_{bCd}/COS(TAN^{-1}(H_{wp}/W_{wp}))$ (for reference only)	Δ_{mCd}:	0.49 in	*(13 mm)*
Required Stroke at Each End of Brace (½ of 2x Max of Δ_{bCd} & Δ_{bSSD})	$c_{req'd}$:	0.71 in	*(18 mm)*
Provided Stroke Distance at Each End of Brace	c:	3.00 in	*(76 mm)*
Controlling Strain (Max of ε_{bSSD} & ε_{bCd})	$\varepsilon_{b,max}$:	0.95%	
Strain at 2*$\varepsilon_{b,max}$	ε_{max}:	1.90%	

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning
Engineering | Public Works
Fire | Traffic

1.2 DETERMINE OVERSTRENGTH FACTORS AT ε_{max} - SEE BACKBONE CURVES

Qualifying Similarity Test per AISC 341 K3.3	Similarity (K3.3) Test:	10P	
Yield Force of Test Specimen	P_y:	86 kip	*(382 kN)*
Test Extrapolation Range Downward per AISC 341-16	Extrapolation Downward	83%	
Minimum Qualified Yield Force	$P_{y,min}$:	72 kip	*(318 kN)*
Test Extrapolation Range Upward per AISC 341-16	Extrapolation Upward	333%	
Maximum Qualified Yield Force	$P_{y,max}$:	286 kip	*(1273 kN)*
Compression Strength Adjustment Factor at ε_{max}	$\beta_{K3.3}$	1.17	
Strain Hardening Adjustment Factor at ε_{max}	$\omega_{K3.3}$	1.38	
Qualifying Sub-Assemblage Test per AISC 341 K3.2	Subassemblage (K3.2) Test	3P	
Yield Force of Test Brace	P_y:	376 kip	*(1673 kN)*
Compression Strength Adjustment Factor at ε_{max}	$\beta_{K3.2}$	1.13	
Strain Hardening Adjustment Factor at ε_{max}	$\omega_{K3.2}$	1.32	
Maximum Compression strength adjustment factor at ε_{max}	β_{max}	1.17	
Maximum Strain hardening adjustment factor at ε_{max}	ω_{max}	1.38	

These values may be increased for length effects where applicable. Design values may be larger.

Adjusted Brace Strength in Compression: $ABS_T = A_{sc} \cdot F_{y\text{-}max} \cdot \omega = P_{ysc,max} \cdot \omega$	**P_{uT}:**	**127 kip**	*(564 kN)*
Adjusted Brace Strength in Compression: $ABS_C = A_{sc} \cdot F_{y\text{-}max} \cdot \beta \cdot \omega = P_{ysc,max} \cdot \beta \cdot \omega$	**P_{uC}:**	**148 kip**	*(658 kN)*

1.3 BRACE ROTATIONAL DEMAND

2x Story Drift Rotation = $2*MAX(\Delta_{m1\%}, \Delta_{mCd})/H_{wp}$

$\delta = 2*MAX(\Delta_{m1\%}, \Delta_{mCd})/H_{wp}$ Equal to Assumed (Conservative) Translational Demand — δ: 0.02 rad

Assumed story drift rotation is considered conservative based on the following:

$\Delta_m = \delta \cdot H$ *Maximum Story Drift for Project* — Δ_m: 1.60 in *(41 mm)*

$\Delta_t \le \Delta_m$ $\delta_t = \Delta_t / L_{wp}$ *Where Δ_t is the translation of the brace/beam joint and L_{wp} is the length of the brace*

$L_b \ge H$ *Where H is the story height*

$\Delta_m/H = \delta \cdot H/H = \delta =$ 0.02 rad

Since $\Delta_t \le \Delta_m$ and $L_b \ge H$ Then: $\Delta_t/L_b \le \Delta_m/H \rightarrow \delta_t \le \delta$

$\theta_{CB} = \tan^{-1}(H_{wp}/W_{wp})$ *Angle between Horiz and BRB before rotation* — θ_{CB}: 0.478 rad

$\Delta_t = \Delta_m \cdot \sin(\Theta_{CB})$ — Δ_t: 0.73 in *(19 mm)*

$\delta_t = \Delta_t / L_{wp}$ — δ_t: 0.004 rad

Alternate Method:

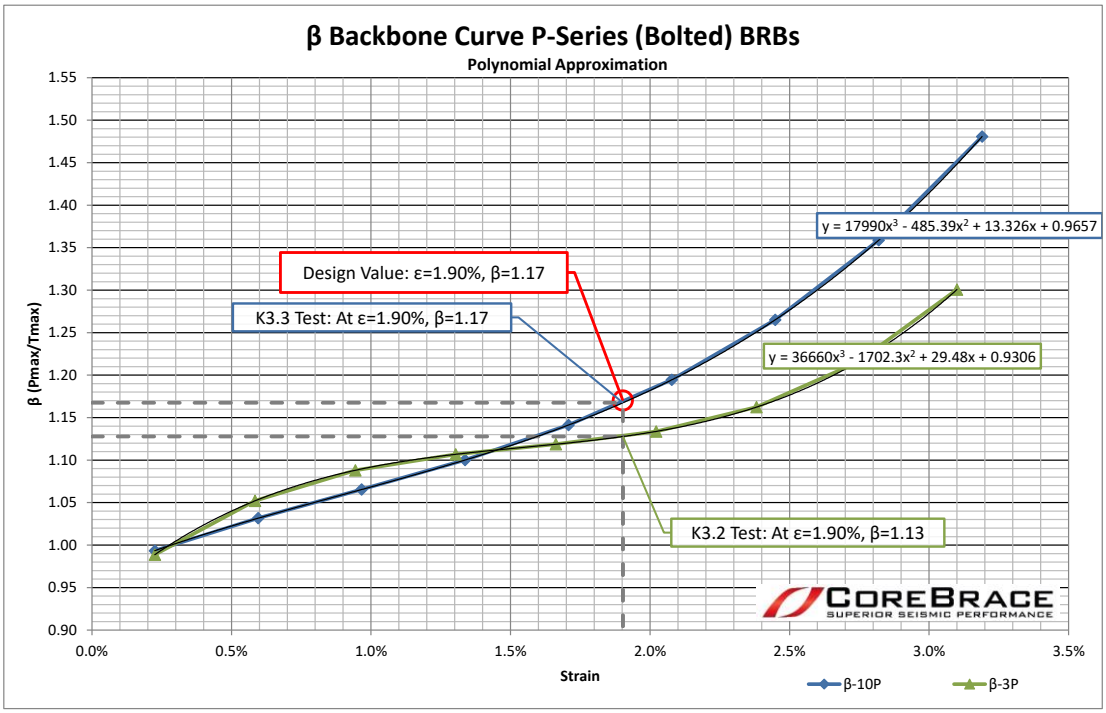
$\theta'_{CB} = \tan^{-1}(H_{wp}/(W_{wp}+\Delta_m))$ *Angle between Horiz and BRB after rotation* — θ_{CB}: 0.474 rad

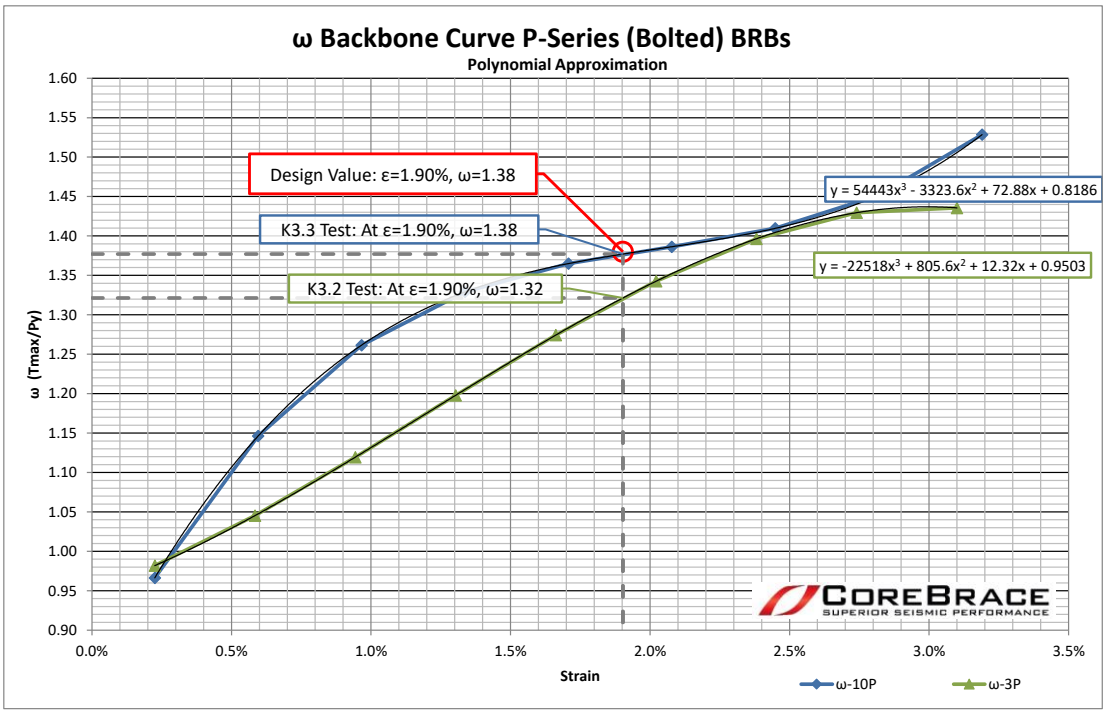
$\delta_{t\text{-}alt} = \theta_{CB} - \theta'_{CB}$ — δ_t: 0.004 rad

Therefore 0.02 Radians is Conservative

Tested Capacity from Test Report Must Equal 0.004 Radians. -- CoreBrace OK

1.4 BACKBONE CURVES





City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning | Engineering | Public Works | Fire | Traffic

COREBRACE STRAIN CALCULATIONS

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

| | | |

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning
Engineering | Public Works
Fire | Traffic

PSE Operational Training Center

Calculation Submittal Package

Description

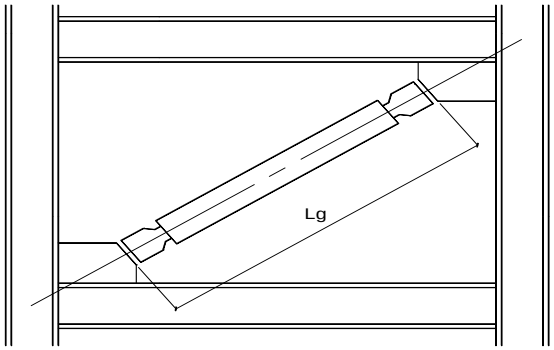
Section 2. **Casing Buckling Calculations**
Casing Buckling Summary Tables

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning
Engineering | Public Works
Fire | Traffic

Buckling Calculation

Example Mark #: 1901

Line 4.1, Grid D.3 to D(+), Level Low Roof



2.0 DESIGN CRITERIA

Tip of gusset to tip of gusset is set as buckling length	L_g:	109.62 in	*(2784 mm)*
Compresssion Strength Adjustment Factor	β:	1.17	
Strain Hardening Adjustment Factor	ω:	1.38	
Upper Bound Yield Strength of Brace (A_{sc}·$F_{y\text{-}max}$)	$P_{ysc\text{-}max}$:	92.0 kip	*(409 kN)*
Upper Bound Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Area of Steel Core	A_{sc}:	2.00 in²	*(1290 mm²)*
Ultimate Load (Adjusted Brace Strength in Compression): P_u = ($P_{ysc\text{-}max}$·β·ω) = ABS_C	P_u:	148.5 kip	*(661 kN)*
Modulus of Elasticity	E:	29000 ksi	*(199955 MPa)*
Model Brace as Pinned Both Ends (conservative)	k:	1.0	
Casing Moment of Inertia **t7x1/4**	I_c:	46.5 in⁴	*(1935 cm⁴)*

2.1 Euler Buckling

Solving Euler's buckling equation for required moment of inertia:

$$I_{Ig} = \frac{FS_B \cdot P_u \cdot \left(k \cdot L_g\right)^2}{\pi^2 E}$$

	I_{Ig}:	7.9 in⁴	*(329 cm⁴)*

Where:

FS_B = Factor of Safety Against Buckling: *Verified by Testing*

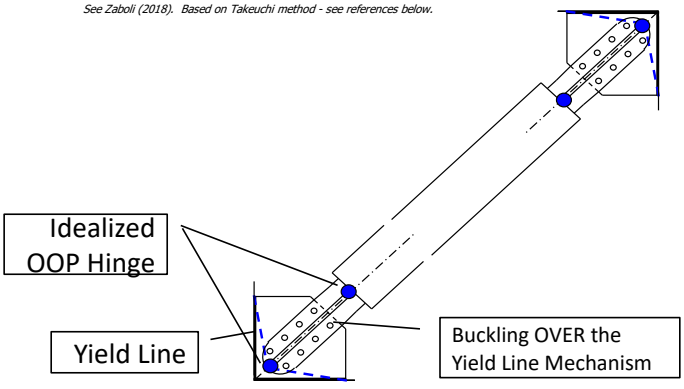
FS_B:	1.27	

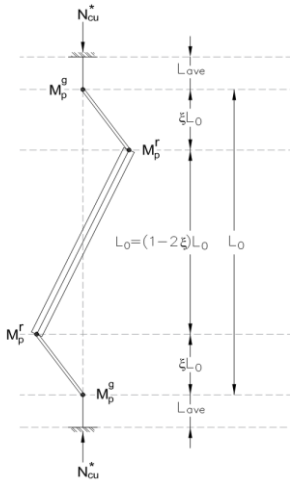
Unity Check:

I'_g/I_c:	0.17	**OK**

2.2 Global Stability (Notional Load Yield Line Method) - Asymmetrical Modes

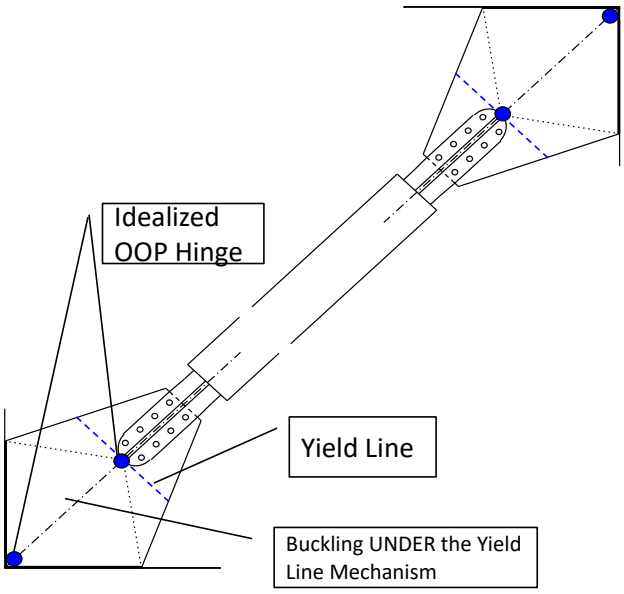
See Zaboli (2018). Based on Takeuchi method - see references below.

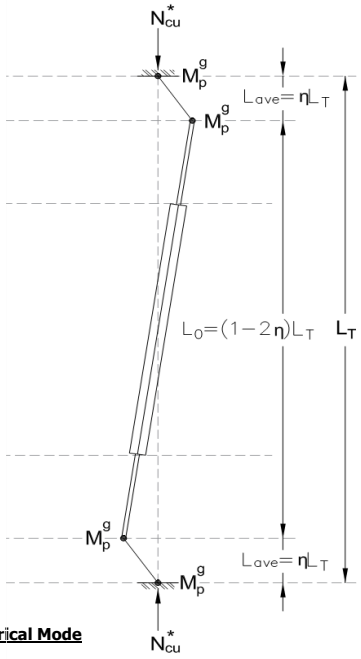




Over-the-Yield Line (OYL) - Asymmetrical Mode

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning
Engineering | Public Works
Fire | Traffic



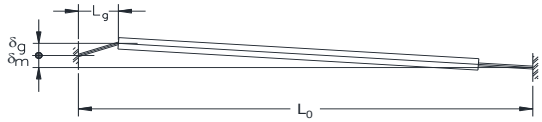


Under-the-Yield Line (UYL) - Asymmetrical Mode

2.2.1 NLYL Method Design Criteria

Overall Brace Length	L_0:	114.48 in	*(2908 mm)*
Additional Out-of-Plane Force on BRB *(half assumed to go to each end)*:	$F_{Add'l\text{-}OOP}$	0.0 kip	*(0 kN)*
Initial Imperfection of Neck Insertion Zone	θ_0:	0.007 rad	
Assumed Out-of-Plumbness of Brace: $\delta_m/L_0 = 1/x_{\delta m}$	$x_{\delta m}$:	500	
Assumed Out-of-Flatness of Gusset Plate: $\delta_g/L_g = 1/x_{\delta g}$	$x_{\delta g}$:	100	

Values of $x_{\delta m}$ and $x_{\delta g}$ per Dowswell (2016) recommendations. Imperfection of Neck per Takeuchi (2014).



Initial Imperfection per Dowswell (2016)

Critical Gusset Dimensions: Top Gusset

Top Gusset is Chev?		$Chev_{Top}$:	FALSE	
Top Gusset is Stiffened?		$Stiff_{Top}$:	FALSE	
Is gusset stiffened sufficiently for Kb to be reduced? Can be "FALSE" even if stiffeners are present.				
Stiffener Width		$W_{stiff,top}$:	-	-
Stiffener Thickness		$t_{stiff,top}$:	-	-
Gusset Thickness		$t_{g,top}$:	0.63 in	*(16 mm)*
Projected Stiffener Plastic Section Modulus *(Proj per Dowswell. All stiff's combined.)*		$Z_{stiff,top}$:	-	-
Yield Strength of Gusset Material		$F_{yg,top}$:	50 ksi	*(345 MPa)*
Ultimate Strength of Gusset Material		$F_{ug,top}$:	65 ksi	*(448 MPa)*
Length from WL Intersection w/Beam or Col along WL to Tip of Brace		a_{top}:	6.71 in	*(170 mm)*
Clear from Col to Lug Edge		b_{top}:	17.54 in	*(446 mm)*
Clear from Beam to Lug Edge		c_{top}:	1.00 in	*(25 mm)*
Controlling Bendline Length, Gusset Edge to Brace Tip:	Bm Side	$L_{b,top}$:	8.38 in	*(213 mm)*
	Col Side	$L_{c,top}$:	7.57 in	*(192 mm)*

Critical Gusset Dimensions: Bottom Gusset

Bottom Gusset is Chev?		V_{Bot}:	TRUE	
Bottom Gusset is Stiffened?		$Stiff_{Bot}$:	FALSE	
Is gusset stiffened sufficiently for Kb to be reduced? Can be "FALSE" even if stiffeners are present.				
Stiffener Width		$W_{stiff,bot}$:	-	-
Stiffener Thickness		$t_{stiff,bot}$:	-	-
Gusset Thickness		$t_{g,bot}$:	0.63 in	*(16 mm)*
Projected Stiffener Plastic Section Modulus *(Proj per Dowswell. All stiff's combined.)*		$Z_{stiff,bot}$:	-	-
Yield Strength of Gusset Material		$F_{yg,bot}$:	50 ksi	*(345 MPa)*
Ultimate Strength of Gusset Material		$F_{ug,bot}$:	65 ksi	*(448 MPa)*
Length from WL Intersection w/Beam or Col along WL to Tip of Brace		a_{bot}:	16.49 in	*(419 mm)*
Clear from Col to Lug Edge		b_{bot}:	28.97 in	*(736 mm)*
Clear from Beam to Lug Edge		c_{bot}:	5.50 in	*(140 mm)*
Controlling Bendline Length, Gusset Edge to Brace Tip:	Bm Side	$L_{b,bot}$:	10.68 in	*(271 mm)*
	Col Side	$L_{c,bot}$:	7.57 in	*(192 mm)*

Core Dimensions and Properties

Ultimate Stress of Core Material	F_{usc}:	66 ksi	*(455 MPa)*
Core Width at Neck Section	W_t:	4.00 in	*(102 mm)*
Core Thickness	t_{sc}:	0.50 in	*(13 mm)*
Neck Insertion Length for Out-of-Plane Buckling Direction	L_{in}:	7.13 in	*(181 mm)*

Note that L_{in}/W_t = Embedment Ratio = 1.78

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning
Engineering | Public Works
Fire | Traffic

Lug and Bolt Pattern Dimensions			
Width of Lug Plate	W_L:	6.00 in	*(152 mm)*
Width of Lug at Neck Section	W_1:	3.61 in	*(92 mm)*
Length of Lug on Gusset Measured to Square Projection	L'_{Lg}:	5.88 in	*(149 mm)*
Transition Length, W_L to W_1	a:	4.00 in	*(102 mm)*
Stroke Length, End of Transition to Casing	c:	3.00 in	*(76 mm)*
Lug Thickness	t_L:	0.50 in	*(13 mm)*
Yield Strength of Lug Material	F_{yL}:	50 ksi	*(345 MPa)*
Ultimate Strength of Lug Material	F_{uL}:	65 ksi	*(448 MPa)*
Number of Bolts in Inner Row Along Brace Axis	n_i:	2	
Number of Bolts in Outer Row Along Brace Axis	n_o:	0	
Bolt Spacing	s:	3.50 in	*(89 mm)*
Plate Edge to CL of Bolt	e_{perp}:	1.19 in	*(30 mm)*
Restrainer (Casing) Size and Properties			
Restrainer Section Name	Section:	t7x1/4	
Yield Stress of Casing Material	F_{yc}:	46 ksi	*(317 MPa)*
Youngs Modulus of Casing Material	E_c:	29000 ksi	*(199955 MPa)*
Casing is Square/Rectangular?	Sq_{Cas}:	TRUE	
Casing Height (Dimension Viewed in Elevation)	H_c:	7.00 in	*(178 mm)*
Casing Width (Dimension Viewed in Plan & Overall Dimension for p Sections)	W_c:	7.00 in	*(178 mm)*
Casing Thickness	t_c:	0.25 in	*(6 mm)*
Factor on Adjusted Brace Strength	F_{PU}:	1.0	
Capacity Reduction Factor, ϕ_{NLYL}	ϕ_{NLYL}:	1.0	
Equal to 1.0 per Takeuchi (2014). Lower values can be used.			
Zaboli (2018) is even more conservative than Takeuchi even with ϕ = 1.0.			

2.2.2 NLYL Global Stability Method

Overstrength Compression Force in the Core of the BRB: $N^*_{cu} = F_{Pu} \cdot P_u$	N^*_{cu}:	**148.5 kip**	*(661 kN)*
NLYL Method Uses: N^*_{cu} = Overstrength Compression Capacity of the BRB. This requires an iterative solution.			
The variant used here checks demand vs capacity based on applied load (Pu).			
Length from End of Casing to Yield Line at Tip of Brace: $\xi L_0 = a+c+L'_{LG}$	ξL_0:	12.88 in	*(327 mm)*
$\xi = \xi L_0 / L_0$	ξ:	0.112	
Effective Length Factor for Brace including Gusset Stiffness Effect: k_b	k_b:	1.00	
If $Stiff_{Top}$ AND $Stiff_{Bot}$ = TRUE, k_b = 0.7			
If $Stiff_{Top}$ AND $Stiff_{Bot}$ = FALSE, k_b = 1.0			
If $Stiff_{Top}$ OR $Stiff_{Bot}$ = FALSE, k_b = 0.85			
Stiffened Gusset Factor, λ = 1.19 for Stiffened Gusset or 1.0 for Unstiffened Gusset	λ_{top}:	1.00	
	λ_{bot}:	1.00	
Global Elastic Buckling Capacity of BRB, Incl Effect of Gusset PL: $N^B_{cr} = \pi^2 \cdot EI_c / (k_b \cdot L_0)^2$	N^B_{cr}:	**1015.6 kip**	*(4518 kN)*
Effective Width in Compression: $b_{qa} = 2 \cdot L_{Br} \cdot \tan(\theta_{disp}) + (W_L - 2 \cdot e_{perp})$			
Lug Lap on Gusset: $L_{Br} = IF(n_i > n_o, (n_i - 1) \cdot s, (n_o - 0.5) \cdot s)$	L_{Br}:	3.50 in	*(89 mm)*
Dispersion Angle at Top Gusset	$\theta_{disp,top}$:	40.0°	
Dispersion Angle at Bottom Gusset	$\theta_{disp,bot}$:	30.0°	
Dispersion angle based on 30° for V or Chev, 40° otherwise per NLYL Methodology.			
Effective Compression Width, Top Gusset	$b_{qa,top}$:	9.50 in	*(241 mm)*
Effective Compression Width, Bottom Gusset	$b_{ga,bot}$:	7.67 in	*(195 mm)*
Average Gusset Buckling Length: L_{ave} = min[(a+min(b,c))/2, (a+b+c)/3]	$L_{ave,top}$:	3.85 in	*(98 mm)*
See Dowswell (2006) and Zaboli (2018)	$L_{ave,bot}$:	10.99 in	*(279 mm)*
Nominal Axial Capacity of Gusset Plate: $N^g_s = b_{qa} \cdot t_q \cdot F_{yq}$	$N^g_{s,top}$:	**296.8 kip**	*(1320 kN)*
	$N^g_{s,bot}$:	**239.6 kip**	*(1066 kN)*
Euler Buckling Capacity of Gusset Plate: $N_e = \pi^2 \cdot E \cdot (b_{qa} \cdot t_q^3 / 12) / L_{ave}^2$	$N_{e,top}$:	**3723.4 kip**	*(16562 kN)*
	$N_{e,bot}$:	**369.4 kip**	*(1643 kN)*
Plastic Moment Capacity of Gusset Plates			
Total Bendline Length: $b_{qf} = L_b + L_c$	$b_{qf,top}$:	15.95 in	*(405 mm)*
	$b_{qf,bot}$:	18.25 in	*(464 mm)*
Plastic Section Modulus: $Z_g = b_{gf} \cdot t_g^2/4 + Z_{stiff}$	$Z_{g,top}$:	1.56 in³	*(25524 mm³)*
	$Z_{q,bot}$:	1.78 in³	*(29205 mm³)*
Plastic Moment Capacity: $M^g_{zy} = Z_g \cdot F_{yg}$	$M^g_{zy,top}$:	**78 k-in**	*(8.8 kN-m)*
	$M^g_{zy,bot}$:	**89 k-in**	*(10.1 kN-m)*
Reduced Plastic Moment Capacity of Gusset Plate Including Axial Force Effect: $M^g_p = \lambda \cdot \phi_{NLYL} \cdot M^g_{zy} [1 - (N^*cu / (\phi_{NLYL} \cdot N^g_s))^2] \geq 0$	**$M^g_{p,top}$:**	**58 k-in**	*(6.6 kN-m)*
	$M^g_{p,bot}$:	**55 k-in**	*(6.2 kN-m)*

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning
Engineering | Public Works
Fire | Traffic

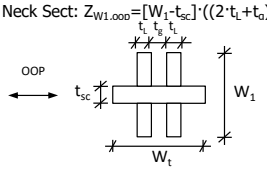
Axial Yield Strength of Neck at Web Zone: $N^n_{wy}=2\cdot(W_1-t_{sc})\cdot t_L\cdot F_{y,L}$ — N^n_{wy}: 155.3 kip *(691 kN)*

Axial Yield Strength of Neck: $N^n_y=W_t\cdot t_{sc}\cdot F_{ymax}+2\cdot(W_1-t_{sc})\cdot t_L\cdot F_{y,L}$ — N^n_y: 247.3 kip *(1100 kN)*

Axial Ultimate Strength of Neck: $N^n_v=W_t\cdot t_{sc}\cdot F_{u.sc}+2\cdot(W_1-t_{sc})\cdot t_L\cdot F_{u.L}$ — N^n_u: 333.9 kip *(1485 kN)*

OOP Plastic Section Modulus of Steel Core (W_t) at Neck Section: $Z_{Wt.oop}=t_{sc}\cdot W_t^2/4$ — $Z_{Wt,oop}$: 2.0 in³ *(32774 mm³)*

OOP Plastic Section Modulus of Lugs (W_1) at Neck Sect: $Z_{W1.oop}=[W_1-t_{sc}]\cdot((2\cdot t_L+t_q)^2-t_q^2)/$ — $Z_{W1,oop}$: 1.7 in³ *(28633 mm³)*



Section at Neck

Out-of-Plane Plastic Moment Capacity of Neck: $M^n_{zv}=Z_{WT.oop}\cdot F_{vmax}+Z_{W1.oop}\cdot F_{v.L}$ — M^n_{zv}: **179 k-in** *(20.3 kN-m)*

Reduced Restrainer Moment Transfer Capacity Determined by Neck + Core Plate, Including Axial Force Effect. — $M_D^{r-neck,top}$: 179.4 k-in *(20.3 kN-m)*; $M_D^{r-neck,bot}$: 179.4 k-in *(20.3 kN-m)*

$M_D^{r-neck}=\phi_{NLYL}\cdot M^n_{zv}\cdot[1-(MAX(N^*_{cu}-N^n_{wv},0)/(\phi_{NLYL}\cdot(N^n_u-N^n_{wv})))^n]$

Exponent, n = 2.0 Use N^n_y if Gst is Not Stiffened? FALSE

Per Takeuchi (2014), N^n_u is used in the denominator. Other methods use N^n_y in the denominator if the gusset is unstiffened.

Plastic Section Modulus of Restrainer, Z_{rp} — Z_{rp}: 17.1 in³ *(280116 mm³)*

Square / Rectangular Section: $Z_{rp}=H_c\cdot W_c^2/4-(H_c-2\cdot t_c)\cdot(W_c-2\cdot t_c)^2/4$

Round Casing Section: $Z_{rp}=W_c^3/6-(W_c-2\cdot t_c)^3/6$

Nominal Plastic Moment Capacity of Restrainer: $M^r_{zv}=Z_{rp}\cdot F_{yc}$ — M^r_{zy}: 786 k-in *(88.8 kN-m)*

Embed Length Calibration Factor: $\alpha^r_p=4.15-1.5\cdot(L_{in}/W_t)=4.15-1.5\cdot L_{in}/W_t\geq 1.5$ — α^r_p: 1.83

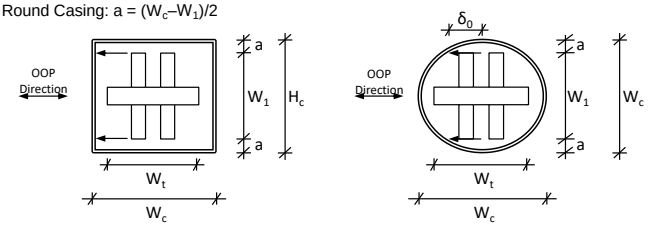
See Takeuchi (2014). While this increases as embedment ratio (L_{in}/W_t) decreases, the net effect of a decreasing embedment ratio decreases M_p^{r-rest}, and this factor only slows the decrease.

Distance between the shear force application point and the outer surface of the restraint tube, a

See Matsui (2010) for calculation of square and round restrainer properties.

Sq/Rect Casing: $a=(H_c-W_1)/2$ — a: 1.70 in *(43 mm)*

Round Casing: $a=(W_c-W_1)/2$



Square Restrainer Round Restrainer

Distance between the Core Plate Surface and the Shear Force Application Point when the Shear Force is not Present, δ_0. Not Applicable to Square/Rect Restrainers.

See Matsui (2010) and Takeuchi (2017). Eqn from Takeuchi (2017) Ch 4

$\delta_0=W_c/2\cdot\sin[\cos^{-1}((W_c-2\cdot a)/(W_c-2\cdot t_c))]$ — δ_0: 2.91 in *(74 mm)*

The Lateral Deflection of the Restraint Tube at the In-Plane Stress Yielding. Not Applicable to Square/Rect Restrainers.

See Matsui (2010) and Takeuchi (2017). Eqn from Takeuchi (2017) Ch 4

$\delta_y=\sqrt{[(\pi\cdot W_c\cdot F_{yc}/(4\cdot E_c)+W_c/2\cdot\cos^{-1}((W_c-2a)/(W_c-2t_c)))^2-a^2]}$ — δ_y: 3.00 in *(76 mm)*

Elastic Rotational Stiffness of Restrainer about Rib End:

Round Casing: $K_{Rr1.Round}=2\cdot F_{vc}\cdot t_c\cdot L_{in}^3/(3\cdot\sqrt{[a^2+\delta_v^2]})\cdot\delta_v/(\delta_v-\delta_0)\geq 0$ — $K_{Rr1,Round}$: 27006 k-in/rad (3.05E+03 kN-m/rad)

Square/Rect Casing: $K_{Rr1.Rect}=E_c\cdot H_c\cdot t_c^3\cdot L_{in}^3/(3\cdot(2\cdot H_c\cdot a^3-3\cdot a^4))\geq 0$ — $K_{Rr1,Rect}$: 8814 k-in/rad (9.96E+02 kN-m/rad)

Post-Yielding Rotational Stiffness of Restrainer about Rib End:

Round Casing: $K_{Rr2,Round}=0$

Square/Rect Casing: $K_{Rr2.Rect}=0.11\cdot F_{vc}\cdot H_c^3\cdot(L_{in}/W_t)^3\geq 0$ — $K_{Rr2,Rect}$: 9841 k-in/rad (1.11E+03 kN-m/rad)

Yield Angle of Circular Casing: $\theta_{y,Round}=(\delta_y-\delta_0)/L_{in}$ — $\theta_{y,Round}$: 0.012573 rad

Pseudo Initial Yield Angle of the Rect Casing: $\theta'_{y1}=0.00164\cdot(F_{yc}/E_{casing})\cdot(H_c/t_c)\cdot(W_t/L_{in})$ — θ'_{y1}: 0.000041 rad

Angle at Which Plastic Hinge Occurs: $\theta_{y2}=H_c/L_{in}\cdot\sqrt{[(F_{vc}/(2\cdot E_{casing}))^2+(a\cdot F_{vc}/(H_c\cdot E_{casing}))]}$ — θ_{y2}: 0.019260 rad

See Matsui (2010) and Takeuchi (2017) ch 4

City of Puyallup
Development & Permitting Services
ISSUED PERMIT
Building | Planning
Engineering | Public Works
Fire | Traffic

Reduced Restrainer Moment Transfer Capacity Determined by Restrainer Section at Rib:

Round Casing: $M_p^{r-rest} = MIN[M^r_{zv}, \alpha^r_p \cdot K_{Rr1.Round} \cdot \theta_{v.Round}]$ — M_p^{r-rest}: 346 k-in *(39.1 kN-m)*

Square/Rect Casing: $M_p^{r-rest} = MIN[M^r_{zv}, \alpha^r_p \cdot (K_{Rr1.Rect} \cdot \theta'_{v1} + K_{Rr2.Rect} \cdot (\theta_{v2} - \theta'_{v1}))]$

Controlling Restrainer Moment Transfer Capacity: $M^r_p = Min\{M_p^{r\text{-}neck,t/b}, M_p^{r\text{-}rest}\}$

Top End of Brace Controlled By: **Neck Capacity**	**$M^r_{p.top}$:**	**179.4 k-in**	*(20.3 kN-m)*
Bottom End of Brace Controlled By: **Neck Capacity**	**$M^r_{p.bot}$:**	**179.4 k-in**	*(20.3 kN-m)*

2.2.3 Over the Yield Line (OYL) Global Buckling Capacity

Total Initial Imperfection with Plastic Hinge at End of Casing: $\theta_{i,OYL}$ — $\theta_{i,OYL}$: 0.0190 rad

$\theta_{i,OYL} = \delta_m/L_0 + \delta_q/L_q + \theta_0$

Moment Amplification Factor to Account for 2nd Order Effects: $\delta_{s,OYL}$ — $\delta_{s,OYL}$: 1.1713

$\delta_{s.OYL} = 1/(1 - N^*_{cu}/N^B_{cr}) \geq 1.0$

Reports as "Error" if result is is less than 1.0, which occurs when applied load (N^*_{cu}) exceeds BRB elastic buckling capacity (N^B_{cr}).

Notional Load Applied at Brace End: $N_{OYL} = N^*_{cu} \cdot \theta_{i.OYL} + F_{Add'l\text{-}OOP}/2$ — N_{OYL}: 2.8 kip *(13 kN)*

$$N\xi L_0\delta_s \leq (1-2\xi)M_p^g + M_p^r \qquad \text{Iterative Solution}$$

$$\frac{N\xi L_0\delta_s}{(1-2\xi)M_p^g + M_p^r} \leq 1.0 \qquad \text{DCR}$$

Demand: $D = N_{OYL}\xi L_0\delta_{s,OYL}$	**D:**	**42.6 k-in**	*(4.8 kN-m)*
Capacity: $C_{top} = (1\text{-}2\xi)M^g_{p,top} + M^r_{p,top}$	**C_{top}:**	**224.6 k-in**	*(25.4 kN-m)*
$C_{bot} = (1\text{-}2\xi)M^g_{p,bot} + M^r_{p,bot}$	**C_{bot}:**	**221.9 k-in**	*(25.1 kN-m)*
DCR: $D/C_{OYL} = D/[\min\{C_{top}, C_{bot}\}]$	**D/C_{OYL}:**	**0.19**	**OK**

2.2.4 Under the Yield Line (UYL) Global Buckling Capacity

Total Initial Imperfection with Plastic Hinge at End of Casing: $\theta_{i,UYL}$ — $\theta_{i,UYL}$: 0.0290 rad

$\theta_{i,UYL} = \delta_m/L_0 + 2\cdot\delta_q/L_q + \theta_0$

Moment Amplification Factor to Account for 2nd Order Effects: $\delta_{s,OYL}$

$\delta_{s.UYL.top} = 1/(1 - N^*_{cu}/N_{e.top}) \geq 1.0$ — $\delta_{s,UYL,top}$: 1.042

$\delta_{s.UYL.bot} = 1/(1 - N^*_{cu}/N_{e.bot}) \geq 1.0$ — $\delta_{s,UYL,bot}$: 1.673

Reports as "Error" if result is is less than 1.0, which occurs when applied load (N^*_{cu}) exceeds gusset elastic buckling capacity (N_e).

Notional Load Applied at Brace End: $N_{UYL} = N^*_{cu} \cdot \theta_{i.UYL} + F_{Add'l\text{-}OOP}/2$ — N_{UYL}: 4.3 kip *(19 kN)*

Total Length, $L_T = L_{ave,bot} + L_0 + L_{ave,Top}$ — L_T: 129.32 in *(3285 mm)*

Length Factor, $\eta = (1 - L_0/L_T)/2$ — η: 0.057

$$NL_{ave}\delta_s\theta = (2-2\eta)M_p^g \Rightarrow M_p^g \geq \frac{NL_{ave}\delta_s}{(2-2\eta)} = M_y^* \qquad \text{Iterative Solution}$$

$$\frac{M_y^*}{M_p^g} \leq 1.0 \qquad \text{DCR}$$

$M^*_{y,top} = N_{UYL} \cdot L_{ave,top} \cdot \delta_{s,UYL,top}/(2\text{-}2\eta)$	**$M^*_{y.top}$:**	**9.2 k-in**	*(1.0 kN-m)*
$M^*_{y,bot} = N_{UYL} \cdot L_{ave,bot} \cdot \delta_{s,UYL,bot}/(2\text{-}2\eta)$	**$M^*_{y.bot}$:**	**42.0 k-in**	*(4.7 kN-m)*
$DCR = \max\{M^*_{y,top}/M^g_{p,top}, M^*_{y,top}/M^g_{p,top}\}$	**DCR_{top}:**	**0.16**	**OK**
	DCR_{bot}:	**0.77**	**OK**
	DCR_{UYL}:	**0.77**	**OK**

Interaction Equation Form of General Solution:

$$\left(\frac{N^*_{cu}}{\phi N^g_s}\right)^2 + \frac{M^*_y}{\lambda\phi M^g_{zy}} \leq 1 \qquad \text{Interaction Equation}$$

*Interaction equation will produce results that equal 1.0 at for same value of N*cu as the UYL DCR equation but it is less senstive (less volatile) to small changes in N*cu. Neither the DCR nor the Int Eqn produces results that are linear with respect to N*cu (i.e. a Int Eqn value = 0.5 is not capableof handling 2x N*cu). An interaction eqn solution is not possible for the OYL method.*

	Int_{top}:	**0.37**	**OK**
	Int_{bot}:	**0.86**	**OK**
	Int_{UYL}:	**0.86**	**OK**

2.2.5 NLYL Summary

Global stability in the Asymmetrical Mode is controlled by the lesser of the capacities determined by the OYL and UYL methods.

OYL:	**DCR_{OYL}:**	**0.19**	**OK**
UYL:	**DCR_{UYL}:**	**0.77**	**OK**
UYL_{INT}:	**Int_{UYL}:**	**0.86**	**OK**
	Summary:	**OK**	

2.2.6 References

Dowswell, B. (2006), Effective length factors for gusset plate buckling, AISC Engineering Journal, Second Quarter, 91-101.

Dowswell, B. (2016), Advances in steel constructino analysis. 2016 NASCC (the Steel Conference) Proceedsings.

Matsui, R. Takeuchi, T. Nishimoto, K. Takahashi, S. & Ohyama, T. (2010), Effective buckling length of buckling restrained braces considering rotational stiffness at restrainer ends, 7th International Conference on Urban Earthquake Engineering & 5th International Conference on Earthquake Engineering, Proceedings 1049-1058

Takeuchi, T. Ozaki, H. Matsui, R. & Sutcu, F. (2014), Out-of-plane stability of buckling-restrained braces including moment transfer capacity, Earthquake Engineering & Structural Dynamics, 43(6), 851-869

Takeuchi, T. & Wada, A (2017), Buckling-restrained braces and applications, Tokyo: The Japan Society of Seismic Isolation (JSSI), Chapter 4

Zaboli, B. Clifton, G.C. & Cowie K. (2018), BRBF and CBF gusset plates: Out-of-plane stability design using a simplified notional load yield line (NLYL) method. Journal of the Structural Engineering Society of NZ, 31(1), 64-76

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

HSS Casing Buckling Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

					Casing Buckling													GLOBAL STABILITY CALCULATIONS Input Parameters															
EOR-ID	Line	Grids	Lvls	Mark	Qty	L_g	$F_{ysc,max}$	$P_{ysc,max}$	β	ω	$P_{u,max}$	FS	I_g	Type	H_c	W_c	t_c	Casing	I_c	I_{gc}*	Is V Bot	Is Chev Too	P_{UC}	L_b	t_{cc}	W_t	OOP Embed	t_g	F_{ye}	Casing is Sq/Rect?	H_c	W_c	t_c	I_c	E_{casing}	F_{yc}
#		#	#	#	#	in	ksi	kips			kips	Buckling	in^4		in	in	in	Size	in^4	I_c	T/F	T/F	kip	in	in	in	Ratio	in	ksi		in	in	in	in^4	ksi	ksi
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	109.62	46.0	92	1.17	1.38	149	1.27	8	t	7	7	0.2500	t7x1/4	46.5	0.17	TRUE	FALSE	148.5	114.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	109.62	46.0	92	1.17	1.38	149	1.27	8	t	7	7	0.2500	t7x1/4	46.5	0.17	TRUE	FALSE	148.5	114.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	217.62	46.0	92	1.11	1.33	136	1.27	28	t	7	7	0.2500	t7x1/4	46.5	0.61	FALSE	TRUE	135.8	222.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	217.62	46.0	92	1.11	1.33	136	1.27	28	t	7	7	0.2500	t7x1/4	46.5	0.61	FALSE	TRUE	135.8	222.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	5	E to D.5	1	**1903**	1	265.73	46.0	92	1.11	1.31	134	1.27	42	t	7	7	0.2500	t7x1/4	46.5	0.90	FALSE	FALSE	133.8	270.6	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	107.24	46.0	92	1.16	1.37	146	1.27	7	t	7	7	0.2500	t7x1/4	46.5	0.16	TRUE	FALSE	146.2	112.1	0.500	4.0	1.8	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	107.24	46.0	92	1.16	1.37	146	1.27	7	t	7	7	0.2500	t7x1/4	46.5	0.16	TRUE	FALSE	146.2	112.1	0.500	4.0	1.8	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	235.63	46.0	92	1.11	1.33	136	1.27	33	t	7	7	0.2500	t7x1/4	46.5	0.72	FALSE	TRUE	135.8	240.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	235.63	46.0	92	1.11	1.33	136	1.27	33	t	7	7	0.2500	t7x1/4	46.5	0.72	FALSE	TRUE	135.8	240.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	145.52	46.0	92	1.11	1.31	134	1.27	13	t	7	7	0.2500	t7x1/4	46.5	0.27	TRUE	FALSE	133.8	150.4	0.500	4.0	1.8	0.9	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	154.09	46.0	92	1.11	1.31	134	1.27	14	t	7	7	0.2500	t7x1/4	46.5	0.30	TRUE	FALSE	133.8	158.9	0.500	4.0	1.8	0.9	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	277.52	46.0	92	1.11	1.32	135	1.27	46	t	7	7	0.2500	t7x1/4	46.5	0.99	FALSE	TRUE	134.8	282.4	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	277.52	46.0	92	1.11	1.32	135	1.27	46	t	7	7	0.2500	t7x1/4	46.5	0.99	FALSE	TRUE	134.8	282.4	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	E	4.7 to 5	1	**1909**	1	278.18	46.0	92	1.11	1.31	134	1.27	46	t	7	7	0.2500	t7x1/4	46.5	0.99	FALSE	FALSE	133.8	283.0	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	130.53	46.0	92	1.12	1.34	138	1.27	10	t	7	7	0.2500	t7x1/4	46.5	0.22	FALSE	FALSE	138.1	135.4	0.500	4.0	1.8	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	225.02	46.0	138	1.17	1.23	199	1.27	45	t	7	7	0.2500	t7x1/4	46.5	0.96	FALSE	FALSE	198.6	233.4	0.750	4.0	2.0	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	4	A.8 to A.99	1	**1912**	1	211.47	46.0	92	1.11	1.32	135	1.27	27	t	7	7	0.2500	t7x1/4	46.5	0.57	FALSE	FALSE	134.8	216.3	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	B	5 to 4.7	1	**1913**	1	258.06	46.0	92	1.11	1.32	135	1.27	40	t	7	7	0.2500	t7x1/4	46.5	0.85	FALSE	TRUE	134.8	262.9	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	258.79	46.0	92	1.11	1.32	135	1.27	40	t	7	7	0.2500	t7x1/4	46.5	0.86	FALSE	TRUE	134.8	263.6	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	165.25	46.0	92	1.11	1.31	134	1.27	16	t	7	7	0.2500	t7x1/4	46.5	0.35	FALSE	FALSE	133.8	170.1	0.500	4.0	1.8	1.0	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-3.00	2	D to C.6	1	**1916**	1	273.02	46.0	138	1.17	1.22	197	1.27	65	t	8	8	0.2500	t8x1/4	70.7	0.92	FALSE	FALSE	197.0	281.4	0.750	4.0	2.0	1.0	50	TRUE	8.0	8.0	0.25	70.7	29000	46.0
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	127.21	46.0	92	1.11	1.31	134	1.27	10	t	7	7	0.2500	t7x1/4	46.5	0.21	TRUE	FALSE	133.8	132.1	0.500	4.0	1.8	1.0	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	127.21	46.0	92	1.11	1.31	134	1.27	10	t	7	7	0.2500	t7x1/4	46.5	0.21	TRUE	FALSE	133.8	132.1	0.500	4.0	1.8	1.0	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	3.2	D to C.6	1	**1918**	1	278.02	46.0	92	1.11	1.32	135	1.27	46	t	7	7	0.2500	t7x1/4	46.5	0.99	FALSE	TRUE	134.8	282.9	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	278.98	46.0	92	1.11	1.32	135	1.27	46	t	7	7	0.2500	t7x1/4	46.5	1.00	FALSE	TRUE	134.8	283.8	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	204.03	46.0	92	1.11	1.31	134	1.27	25	t	7	7	0.2500	t7x1/4	46.5	0.53	FALSE	FALSE	133.8	208.9	0.500	4.0	1.8	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.50	2	A.2 to A	1	**1921**	1	336.90	46.0	115	1.11	1.31	167	1.27	84	t	8	8	0.3125	t8x5/16	85.6	0.98	FALSE	FALSE	167.2	345.3	0.625	4.0	1.8	0.6	50	TRUE	8.0	8.0	0.31	85.6	29000	46.0
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	161.54	46.0	115	1.11	1.31	167	1.27	19	t	7	7	0.2500	t7x1/4	46.5	0.42	FALSE	FALSE	167.2	169.9	0.625	4.0	1.8	1.0	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-3.50	A	3 to 2.7	1	**1923**	1	263.02	46.0	161	1.17	1.23	232	1.27	71	t	8	8	0.3125	t8x5/16	85.6	0.83	FALSE	FALSE	231.7	271.4	0.750	4.7	1.8	1.0	50	TRUE	8.0	8.0	0.31	85.6	29000	46.0
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	149.45	46.0	92	1.11	1.33	136	1.27	13	t	7	7	0.2500	t7x1/4	46.5	0.29	FALSE	FALSE	135.8	154.3	0.500	4.0	2.0	1.3	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	3	A.2 to A	1	**1925**	1	270.52	46.0	92	1.11	1.32	135	1.27	44	t	7	7	0.2500	t7x1/4	46.5	0.94	FALSE	FALSE	134.8	275.4	0.500	4.0	1.8	1.3	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0

Table Symbols & Definitions

L_g = Length between tips of gussets
F_{ysc} = Specified yield force of core
P_{ysc} = Yield force of yielding core
β = Maximum compressive force to Tension force ratio
ω = Maximum Tension force to yield force ratio
$P_{u,max}$ = Buckling load, $P_{ysc,max}$ * β * ω
I_g = Inertia of casing to resist buckling from Euler Equation (F.S.*(P_uxL_b^2)/(π^2xE))

Type = Casing tpye, t = tube (rectangular) and p =pipe (round)
w = Width of casing
h = Height of casing
t = thickness of casing
L_{HSS} = Length of casing w/o extensions
FS Buckling = Buckling Factor of Safety. Typically Incl 1/(0.9*0.877).

HSS Casing Buckling Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

					--	GLOBAL STABILITY CALCULATIONS																								
					Calculation Parameters																	Gusset Capacity							
EOR-ID	Line	Grids	Lvls	Mark	Qty	S_r	L_{sh}	EI_0	θ_0	δ_m/L_0	δ_g/L_g	L_θ	ξL_0	ξ	Stiffened Gusset T/F	Stiffened Gusset T/F	k_b	N^e_{cr}	$Z_{g,bot}$	$Z_{g,top}$	N^*_{cu}	ϕ	$N^E_{t,bot}$	$N^E_{t,top}$	$N_{e,bot}$	$N_{e,top}$	$M^E_{zy,bot}$	$M^E_{zy,top}$	$M^E_{p,bot}$	$M^E_{p,top}$
#		#	#	#	#	in	in	kip-in^2	rad	rad	rad	in	in		T/F	T/F		kip	in^3	in^3	kip		kip	kip	kip	kip	kip-in	kip-in	kip-in	kip-in
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	0.0	7.1	1348500	0.007	0.002	0.010	114.5	12.88	0.11	FALSE	FALSE	1.0	1016	1.8	1.6	149	1.0	240	297	369	3723	89	78	55	58
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	0.0	7.1	1348500	0.007	0.002	0.010	114.5	12.88	0.11	FALSE	FALSE	1.0	1016	1.8	1.6	149	1.0	240	297	369	3723	89	78	55	58
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	0.0	7.1	1348500	0.007	0.002	0.010	222.5	12.88	0.06	FALSE	FALSE	1.0	269	1.7	1.8	136	1.0	297	240	4834	8077	87	92	69	62
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	0.0	7.1	1348500	0.007	0.002	0.010	222.5	12.88	0.06	FALSE	FALSE	1.0	269	1.7	1.8	136	1.0	297	240	4834	8077	87	92	69	62
BRB-2.00	5	E to D.5	1	**1903**	1	0.0	7.1	1348500	0.007	0.002	0.010	270.6	12.88	0.05	FALSE	FALSE	1.0	182	1.6	1.7	134	1.0	297	297	8663	5663	80	84	64	67
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	0.0	7.1	1348500	0.007	0.002	0.010	112.1	12.88	0.11	FALSE	FALSE	1.0	1059	2.7	2.1	146	1.0	287	356	396	3681	135	107	100	89
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	0.0	7.1	1348500	0.007	0.002	0.010	112.1	12.88	0.11	FALSE	FALSE	1.0	1059	2.7	2.3	146	1.0	287	356	396	3681	133	114	99	95
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	0.0	7.1	1348500	0.007	0.002	0.010	240.5	12.88	0.05	FALSE	FALSE	1.0	230	1.7	1.9	136	1.0	297	240	6558	7370	87	96	69	65
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	0.0	7.1	1348500	0.007	0.002	0.010	240.5	12.88	0.05	FALSE	FALSE	1.0	230	1.7	1.9	136	1.0	297	240	6558	7370	87	96	69	65
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	0.0	7.1	1348500	0.007	0.002	0.010	150.4	12.88	0.09	FALSE	FALSE	1.0	589	3.7	3.7	134	1.0	335	416	895	3057	184	187	155	168
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	0.0	7.1	1348500	0.007	0.002	0.010	158.9	12.88	0.08	FALSE	FALSE	1.0	527	3.7	3.7	134	1.0	335	416	1144	2930	187	183	157	164
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	0.0	7.1	1348500	0.007	0.002	0.010	282.4	12.88	0.05	FALSE	FALSE	1.0	167	1.8	1.8	135	1.0	297	240	3227	2433	88	90	69	62
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	0.0	7.1	1348500	0.007	0.002	0.010	282.4	12.88	0.05	FALSE	FALSE	1.0	167	1.8	1.8	135	1.0	297	240	3227	3306	88	90	69	62
BRB-2.00	E	4.7 to 5	1	**1909**	1	0.0	7.1	1348500	0.007	0.002	0.010	283.0	12.88	0.05	FALSE	FALSE	1.0	166	1.6	1.7	134	1.0	297	297	10455	6025	80	86	64	69
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	0.0	7.1	1348500	0.007	0.002	0.010	135.4	12.88	0.10	FALSE	FALSE	1.0	726	1.7	2.2	138	1.0	356	356	2199	5655	84	109	71	92
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	0.0	7.8	1348500	0.006	0.002	0.010	233.4	16.38	0.07	FALSE	FALSE	1.0	244	3.3	4.0	199	1.0	576	576	17409	14652	163	199	144	176
BRB-2.00	4	A.8 to A.99	1	**1912**	1	0.0	7.1	1348500	0.007	0.002	0.010	216.3	12.88	0.06	FALSE	FALSE	1.0	284	1.7	1.6	135	1.0	297	297	4959	9842	85	79	68	63
BRB-2.00	B	5 to 4.7	1	**1913**	1	0.0	7.1	1348500	0.007	0.002	0.010	262.9	12.88	0.05	FALSE	FALSE	1.0	193	1.7	1.8	135	1.0	297	240	7605	5447	83	89	66	61
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	0.0	7.1	1348500	0.007	0.002	0.010	263.6	12.88	0.05	FALSE	FALSE	1.0	191	1.7	1.9	135	1.0	297	240	7605	6067	83	97	66	66
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	0.0	7.1	1348500	0.007	0.002	0.010	170.1	12.88	0.08	FALSE	FALSE	1.0	460	4.7	3.8	134	1.0	475	475	1216	4422	234	192	216	176
BRB-3.00	2	D to C.6	1	**1916**	1	0.0	7.8	2050300	0.006	0.002	0.010	281.4	16.38	0.06	FALSE	FALSE	1.0	256	5.4	6.9	197	1.0	769	769	28236	1816	271	347	253	324
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	0.0	7.1	1348500	0.007	0.002	0.010	132.1	12.88	0.10	FALSE	FALSE	1.0	763	5.0	4.5	134	1.0	383	475	1098	3676	250	226	220	208
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	0.0	7.1	1348500	0.007	0.002	0.010	132.1	12.88	0.10	FALSE	FALSE	1.0	763	5.0	4.5	134	1.0	383	475	1098	3676	250	226	220	208
BRB-2.00	3.2	D to C.6	1	**1918**	1	0.0	7.1	1348500	0.007	0.002	0.010	282.9	12.88	0.05	FALSE	FALSE	1.0	166	1.7	1.8	135	1.0	297	240	3908	1954	86	91	68	62
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	0.0	7.1	1348500	0.007	0.002	0.010	283.8	12.88	0.05	FALSE	FALSE	1.0	165	1.7	2.0	135	1.0	297	240	3908	2143	86	98	68	67
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	0.0	7.1	1348500	0.007	0.002	0.010	208.9	12.88	0.06	FALSE	FALSE	1.0	305	2.8	2.1	134	1.0	356	356	1002	3503	140	103	120	89
BRB-2.50	2	A.2 to A	1	**1921**	1	0.0	7.2	2482400	0.007	0.002	0.010	345.3	16.38	0.05	FALSE	FALSE	1.0	206	2.3	2.1	167	1.0	480	480	3984	6285	116	107	102	94
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	0.0	7.1	1348500	0.007	0.002	0.010	169.9	16.38	0.10	FALSE	FALSE	1.0	461	5.6	4.7	167	1.0	769	769	2717	8236	282	234	268	223
BRB-3.50	A	3 to 2.7	1	**1923**	1	0.1	8.6	2482400	0.012	0.002	0.010	271.4	16.38	0.06	FALSE	FALSE	1.0	333	5.3	7.1	232	1.0	769	769	50975	1583	266	353	242	321
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	0.0	7.9	1348500	0.006	0.002	0.010	154.3	12.88	0.08	FALSE	FALSE	1.0	559	9.5	5.6	136	1.0	594	594	1269	13780	473	281	448	267
BRB-2.00	3	A.2 to A	1	**1925**	1	0.0	7.1	1348500	0.007	0.002	0.010	275.4	12.88	0.05	FALSE	FALSE	1.0	176	6.5	7.3	135	1.0	594	594	69117	12825	325	366	308	348

HSS Casing Buckling Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Restrainer Capacity											NLYL Global Stability									
						Based on Moment Capacity of Neck						Based on Mom Txfr Cap of Rest			Controlling Rest Cap		Over the Yield Line Buckling (Asymm Mode)				Under the Yield Line Buckling (Asymm Mode)					
EOR-ID	Line	Grids	Lvls	Mark	Qty	N^n_u	Z_{WT}	Z_{W1}	M^n_{zy}	$M_p^{r\text{-}neck,bot}$	$M_p^{r\text{-}neck,top}$	Z_{rp}	$Z_{rp}\sigma_{ry}$	$M_p^{r\text{-}rest}$	$M^r_{p,bot}$	$M^r_{p,top}$	θ_{LOYL}	$\delta_{L\,OYL}$	N_{OYL}	Stability Index Max	θ_{LUYL}	$\delta_{LUYL,bot}$	$\delta_{LUYL,top}$	N_{UYL}	Stability Index Max
#		#	#	#	#	kip	in^3	in^3	kip-in	kip-in	kip-in	in^3	kip-in	kip-in	kip-in	kip-in	rad	*M Mag factor*	kip	OYL	rad	*M Mag factor*	*M Mag factor*	kip	UYL
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	1.17	2.8	**0.19**	0.03	1.67	1.04	4.3	**0.77**
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	1.17	2.8	**0.19**	0.03	1.67	1.04	4.3	**0.77**
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	2.02	2.6	**0.29**	0.03	1.03	1.02	3.9	**0.10**
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	2.02	2.6	**0.29**	0.03	1.03	1.02	3.9	**0.10**
BRB-2.00	5	E to D.5	1	**1903**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	3.79	2.5	**0.52**	0.03	1.02	1.02	3.9	**0.09**
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	370	2.00	2.75	230	230	230	17.1	786	376	230	230	0.019	1.16	2.8	**0.14**	0.03	1.59	1.04	4.3	**0.51**
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	370	2.00	2.75	230	230	230	17.1	786	376	230	230	0.019	1.16	2.8	**0.14**	0.03	1.59	1.04	4.3	**0.51**
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	2.44	2.6	**0.34**	0.03	1.02	1.02	3.9	**0.09**
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	2.44	2.6	**0.34**	0.03	1.02	1.02	3.9	**0.09**
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	370	2.00	2.98	241	241	241	17.1	786	376	241	241	0.019	1.29	2.6	**0.12**	0.03	1.18	1.05	3.9	**0.18**
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	370	2.00	2.98	241	241	241	17.1	786	376	241	241	0.019	1.34	2.6	**0.12**	0.03	1.13	1.05	3.9	**0.15**
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.20	2.6	**0.73**	0.03	1.04	1.06	3.9	**0.15**
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.20	2.6	**0.73**	0.03	1.04	1.04	3.9	**0.12**
BRB-2.00	E	4.7 to 5	1	**1909**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.13	2.5	**0.71**	0.03	1.01	1.02	3.9	**0.09**
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	334	2.00	1.94	189	189	189	17.1	786	346	189	189	0.019	1.23	2.6	**0.17**	0.03	1.07	1.03	4.0	**0.21**
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	436	3.00	2.29	253	252	252	17.1	786	312	252	252	0.018	5.34	3.7	**0.85**	0.03	1.01	1.01	5.6	**0.06**
BRB-2.00	4	A.8 to A.99	1	**1912**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	1.90	2.6	**0.27**	0.03	1.03	1.01	3.9	**0.10**
BRB-2.00	B	5 to 4.7	1	**1913**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	3.33	2.6	**0.47**	0.03	1.02	1.03	3.9	**0.10**
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	3.38	2.6	**0.47**	0.03	1.02	1.02	3.9	**0.08**
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	370	2.00	3.21	252	252	252	17.1	786	376	252	252	0.019	1.41	2.6	**0.12**	0.03	1.12	1.03	3.9	**0.15**
BRB-3.00	2	D to C.6	1	**1916**	1	436	3.00	2.75	276	275	275	22.5	1036	585	275	275	0.018	4.36	3.6	**0.52**	0.03	1.01	1.12	5.6	**0.14**
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	370	2.00	3.21	252	252	252	17.1	786	376	252	252	0.019	1.21	2.6	**0.09**	0.03	1.14	1.04	3.9	**0.14**
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	370	2.00	3.21	252	252	252	17.1	786	376	252	252	0.019	1.21	2.6	**0.09**	0.03	1.14	1.04	3.9	**0.14**
BRB-2.00	3.2	D to C.6	1	**1918**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.28	2.6	**0.74**	0.03	1.04	1.07	3.9	**0.16**
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.43	2.6	**0.75**	0.03	1.04	1.07	3.9	**0.14**
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	334	2.00	1.94	189	189	189	17.1	786	346	189	189	0.019	1.78	2.5	**0.22**	0.03	1.15	1.04	3.9	**0.19**
BRB-2.50	2	A.2 to A	1	**1921**	1	373	2.50	1.80	205	205	205	27.7	1275	617	205	205	0.019	5.36	3.2	**0.96**	0.03	1.04	1.03	4.8	**0.12**
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	409	2.50	3.28	279	279	279	17.1	786	369	279	279	0.019	1.57	3.2	**0.18**	0.03	1.07	1.02	4.9	**0.12**
BRB-3.50	A	3 to 2.7	1	**1923**	1	508	4.08	3.19	348	346	346	27.7	1275	452	346	346	0.024	3.29	5.5	**0.53**	0.03	1.00	1.17	7.8	**0.22**
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	334	2.00	2.72	228	228	228	17.1	786	357	228	228	0.018	1.32	2.5	**0.09**	0.03	1.12	1.01	3.8	**0.10**
BRB-2.00	3	A.2 to A	1	**1925**	1	334	2.00	2.72	228	228	228	17.1	786	346	228	228	0.019	4.31	2.6	**0.28**	0.03	1.00	1.01	3.9	**0.03**

PSE Operational Training Center

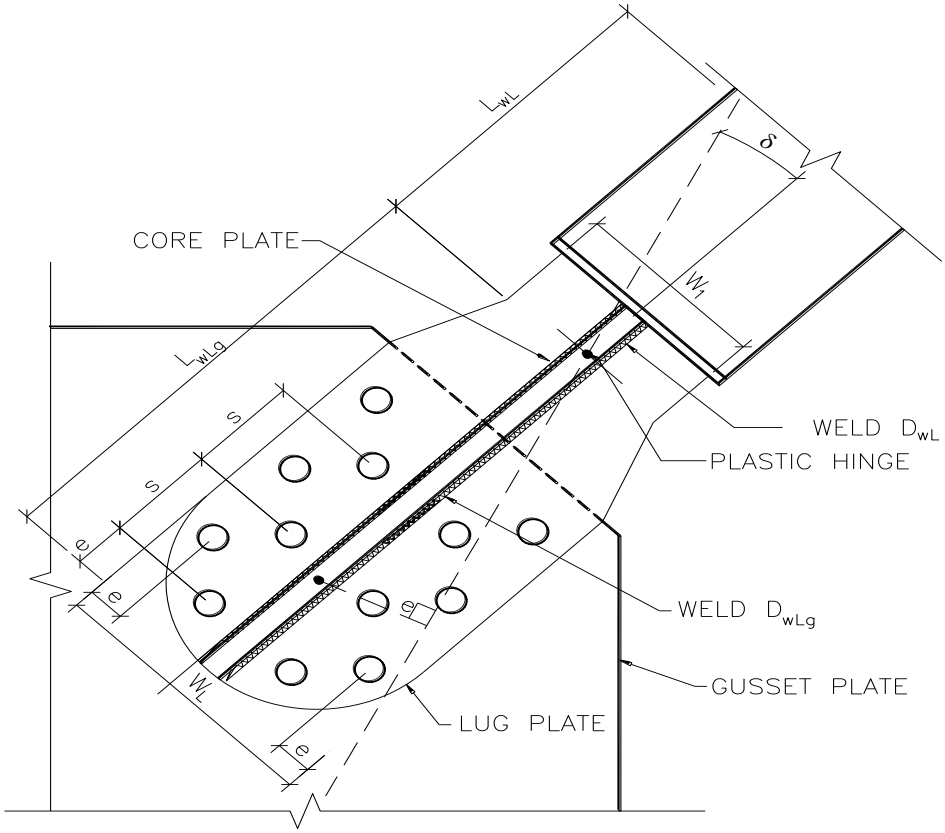
Calculation Submittal Package

Description

Section 3. **Brace End Connection Sample Calculation**
End Connection Summary Table

Brace Connection

Example Mark #: 1901
Line 4.1, Grid D.3 to D(+), Level Low Roof



WELD CONFIGURATION

3.0 DESIGN CRITERIA Example Mark #: 1901

Compresssion Strength Adjustment Factor	β:	1.17	
Strain Hardening Adjustment Factor	ω:	1.38	
Area of (Yielding) Steel Core (as Spec'd on Drawings)	A_{sc}:	2.00 in²	*(1290 mm²)*
Core Plate Ultimate Tensile Strength *Based on Coupon Test History*	F_{usc}:	66 ksi	*(455 MPa)*
Upper Bound Compressive Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Lower Bound Compressive Yield Stress of Core Material *Note:* *Ry factor not applicable since Fy of core material will be established based on results of coupon tests.*	$F_{y\text{-}min}$:	38 ksi	*(262 MPa)*

Axial Design Load:

Connection Strain Hardening Factor	CF:	1.00	
$P_{uC\text{-}max} = CF \cdot A_{sc} \cdot F_{y\text{-}max} \cdot \beta \cdot \omega$	$P_{uC\text{-}max}$:	148.5 kip	*(661 kN)*
$P_{uT\text{-}max} = CF \cdot A_{sc} \cdot F_{y\text{-}max} \cdot \omega$	$P_{uT\text{-}max}$:	127.0 kip	*(565 kN)*
$P_{ysc\text{-}max} = A_{sc} \cdot F_{y\text{-}max}$	$P_{ysc\text{-}max}$:	92.0 kip	*(409 kN)*
Core Dimensions: At Lug Connection	W_t:	4.00 in	*(102 mm)*
Lug Dimensions: Width of Lug Plate	W_L:	6.00 in	*(152 mm)*
At Extension Exit from Casing (Transv. Stiffener)	W_1:	3.61 in	*(92 mm)*
Plate Edge to CL of Bolt	e:	1.19 in	*(30 mm)*
Bolt Specifications: Number of Bolts in Inside Row	n_i:	2	
Number of Bolts in Outside Row	n_o:	0	
Total Number of Bolts at Each End $2(n_i + n_o)$	n_b:	4	
Bolt Spacing	s:	3.50 in	*(89 mm)*
Bolt Gage	g:	0.00 in	*(0 mm)*
Bolt Diameter	d_b:	0.875 in	*(22 mm)*
Standard Bolt Hole $d_s = d_b + x_{std}$ x_{std} = 1/16" (1.6mm)	d_s:	0.938 in	*(24 mm)*
Slip Plane (Single Shear = 1, Double Shear = 2)	n_s:	2	

3.1.0 Bolt Shear - LRFD J3.6

LRFD Resistance Factor	ϕ_v:	0.75	
Bolt Shear Strength $F_{nv} = F_{ub}*0.625*0.9*TCF*CLF$ *0.625 = V//T Ratio, 0.9 = Base Connection Length Factor for Non-Uniformity of Loading*	F_{nv}:	64.8 ksi	*(447 MPa)*
Bolt Grade and Ultimate Tensile Strength for Shear **Gr A490/F3148**	F_{ub}:	144 ksi	*(993 MPa)*
Thread Condition Factor TCF: IF BTC = "X" then 1.0, IF BTC = "N" then 0.8	TCF:	0.80	
Bolt Thread Condition (N = Include, X = Exclude)	BTC:	N	
Connection Length Factor Table J3.2 Note b *(For L'_{Lg} > 38")*	CLF:	1.00	
Connection Length	L'_{Lg}:	3.50 in	*(89 mm)*
Bolt Shear Capacity $\phi r_v = \phi_v F_{nv} n_s A_b$	ϕr_v:	58.4 kip	*(260 kN)*
Bolt Area $A_b = \pi d_b^2/4$	A_b:	0.601 in²	*(388 mm²)*
Bolt Group Shear Strength $\phi R_v = (n_i + n_o) \cdot 2 \cdot \phi r_v$	ϕR_v:	233.8 kip	*(1040 kN)*
Demand-Capacity Ratio $DCR_{Shear} = P_{uc\text{-}max}/R_v$	DCR_{Shear}:	0.64	

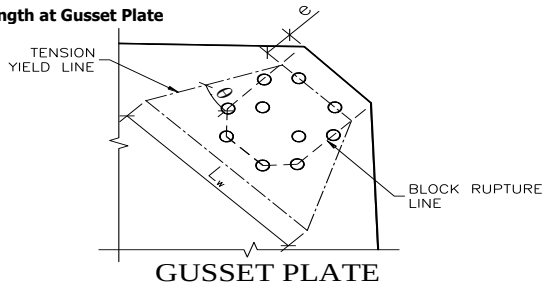
3.2.0 Bolt Friction - LRFD J3.8

LRFD Resistance Factor	ϕ_s:	0.85	
Min Bolt Tensile Area $A_{Tb_min} = \pi/4 \cdot (d-0.9743/n)^2$, where n = threads/in	A_{Tb_min}:	0.462 in²	*(298 mm²)*
Factor for fillers	h_f:	1.00	
Mean Slip Coefficient	μ:	0.30	
Bolt Pretension Adjustment Factor, f_T **Gr A490/F3148**	f_T:	1.04	
Accounts for fact that some bolt grades, such as F3148, have a specified Tb greater than that associated with Fub alone. If the combined grade A490/F3148 is specified and A490's are used, then Tb would be equal to that for the grade and FnV would be conservatively low by $1/f_T$.			
Fastener Tension $T_b = 0.7 \cdot f_T \cdot F_{ub} \cdot A_{Tb_min}$	T_b:	48 kip	*(216 kN)*
Bolt Tension Factor	D_u:	1.13	
Bolt Slip Capacity $\phi r_s = \phi_s m D_u h_f T_b n_s$	ϕr_s:	27.9 kip	*(124 kN)*
Bolt Group Slip Capacity $\phi R_s = (n_i + n_o) \cdot 2 \cdot \phi r_s$	ϕR_s:	111.8 kip	*(497 kN)*
Demand-Capacity Ratio $DCR_{Slip} = P_{ysc\text{-}max}/\phi R_s$	DCR_{Slip}:	0.82	

3.3.0 Bearing Strength at Bolt Holes - LRFD J3.10

LRFD Resistance Factor for Bearing or Tearout	$\phi_{brg\text{-}v}$:	0.75	

3.3.1 Bearing Strength at Gusset Plate



GUSSET PLATE

Additional Diameter of Hole in Gusset Plate	ovs_g:	0.13 in	*(3 mm)*
Thickness of Gusset Plate:	t_q:	0.63 in	*(16 mm)*
Thickness of Repad Plate for Design:	t_r:	0.00 in	*(0 mm)*
Gusset Plate Tensile Strength	F_{uq}:	65 ksi	*(448 MPa)*
Clear Distance Between Edge of Bolt Holes $L_{csg} = s - (d_s + ovs_g)$	L_{csg}:	2.438 in	*(62 mm)*
Number of Occurances of L_{cs} If $n_o = 0$ Then $n_{cs} = n_i - 1$, Otherwise $n_{cs} = n_i - ½ + n_o - 1$	n_{cs}:	1.0	
Clear Distance Between Plate Edge and Bolt Hole $L_{ceg} = e - (d_s + ovs_g)/2$	L_{ceg}:	0.656 in	*(17 mm)*
Number of Occurances of L_{ce} If $n_o = 0$ Then $n_{ce} = 1$, Otherwise $n_{ce} = 2$	n_{ce}:	1	
Clear Distance of Bolt Group $L_{cq} = 2 \cdot (n_{ce} \cdot L_{ceq} + n_{cs} \cdot L_{csq})$	L_{cq}:	6.19 in	*(157 mm)*

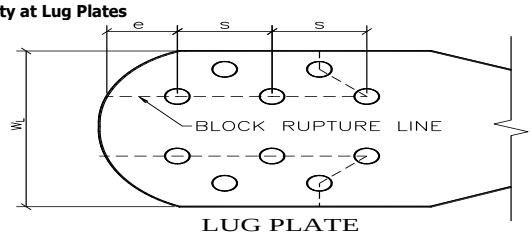
Gusset Plate Bearing Strength at Bolt Holes

$\phi R_{n\text{-}brq}$ = min of:			$\phi R_{n\text{-}brq}$:	226.2 kip	*(1006 kN)*
$\phi_{brq} 1.2 \cdot L_{cq} \cdot (t_q + 2t_r) \cdot F_{uq}$ =	226.2 kip	(Clear Dist/Tear-Out Controlled)			
$\phi_{brg} 2.4 \cdot d_b \cdot n_b \cdot (t_g + 2t_r) \cdot F_{ug}$ =	255.9 kip	(Bearing/Ovalization Controlled)			

Bearing Strength Stress Ratio $DCR_{brg\text{-}g} = P_{uc\text{-}max}/\phi_{brg} R_{n\text{-}brg}$	$DCR_{brg\text{-}g}$:	0.66	

Slip checked at serviceability limit state.

3.3.2 Bearing Capacity at Lug Plates



Additional Diameter of Holes in Lug Beyond Standard Hole Diam	ovs_L:	0.00 in	*(0 mm)*
Lug Plate Thickness	t_L:	0.50 in	*(13 mm)*
Lug Plate Tensile Strength	F_{uL}:	65 ksi	*(448 MPa)*
Clear Distance Between Edge of Bolt Holes $L_{csL} = s - (d_s + ovs_L)$	L_{csL}:	2.563 in	*(65 mm)*
Clear Distance Between Plate Edge and Bolt Hole $L_{ceL} = e - (d_s + ovs_q)/2$	L_{ceL}:	0.719 in	*(18 mm)*
Clear Distance of Bolt Group $L_{cL} = 2\cdot(n_{ce}\cdot L_{ceL} + n_{cs}\cdot L_{csL})$	L_{cL}:	6.56 in	*(167 mm)*

Lug Plate Bearing Strength at Bolt Holes

$\phi R_{n\text{-}brg}$ = min of: — $\phi R_{n\text{-}brg}$: 383.9 kip *(1708 kN)*

$\phi_{brq}1.2\cdot L_{cL}\cdot t_L\cdot F_{uL}\cdot n_s$ =	383.9 kip	*(1708 kN)*	(Clear Dist/Tear-Out Controlled)
$\phi_{brg}2.4\cdot d_b\cdot n_b\cdot t_L\cdot F_{uL}\cdot n_s$ =	409.5 kip	*(1822 kN)*	(Bearing/Ovalization Controlled)

Bearing Strength Stress Ratio
$DCR_{brg\text{-}L} = P_{uc\text{-}max}/\phi_{brg}R_{n\text{-}brg}$ — $DCR_{brg\text{-}L}$: 0.39

3.3.3 Combined Bolt Bearing/Tear-out/Bolt Shear at Lug and Gusset (Bolt by Bolt Method)

Extreme (Edge) Bolts - "Edge Bolts" Use Lceg, "Field Bolts" use Lcsg

Brace in Tension (T):
Free Edge Bolt when: Lug Field Bolt (LFB) or Gusset Edge Bolt (GEB)
Other Edge Bolt when: Lug Edge Bolt (LEB) or Gusset Edge Bolt (GFB)

Brace in Compression (C):
Free Edge Bolt when: Lug Field Bolt (LFG) or Gusset Edge Bolt (GFB)
Other Edge Bolt when: Lug Field Bolt (LFG) or Gusset Edge Bolt (GFB)

At all Conditions Check Min of Bearing, Edge Tear-out, and Bolt Shear

Gusset

G. Edge Bolts on n_i Row: $\phi_{brq\text{-}V}\cdot(t_q+2t_r)\cdot F_{uq}\cdot MIN[1.2\cdot L_{ceq}, 2.4\cdot d_b]$	GEB_{ni}:	24.0 kip	*(107 kN)*
G. Edge Bolts on n_o Row: $\phi_{brq\text{-}V}\cdot(t_q+2t_r)\cdot F_{uq}\cdot MIN[1.2\cdot(L_{ceq}+0.5s), 2.4\cdot d_b]$	GEB_{no}:	0.0 kip	*(0 kN)*
GEB Capacity = 0 Unless $n_o > 0$			
G. Field Bolts on n_i Row: $\phi_{brq\text{-}V}\cdot(t_g+2t_r)\cdot F_{ug}\cdot MIN[1.2\cdot L_{csg}, 2.4\cdot d_b]$	GFB_{ni}:	64.0 kip	*(285 kN)*
G. Field Bolts on n_o Row: $\phi_{brq\text{-}V}\cdot(t_q+2t_r)\cdot F_{uq}\cdot MIN[1.2\cdot(L_{csq}+0.5s), 2.4\cdot d_b]$	GFB_{no}:	0.0 kip	*(0 kN)*
GFB Capacity = 0 Unless $n_o > 0$			

Lug

L. Edge Bolts on n_i Row: $\phi_{brq\text{-}V}\cdot t_L\cdot F_{uL}\cdot MIN[1.2\cdot L_{ceL}, 2.4\cdot d_b]*2Lugs$	LEB_{ni}:	42.0 kip	*(187 kN)*
L. Edge Bolts on n_o Row: $\phi_{brq\text{-}V}\cdot t_L\cdot F_{uL}\cdot MIN[1.2\cdot(L_{ceL}+0.5s), 2.4\cdot d_b]*2Lugs$	LEB_{no}:	0.0 kip	*(0 kN)*
LEB Capacity = 0 Unless $n_o > 0$			
L. Field Bolts on n_i Row: $\phi_{brq\text{-}V}\cdot t_L\cdot F_{uL}\cdot MIN[1.2\cdot L_{csL}, 2.4\cdot d_b]*2Lugs$	LFB_{ni}:	102.4 kip	*(455 kN)*
L. Field Bolts on n_o Row: $\phi_{brq\text{-}V}\cdot t_L\cdot F_{uL}\cdot MIN[1.2\cdot(L_{csL}+0.5s), 2.4\cdot d_b]*2Lugs$	LFB_{no}:	0.0 kip	*(0 kN)*
LFB Capacity = 0 Unless $n_o > 0$			

Sum of Extreme Bolt Capacities (at each end of each line):

Tension: $2[MIN(LFB,\phi r_v$ or $GEB,\phi r_v) + MIN(LEB,\phi r_v$ or $GFB,\phi r_v)]$	$\phi R_{n\text{-}TE}$:	132.1 kip	*(588 kN)*
Compression: $2[2*MIN(LFB,\phi r_v$ or $GFB,\phi r_v)]$	$\phi R_{n\text{-}CE}$:	233.8 kip	*(1040 kN)*
Note Brace in Compression Results in "Field Bolt" Condition for all Extreme Bolts			

Sum of Remaining Field Bolt Capacities:

At Gusset: $2[MAX(n_i-2,0)*min(GFB_{ni},\phi r_v) + MAX(n_o-2,0)*min(GFB_{no},\phi r_v)]$:	$\phi R_{n\text{-}GF}$:	0.0 kip	*(0 kN)*
At Lug: $2[MAX(n_i-2,0)*min(LFB_{ni},\phi r_v) + MAX(n_o-2,0)*min(LFB_{no},\phi r_v)]$:	$\phi R_{n\text{-}LF}$:	0.0 kip	*(0 kN)*
Total Tension Capacity at Gusset:	$\phi R_{n\text{-}TG}$:	132.1 kip	*(588 kN)*
Total Compression Capacity at Gusset:	$\phi R_{n\text{-}CG}$:	233.8 kip	*(1040 kN)*
Total Tension Capacity at Lug:	$\phi R_{n\text{-}TL}$:	132.1 kip	*(588 kN)*
Total Compression Capacity at Lug:	$\phi R_{n\text{-}CL}$:	233.8 kip	*(1040 kN)*

Bearing/Tearout Strength Stress Ratio:

$DCR_{brg/Tear\text{-}G} = MAX(P_{uc\text{-}max}/\phi R_{n\text{-}CG}, P_{uT\text{-}max}/\phi R_{n\text{-}TG})$	$DCR_{brg/Tear\text{-}G}$:	0.96
$DCR_{brg/Tear\text{-}L} = MAX(P_{uc\text{-}max}/\phi R_{n\text{-}CL}, P_{uT\text{-}max}/\phi R_{n\text{-}TL})$	$DCR_{brg/Tear\text{-}L}$:	0.96

3.4.0 Tension Rupture Strength - LRFD D4

LRFD Resistance Factor	ϕ_{tr}:	0.75	
Compresssion Strength Adjustment Factor	β:	1.17	
Thickness of Yielding Core	t_{sc}:	0.50 in	*(13 mm)*
Shear Lag Factor (Table D3.1 Case 2)	U:	0.89	
Overslot for Gusset	OSL_g:	0.19 in	*(5 mm)*

Net Area Subject to Tension (Use AISC D3 for Staggered Bolt Net Area)

Stagger Adjustment Term If $n_o = 0$, then stg = 0, otherwise $stg = 2[(s/2)^2/(4g)]$	stg	0.00 in	*(0 mm)*
Number of Rows of Bolts If $n_o = 0$, then $n_r = 2$, otherwise $n_r = 4$	n_r:	2	
Net Area of Lug Transverse to Line of Force $A_{ntLb1} = 2t_L \cdot [W_L - n_r \cdot (d_s + ovs_L + 1/16) + stg]$	A_{ntLb1}:	4.00 in²	*(2581 mm²)*
$A_{ntLbx} = 2t_L \cdot [W_L - 2 \cdot (d_b + 1/8)]$	A_{ntLbx}:	4.00 in²	*(2581 mm²)*
$A_{ntLb} = \min(A_{ntLb1}, A_{ntLbx})$	A_{ntLb}:	4.00 in²	*(2581 mm²)*
Net Area of Lug Stiffener $A_{ntLc} = t_{sc} \cdot [W_t - (t_g + 2 \cdot t_L + OSL_g)]$	A_{ntLc}:	1.09 in²	*(706 mm²)*
Lug Plate Tension Rupture Strength $\phi R_{n\text{-}tr} = \phi_{tr} \cdot U \cdot (F_{uL} \cdot A_{ntLb} + F_{usc} \cdot A_{ntLc})$	$\phi R_{n\text{-}tr}$:	222.6 kip	*(990 kN)*
Tension Rupture Stress Ratio $DCR_{tr} = P_{ut\text{-}max}/\phi R_{n\text{-}tr}$	DCR_{tr}:	0.57	

3.5.0 Block Rupture Strength - LRFD J4.3

LRFD Resistance Factor	ϕ_{blk}:	0.75	
Block Shear Shear-Lag Factor	U_{bs}:	1.00	

3.5.1 Gusset Block Rupture Strength

Gusset Plate Yield Strength	F_{yg}:	50 ksi	*(345 MPa)*
Gusset Plate Edge Distance	e:	1.19 in	*(30 mm)*
Gross Area Subject to Shear	$L_{gv\text{-}g}$:	4.69 in	*(119 mm)*

If	Then
$n_o = 0$	$L_{gv\text{-}q} = (n_i - 1) \cdot s + e$
$n_o = n_i$	$L_{gv\text{-}g} = (n_o - 1) \cdot s + \sqrt{[(s/2)^2 + g^2]} + e$
Otherwise	$L_{gv\text{-}g} = (n_o - ½) \cdot s + \sqrt{[(s/2)^2 + g^2]} + e$

$A_{gv\text{-}q} = 2 \cdot L_{gv\text{-}q} \cdot (t_q + 2 \cdot t_r)$	$A_{gv\text{-}q}$:	5.86 in²	*(3780 mm²)*

Net Area Subject to Shear

If $n_o = 0$, Then $n_{na\text{-}g} = n_i - ½$, Otherwise $n_{na\text{-}g} = n_o + ½$ — $n_{na\text{-}g}$: 1.5

$L_{nv\text{-}q} = (d_s + ovs_q + 1/16)\cdot n_{na\text{-}q}$ — $L_{nv\text{-}q}$: 1.69 in *(43 mm)*

$A_{nv\text{-}g} = A_{gv\text{-}g} - 2\cdot L_{nv\text{-}g}\cdot(t_g + 2\cdot t_r)$ — $A_{nv\text{-}g}$: 3.75 in² *(2419 mm²)*

Gross Area Subject to Tension

$L_{gt\text{-}g} = W_L - 2\cdot(e + g)$ — $L_{gt\text{-}g}$: 3.63 in *(92 mm)*

Note: g = 0 if $n_o = 0$

$A_{qt\text{-}q} = L_{qt\text{-}q}\cdot(t_q + 2\cdot t_r)$ — $A_{qt\text{-}q}$: 2.27 in² *(1462 mm²)*

Net Area Subject to Tension

$L_{nt\text{-}g} = (d_s + ovs_g + 1/16)$ — $L_{nt\text{-}g}$: 1.13 in *(29 mm)*

$A_{nt\text{-}q} = A_{qt\text{-}q} - L_{nt\text{-}q}\cdot(t_q + 2\cdot t_r)$ — $A_{nt\text{-}q}$: 1.56 in² *(1008 mm²)*

Gusset Plate Block Rupture Strength

Shear Rupture Term $0.6\cdot F_{ug}\cdot A_{nv\text{-}q}$ — SRT: 146.3 kip *(651 kN)*

Shear Yield Term $0.6\cdot F_{yg}\cdot A_{gv\text{-}g}$ — SYT: 175.8 kip *(782 kN)*

Tension Rupture Term $U_{bs}\cdot F_{ug}\cdot A_{nt\text{-}g}$ — TRT: 101.6 kip *(452 kN)*

$\phi R_{n\text{-}blk\text{-}g} = \phi[\min(SRT, SYT) + TRT]$ — $\phi R_{n\text{-}blk\text{-}g}$: 185.9 kip *(827 kN)*

Block Shear Strength Stress Ratio at Gusset

$DCR_{blk\text{-}g} = P_{ut\text{-}max}/\phi R_{n\text{-}blk\text{-}g}$ — $DCR_{blk\text{-}g}$: 0.68

3.5.2 Lug Plates Block Rupture Strength

Lug Plate Yield Strength — F_{yL}: 50 ksi *(345 MPa)*

Gusset Plate Edge Distance — e: 1.19 in *(30 mm)*

Gross Area Subject to Shear

If — Then — $L_{gv\text{-}L}$: 4.69 in *(119 mm)*

$n_o = 0$ — $L_{gv\text{-}L} = (n_i - 1)\cdot s + e$

Otherwise — $L_{gv\text{-}L} = (n_i - 1)\cdot s + \sqrt{[(s/2)^2 + g^2]} + e$

$A_{gv\text{-}L} = 4\cdot L_{gv\text{-}L}\cdot t_L$ — $A_{gv\text{-}L}$: 9.38 in² *(6048 mm²)*

Net Area Subject to Shear

If $n_o = 0$, Then $n_{na\text{-}L} = n_i - ½$, Otherwise $n_{na\text{-}L} = n_i + ½$ — $n_{na\text{-}L}$: 1.5

$L_{nv\text{-}L} = (d_s + ovs_L + 1/16)\cdot n_{na\text{-}L}$ — $L_{nv\text{-}L}$: 1.50 in *(38 mm)*

$A_{nv\text{-}L} = A_{gv\text{-}L} - 4\cdot L_{nv\text{-}L}\cdot t_L$ — $A_{nv\text{-}L}$: 6.38 in² *(4113 mm²)*

Gross Area Subject to Tension

$A_{qt\text{-}L} = 4\cdot e\cdot t_L$ — $A_{qt\text{-}L}$: 2.38 in² *(1532 mm²)*

Net Area Subject to Tension

$L_{nt\text{-}L} = (d_s + ovs_L + 1/16)/2$ — $L_{nt\text{-}L}$: 0.50 in *(13 mm)*

$A_{nt\text{-}L} = A_{gt\text{-}L} - L_{nt\text{-}L}\cdot t_L\cdot 4$ — $A_{nt\text{-}L}$: 1.38 in² *(887 mm²)*

Lug Plate Block Rupture Strength

Shear Rupture Term $0.6\cdot F_{uL}\cdot A_{nv\text{-}L}$ — SRT: 248.6 kip *(1106 kN)*

Shear Yield Term $0.6\cdot F_{yL}\cdot A_{gv\text{-}L}$ — SYT: 281.3 kip *(1251 kN)*

Tension Rupture Term $U_{bs}\cdot F_{uL}\cdot A_{nt\text{-}L}$ — TRT: 89.4 kip *(398 kN)*

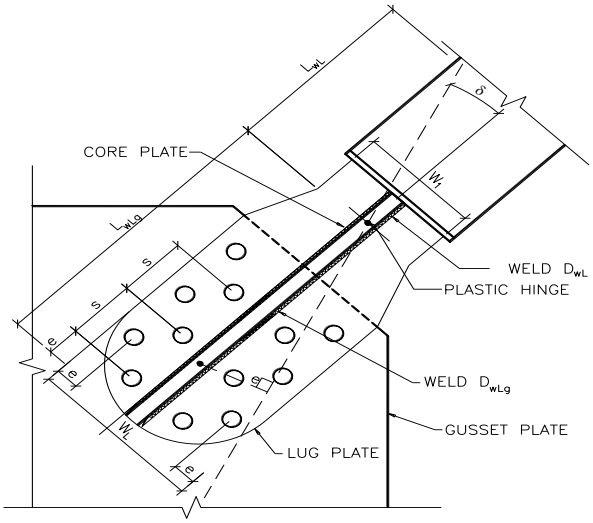
$\phi R_{n\text{-}blk\text{-}L} = \phi[\min(SRT, SYT) + TRT]$ — $\phi R_{n\text{-}blk\text{-}L}$: 253.5 kip *(1128 kN)*

Block Shear Strength Stress Ratio at Lug

$DCR_{blk\text{-}L} = P_{ut\text{-}max}/\phi R_{n\text{-}blk\text{-}L}$ — $DCR_{blk\text{-}L}$: 0.50

3.6.0 Weld Design

Assume plastic hinge forms in core just outside casing to accommodate story drift rotation δ



WELD CONFIGURATION

LRFD Resistance Factor	ϕ_{Weld}:	0.75	
Upper Bound Compressive Yield Stress of Core Material	$F_{ysc\text{-}max}$:	46 ksi	*(317 MPa)*
Weld Material Minimum Yield Strength for BRB Components	$F_{exx,BRB}$:	70 ksi	*(483 MPa)*
Length of Lug to Core Weld at Bolt Pattern	L_{wLg}:	9.88 in	*(251 mm)*
Length of Lug to Core Weld beyond Bolt Pattern	L_{wL}:	10.13 in	*(257 mm)*
Weld Both Sides of Lug Beyond Bolt Pattern?	WBS:	FALSE	
Width of Steel Yielding Core	W_{sc}:	4.00 in	*(102 mm)*
Width of Stiffener at Lug	W_s:	1.09 in	*(28 mm)*
Thickness of Stiffener at Lug	t_s:	0.50 in	*(13 mm)*

3.6.1 Weld Size Required at Bolt Pattern

Percent of Core Stub Capacity at Lug Allowed to be Transferred thru that Section (max 100%). — $\%A_{sc\text{-}stub}$: 100%

Max Force in Stiffener at Lug

$P_{wLg} = P_{uC\text{-}max} \cdot W_s/W_{sc} \cdot \min(\%A_{sc\text{-}Stub}, 1.0)$ — P_{wLg}: 40.6 kip *(181 kN)*

**Conservative for sizing weld*

Min Weld Size Based on Material Thickness

IF	Then
$\min(t_L, t_s) \le$ ½"	$D_{wLg\text{-}min} = 3^{16ths}$
$\min(t_L, t_s) \le$ ¾"	$D_{wLg\text{-}min} = 4^{16ths}$
Otherwise	$D_{wLg\text{-}min} = 5^{16ths}$

$D_{wLg\text{-}min}$: 3.00 (16ths) *(5 mm)*

Weld Size Based on Required Force

$D'_{wLg} = P_{wLg}/(\phi_{Weld} \cdot 0.6 \cdot F_{exx} \cdot 0.7071 \cdot 2 \cdot L_{wLg}) \cdot 16$ — D'_{wLg}: 1.48 (16ths) *(2 mm)*

Required Weld Size

D_{wLg}:	3.00	*(5 mm)*
D_{wLg}:	3.00 (16ths)	*(5 mm)*
D_{wLg}:	3/16"	*(5 mm)*

Base Metal Thickness Check

$t_{min}/t_{L,sc}$ = Max of:

$1 \cdot F_{EXX,BRB} \cdot 0.7071 \cdot (D_{wLg}/16)/(F_{uL} \cdot t_L)$ = 0.286

$2 \cdot F_{EXX,BRB} \cdot 0.7071 \cdot (D_{wLg}/16)/(F_{usc} \cdot t_s)$ = 0.562

$DCR_{Weld\text{-}Lg}$: 0.56

3.6.2 Weld Size Required Beyond Bolt Pattern

Yield Strength of Stub Section

$F_{Y\text{-}wLq} = W_s \cdot t_s \cdot F_{ysc\text{-}max} \cdot \min(\%A_{sc\text{-}Stub}, 1.0)$ — $F_{Y\text{-}wLq}$: 25.2 kip *(112 kN)*

**Conservative for determining force in section before stub*

Force in Weld Beyond Bolt Group

$P_{wL} = P_{uC\text{-}max} - 2 \cdot F_{Y\text{-}wLg}$ — P_{wL}: 98.2 kip *(437 kN)*

Weld Size Based on Required Force

$D'_{wL} = P_{wL}/(\phi_{Weld} \cdot 0.6 \cdot F_{exx} \cdot 0.7071 \cdot 4 \cdot L_{wL}) \cdot 16$ — D'_{wL}: 1.74 (16ths) *(3 mm)*

Required Weld Size — D_{wL}: 3.00 (16ths) *(5 mm)*

Note that minimum weld size here equal to minimum size req'd at bolt pattern ($D_{wLg\text{-}min}$) since lug and core thickness are the same as at that location. — D_{wL}: 3.00 (16ths) *(5 mm)*; D_{wL}: 3/16" *(5 mm)*

Base Metal Thickness Check

Factor for Weld Both Sides (WBS) Beyond Bolt Pattern:

IF WBS = TRUE Then WBSF = 2, Otherwise WBSF = 1 — WBSF: 1

$t_{min}/t_{L,sc}$ = Max of: — $DCR_{Weld\text{-}L}$: 0.56

$WBSF \cdot F_{EXX,BRB} \cdot 0.7071 \cdot (D_{wL}/16)/(F_{uL} \cdot t_L)$ = 0.286

$2 \cdot F_{EXX,BRB} \cdot 0.7071 \cdot (D_{wL}/16)/(F_{usc} \cdot t_{sc})$ = 0.562

3.6.3 Weld Around Lug in Lieu of Bolting

Weld Material Minimum Yield Strength for Lug to Gusset (Alt Weld) — $F_{exx,BRB}$: 70 ksi *(483 MPa)*

Length of Sides of Lug Only — L_{LS}: 13.56 in *(344 mm)*

$L_{LS} = (L_{Lg} - W_L/2 - Tol_{LLS}) \cdot 4$ Tol_{LLS} = 0.50 in *(13 mm)*

Length Around Lug (Including Sides) — L_{rs}: 32.41 in *(823 mm)*

$L_{Lrs} = L_{Ls} + \pi \cdot (W_L/2) \cdot 2$

Plastic Section Modulus of Core Extension (Section Just Outside Casing)

$Z_+ = (2t_L \cdot W_1^2 + (W_t - 2t_L) \cdot t_{sc}^2)/4$ — Z_+: 3.44 in³ *(56351 mm³)*

Force Couple to Resist Plastification of Core Extension $F_R = Z_+ * F_{yL}/W_L$ — F_R: 28.7 kip *(127 kN)*

Required Weld if Welded Around Lug — D_{rs}: 4.56 *(7 mm)*

$D_{rs} = (P_{uC\text{-}max} + 2 \cdot F_R)/(L_{rs} \cdot 0.7071 \cdot 0.6 \cdot \phi_{Weld} \cdot F_{exx,Gst}) * 16$ — D_{rs}: 5.00 (16ths) *(8 mm)*; D_{rs}: 5/16" *(8 mm)*

Required Weld if Welded Around Sides of Lug Only — D_s: 10.90 *(17 mm)*

$D_s = (P_{uC\text{-}max} + 2 \cdot F_R)/(L_{Ls} \cdot 0.7071 \cdot 0.6 \cdot \phi_{Weld} \cdot F_{exx,Gst}) * 16$ — D_s: 11.00 (16ths) *(17 mm)*; D_s: 11/16" *(17 mm)*

3.7.0 Summary

3.1.0 Bolt Shear	DCR_{Shear}:	0.64
3.2.0 Bolt Friction	DCR_{Slip}:	0.82
3.3.1 Bolt Bearing - Gusset Plate	$DCR_{brq\text{-}g}$:	0.66
3.3.2 Bolt Bearing - Lug Plates	$DCR_{brg\text{-}L}$:	0.39
3.3.3 Combined Bolt Bearing & Tearout - Gusset	$DCR_{brq/Tear\text{-}G}$:	0.96
3.3.3 Combined Bolt Bearing & Tearout - Lug	$DCR_{brg/Tear\text{-}L}$:	0.96
3.4.0 Tension Fracture - Lug Plates	DCR_{tr}:	0.57
3.5.1 Block Rupture - Gusset Plate	$DCR_{blk\text{-}g}$:	0.68
3.5.2 Block Rupture - Lug Plates	$DCR_{blk\text{-}L}$:	0.50
3.6.1 Weld Strength at Bolt Pattern	$DCR_{Weld\text{-}Lq}$:	0.56
3.6.2 Weld Strength Beyond Bolt Pattern	$DCR_{Weld\text{-}L}$:	0.56
	Max:	0.96

End Connection Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																												Bolt Shear						Bolt Friction							
EOR-ID	Line	Grids	Lvls	Mark	Qty	W_T	W_s	W_L	t_{sc}	t_L	d_b	e	d_s	os_L	os_g	A_{sc}	n_i	n_o	g	s	$F_{u,sc}$	F_{ug}	F_{uL}	F_{vsc} max	F_{yg}	F_{yL}	β	$P_{ysc-max}$	P_{uc-max}	F_{nv}	Shear Type	L'_{Lg}	CLF	R_v	$\frac{P_u}{R_v}$	μ	ϕ	D_u	A_{Tb_min}	$F_{u,bolt}$	T_b	R_{str}	$\frac{P_{vsc}}{R_{str}}$
#		#	#	#	#	in	in	in	in	in	in	in	in	in	in	in^2	qty	qty	in	in	ksi	ksi	ksi	ksi	ksi	ksi		kip	kip	ksi		in		kip	$\frac{P_u}{R_v}$				in^2	ksi	kip	kip	$\frac{P_{vsc}}{R_{str}}$
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.17	92	149	64.8	N	3.5	1.00	234	0.64	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.17	92	149	64.8	N	3.5	1.00	234	0.64	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	5	E to D.5	1	**1903**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	4.000	0.781	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.16	92	146	64.8	N	3.5	1.00	234	0.63	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	4.000	0.781	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.16	92	146	64.8	N	3.5	1.00	234	0.63	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	4.000	0.719	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	4.000	0.719	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	E	4.7 to 5	1	**1909**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	4.000	1.031	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.12	92	138	64.8	N	3.5	1.00	234	0.59	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	4.000	1.031	6.00	0.750	0.50	0.875	1.188	0.9375	0.000	0.13	3.00	3	0	0.000	3.500	66	65	65	46	50	50	1.17	138	199	64.8	N	7.0	1.00	351	0.57	0.30	0.85	1.13	0.46	144	48	168	0.82
BRB-2.00	4	A.8 to A.99	1	**1912**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	B	5 to 4.7	1	**1913**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	4.000	0.656	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-3.00	2	D to C.6	1	**1916**	1	4.000	0.906	6.00	0.750	0.50	0.875	1.188	0.9375	0.000	0.13	3.00	3	0	0.000	3.500	66	65	65	46	50	50	1.17	138	197	64.8	N	7.0	1.00	351	0.56	0.30	0.85	1.13	0.46	144	48	168	0.82
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	4.000	0.656	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	4.000	0.656	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	3.2	D to C.6	1	**1918**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	4.000	1.031	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.50	2	A.2 to A	1	**1921**	1	4.000	1.094	6.00	0.625	0.50	0.875	1.188	0.9375	0.000	0.13	2.50	3	0	0.000	3.500	66	65	65	46	50	50	1.11	115	167	64.8	N	7.0	1.00	351	0.48	0.30	0.85	1.13	0.46	144	48	168	0.69
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	4.000	0.656	6.00	0.625	0.75	0.875	1.188	0.9375	0.000	0.13	2.50	3	0	0.000	3.500	66	65	65	46	50	50	1.11	115	167	64.8	N	7.0	1.00	351	0.48	0.30	0.85	1.13	0.46	144	48	168	0.69
BRB-3.50	A	3 to 2.7	1	**1923**	1	4.667	1.240	6.00	0.750	0.50	0.875	1.188	0.9375	0.000	0.13	3.50	3	0	0.000	3.500	66	65	65	46	50	50	1.17	161	232	64.8	N	7.0	1.00	351	0.66	0.30	0.85	1.13	0.46	144	48	168	0.96
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	4.000	0.781	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	3	A.2 to A	1	**1925**	1	4.000	0.781	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82

Table Symbols & Definitions

W_T = Width of CB at connection
W_L = Width of lug
t_{sc} = Thickness of main core
t_L = Thickness of lug
d_b = Bolt diameter (A490 SC)
e = Edge distance
d_s = Standard bolt size
os_L = Amount lug hole oversized beyond standard hole
os_g = Amount gusset hole oversize beyond standard hole

A_{sc} = Cross sectional area of yielding core
n = Number of bolts in a row
g_o = Outer Bolt gauge
g_i = Inner Bolt gauge
s = Bolt spacing
$F_{u,sc}$ = Minimum tensile strength of core, MTRs
$F_{u,L\&g}$ = Minimum tensile strength of lug & gusset, ASTM
$F_{ysc,max}$ = Maximum yield strength of core per specification
$F_{y,L\&g}$ = Minimum yield strength of lug & gusset, ASTM

β = Compression strength adjustment factor
P_{ysc} = Minimum yield force of yielding element of steel core
P_u = Ultimate CB demand
F_{nv} = Nominal shear stress of bolt
L'_{Lg} = Length of bolt group parallel to direction of load.
CLF = Connection Length Factor per AISC 360 Table J3.2
R_v = Design shear strength of bolts at connection (double shear)
ϕ = LRFD Resistance Factor for oversized and short-slotted holes parallel to the direction of the load per AISC 360-10 J3.8

End Connection Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Gusset Dims		Bearing: Gusset				Bearing: Lug				Combined Bolt Bearing, Tearout, & Shear: Gusset										Combined Bolt Bearing, Tearout, & Shear: Lug										Tension Rupture (Fracture): Lug					
EOR-ID	Line	Grids	Lvls	Mark	Qty	t_g	t_{r_Des}	L_{ce}	L_{cs}	$R_{b,g}$	$\underline{P_\mu}$	$L_{c,e}$	$L_{c,s}$	$R_{b,L}$	$\underline{P_\mu}$	GEB_{ni}	GEB_{no}	GFB_{ni}	GFB_{no}	ϕr_{nv}	$\phi R_{n\text{-}C,Edge}$	$\phi R_{n\text{-}T,Edge}$	$\phi R_{n\text{-}G,Field}$	$\phi R_{n\text{-}CG}$	$\phi R_{n\text{-}TG}$	$\underline{P_\mu}$	LEB_{ni}	LEB_{no}	LFB_{ni}	LFB_{no}	$\phi R_{n\text{-}L,Field}$	$\phi R_{n\text{-}CL}$	$\phi R_{n\text{-}TL}$	$\underline{P_\mu}$	$A_{e,L}$	A_{gt}	$A_{e,L\&t}$	U	$R_{n,L}$	$\underline{P_\mu}$
#		#	#	#	#	in	in	in	in	kip	R_{bg}	in	in	kip	$R_{b,L}$	kip	kip	kip	kip	kip	kip	kip	kip	kip	kip	$\phi R_{n\text{-}G}$	kip	kip	kip	kip	kip	kip	kip	$\phi R_{n\text{-}L}$	in^2	in^2	in^2		kip	$R_{n,L}$
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	0.63	0.000	0.66	2.44	226	0.66	0.72	2.56	384	0.39	24	0	64	0	58	234	132	0	234	132	0.96	42	0	102	0	0	234	132	0.96	4.00	1.09	5.09	0.89	223	0.57
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	0.63	0.000	0.66	2.44	226	0.66	0.72	2.56	384	0.39	24	0	64	0	58	234	132	0	234	132	0.96	42	0	102	0	0	234	132	0.96	4.00	1.09	5.09	0.89	223	0.57
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.93	42	0	102	0	0	234	132	0.93	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.93	42	0	102	0	0	234	132	0.93	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	5	E to D.5	1	**1903**	1	0.63	0.000	0.66	2.44	226	0.59	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.91	42	0	102	0	0	234	132	0.91	4.00	1.09	5.09	0.89	223	0.54
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	0.75	0.000	0.66	2.44	271	0.54	0.72	2.56	576	0.25	29	0	77	0	58	234	174	0	234	174	0.72	63	0	154	0	0	234	174	0.72	6.00	0.78	6.78	0.88	290	0.43
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	0.75	0.000	0.66	2.44	271	0.54	0.72	2.56	576	0.25	29	0	77	0	58	234	174	0	234	174	0.72	63	0	154	0	0	234	174	0.72	6.00	0.78	6.78	0.88	290	0.43
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.93	42	0	102	0	0	234	132	0.93	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.93	42	0	102	0	0	234	132	0.93	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	0.88	0.000	0.66	2.44	317	0.42	0.72	2.56	576	0.23	34	0	90	0	58	234	184	0	234	184	0.65	63	0	154	0	0	234	184	0.65	6.00	0.72	6.72	0.88	288	0.42
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	0.88	0.000	0.66	2.44	317	0.42	0.72	2.56	576	0.23	34	0	90	0	58	234	184	0	234	184	0.65	63	0	154	0	0	234	184	0.65	6.00	0.72	6.72	0.88	288	0.42
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	E	4.7 to 5	1	**1909**	1	0.63	0.000	0.66	2.44	226	0.59	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.91	42	0	102	0	0	234	132	0.91	4.00	1.09	5.09	0.89	223	0.54
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	0.75	0.000	0.66	2.44	271	0.51	0.72	2.56	384	0.36	29	0	77	0	58	234	142	0	234	142	0.87	42	0	102	0	0	234	142	0.87	4.00	1.03	5.03	0.90	221	0.56
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	0.75	0.000	0.66	2.44	461	0.43	0.72	2.56	614	0.32	29	0	77	0	58	234	142	117	351	259	0.66	42	0	102	0	117	351	259	0.66	4.00	1.55	5.55	0.94	256	0.66
BRB-2.00	4	A.8 to A.99	1	**1912**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	B	5 to 4.7	1	**1913**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	1.00	0.000	0.66	2.44	362	0.37	0.72	2.56	576	0.23	38	0	102	0	58	234	194	0	234	194	0.62	63	0	154	0	0	234	194	0.62	6.00	0.66	6.66	0.88	286	0.42
BRB-3.00	2	D to C.6	1	**1916**	1	1.00	0.000	0.66	2.44	614	0.32	0.72	2.56	614	0.32	38	0	102	0	58	234	161	117	351	278	0.61	42	0	102	0	117	351	278	0.61	4.00	1.36	5.36	0.95	248	0.68
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	1.00	0.000	0.66	2.44	362	0.37	0.72	2.56	576	0.23	38	0	102	0	58	234	194	0	234	194	0.62	63	0	154	0	0	234	194	0.62	6.00	0.66	6.66	0.88	286	0.42
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	1.00	0.000	0.66	2.44	362	0.37	0.72	2.56	576	0.23	38	0	102	0	58	234	194	0	234	194	0.62	63	0	154	0	0	234	194	0.62	6.00	0.66	6.66	0.88	286	0.42
BRB-2.00	3.2	D to C.6	1	**1918**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	0.75	0.000	0.66	2.44	271	0.49	0.72	2.56	384	0.35	29	0	77	0	58	234	142	0	234	142	0.85	42	0	102	0	0	234	142	0.85	4.00	1.03	5.03	0.90	221	0.55
BRB-2.50	2	A.2 to A	1	**1921**	1	0.63	0.000	0.66	2.44	384	0.44	0.72	2.56	614	0.27	24	0	64	0	58	234	132	117	351	249	0.61	42	0	102	0	117	351	249	0.61	4.00	1.37	5.37	0.94	248	0.61
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	1.00	0.000	0.66	2.44	614	0.27	0.72	2.56	921	0.18	38	0	102	0	58	234	194	117	351	311	0.49	63	0	154	0	117	351	311	0.49	6.00	0.82	6.82	0.94	312	0.48
BRB-3.50	A	3 to 2.7	1	**1923**	1	1.00	0.000	0.66	2.44	614	0.38	0.72	2.56	614	0.38	38	0	102	0	58	234	161	117	351	278	0.71	42	0	102	0	117	351	278	0.71	4.00	1.86	5.86	0.93	268	0.74
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	1.25	0.000	0.66	2.44	452	0.30	0.72	2.56	384	0.35	48	0	128	0	58	234	180	0	234	180	0.68	42	0	102	0	0	234	180	0.68	4.00	0.78	4.78	0.91	212	0.58
BRB-2.00	3	A.2 to A	1	**1925**	1	1.25	0.000	0.66	2.44	452	0.30	0.72	2.56	384	0.35	48	0	128	0	58	234	180	0	234	180	0.67	42	0	102	0	0	234	180	0.67	4.00	0.78	4.78	0.91	212	0.57

μ = Slip coefficient
D_u = Multiplier that reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension.
A_{Tb_min} = Minimum tensile area of bolt
$F_{u,bolt}$ = Specified minimum tensile strength of bolt
T_b = Minimum fastener tension
R_{str} = Design friction strength of bolts at connection

t_g = Total thickness of gusset
t_{r_Des} = Thickness of the gusset repad that gets used for strength calculations.
$L_{c,e}$ = Distance between edge of plate and edge of bolt hole
$L_{c,s}$ = Distance between edge of bolt holes
$R_{b,g}$&$R_{b,L}$ = Bearing strength of bolts at gusset and lug
$A_{c,Wc1}$ = Area of core at end connection
$R_{n,sc}$&$R_{n,L}$ = Tension and or shear strength of core and splice plate at bolts.
$A_{e,L}$ = Net area of lugs at end connection

GEB = Gusset Capacity at Edge Bolt (min of Bearing and Tearout)
GFB = Gusset Capacity at Field Bolt (min of Bearing and Tearout)
LEB = Lug Capacity at Edge Bolt (min of Bearing and Tearout)
LFB = Lug Capacity at Field Bolt (min of Bearing and Tearout)
$\phi R_{n\text{-}C}$ = Group (or Subgroup) Capacity in Compression
$\phi R_{n\text{-}T}$ = Group (or Subgroup) Capacity in Tension
Note, T or C Edge Subgroup Capacities are the Same for Lug or Gusset
$\phi R_{n\text{-}G}$ = Group (or Subgroup) Capacity at Gusset
$\phi R_{n\text{-}L}$ = Group (or Subgroup) Capacity at Lug

End Connection Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Block Rupture												Weld Lengths																			
						Gusset							Lug					Lug to Core																Alt Lug Weld			
EOR-ID	Line	Grids	Lvls	Mark	Qty	$A_{nv,g}$	$A_{gt,g}$	$A_{gv,g}$	$A_{nt,g}$	U_{bs}	$R_{n,g}$	$\underline{P_u}$	$A_{gv,L}$	$A_{nv,L}$	$A_{gt,L}$	$A_{nt,L}$	$R_{n,L}$	$\underline{P_u}$	$F_{exx,BRB}$	$F_{exx,Gst}$	$\underline{W_s}$	Weld 2	L_{wL}	P_{wL}	$D_{wL\text{-}min}$	$D_{wL\text{-}req'd}$	$L_{wL\text{-}stub}$	$P_{wL\text{-}stub}$	$D_{wLg\text{-}req'd}$	D_{wLg}	$\underline{t_{min}}$	D_{wL}	$\underline{t_{min}}$	L_{Lr+s}	L_{Ls}	Alt	Alt
#		#	#	#	#	in^2	in^2	in^2	in^2		kip	$R_{n,g}$	in^2	in^2	in2	in2	kip	$R_{n,L}$	ksi	ksi	W_{sc}	Sides?	in	kip	#	#	in	kip	#	#	$t_{g,sc}$	#	$t_{g,sc}$	in	in	D_{Lr+s}	D_{Ls}
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	3.8	2.3	5.9	1.6	1.0	186	0.68	9.4	6.4	2.4	1.4	254	0.50	70	70	0.27	FALSE	10	98	3.0	1.7	9.9	41	1.5	3	0.56	3	0.56	32	14	5	11
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	3.8	2.3	5.9	1.6	1.0	186	0.68	9.4	6.4	2.4	1.4	254	0.50	70	70	0.27	FALSE	10	98	3.0	1.7	9.9	41	1.5	3	0.56	3	0.56	32	14	5	11
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	3.8	2.3	5.9	1.6	1.0	186	0.66	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	86	3.0	1.5	9.9	37	1.4	3	0.56	3	0.56	32	14	5	11
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	3.8	2.3	5.9	1.6	1.0	186	0.66	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	86	3.0	1.5	9.9	37	1.4	3	0.56	3	0.56	32	14	5	11
BRB-2.00	5	E to D.5	1	**1903**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	83	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	4.5	2.7	7.0	1.9	1.0	223	0.57	14.1	9.6	3.6	2.1	380	0.33	70	70	0.20	FALSE	10	110	3.0	2.0	9.9	29	1.0	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	4.5	2.7	7.0	1.9	1.0	223	0.57	14.1	9.6	3.6	2.1	380	0.33	70	70	0.20	FALSE	10	110	3.0	2.0	9.9	29	1.0	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	3.8	2.3	5.9	1.6	1.0	186	0.66	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	86	3.0	1.5	9.9	37	1.4	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	3.8	2.3	5.9	1.6	1.0	186	0.66	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	86	3.0	1.5	9.9	37	1.4	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	5.3	3.2	8.2	2.2	1.0	260	0.46	14.1	9.6	3.6	2.1	380	0.32	70	70	0.18	FALSE	10	101	3.0	1.8	9.9	24	0.9	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	5.3	3.2	8.2	2.2	1.0	260	0.46	14.1	9.6	3.6	2.1	380	0.32	70	70	0.18	FALSE	10	101	3.0	1.8	9.9	24	0.9	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	E	4.7 to 5	1	**1909**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	83	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	4.5	2.7	7.0	1.9	1.0	223	0.55	9.4	6.4	2.4	1.4	254	0.49	70	70	0.26	FALSE	10	91	3.0	1.6	9.9	36	1.3	3	0.56	3	0.56	32	14	5	11
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	8.1	2.7	12.3	1.9	1.0	327	0.52	16.4	11.4	2.4	1.4	400	0.42	70	70	0.26	FALSE	11	127	3.0	2.1	13.4	51	1.4	3	0.37	3	0.37	46	28	5	8
BRB-2.00	4	A.8 to A.99	1	**1912**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	B	5 to 4.7	1	**1913**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	6.0	3.6	9.4	2.5	1.0	297	0.41	14.1	9.6	3.6	2.1	380	0.32	70	70	0.16	TRUE	20	104	3.0	0.9	9.9	22	0.8	3	0.56	3	0.56	32	14	5	11
BRB-3.00	2	D to C.6	1	**1916**	1	10.8	3.6	16.4	2.5	1.0	436	0.39	16.4	11.4	2.4	1.4	400	0.42	70	70	0.23	TRUE	22	134	3.0	1.1	13.4	45	1.2	3	0.37	3	0.57	46	28	5	8
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	6.0	3.6	9.4	2.5	1.0	297	0.41	14.1	9.6	3.6	2.1	380	0.32	70	70	0.16	TRUE	20	104	3.0	0.9	9.9	22	0.8	3	0.56	3	0.56	32	14	5	11
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	6.0	3.6	9.4	2.5	1.0	297	0.41	14.1	9.6	3.6	2.1	380	0.32	70	70	0.16	TRUE	20	104	3.0	0.9	9.9	22	0.8	3	0.56	3	0.56	32	14	5	11
BRB-2.00	3.2	D to C.6	1	**1918**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	4.5	2.7	7.0	1.9	1.0	223	0.54	9.4	6.4	2.4	1.4	254	0.48	70	70	0.26	FALSE	10	86	3.0	1.5	9.9	34	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.50	2	A.2 to A	1	**1921**	1	6.7	2.3	10.2	1.6	1.0	273	0.55	16.4	11.4	2.4	1.4	400	0.38	70	70	0.27	FALSE	10	104	3.0	1.8	13.4	46	1.2	3	0.45	3	0.45	46	28	5	7
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	10.8	3.6	16.4	2.5	1.0	436	0.35	24.6	17.1	3.6	2.1	600	0.25	70	70	0.16	TRUE	20	129	4.0	1.1	13.4	27	0.7	4	0.60	4	0.60	46	28	5	7
BRB-3.50	A	3 to 2.7	1	**1923**	1	10.8	3.6	16.4	2.5	1.0	436	0.45	16.4	11.4	2.4	1.4	400	0.50	70	70	0.27	FALSE	12	146	3.0	2.3	13.4	62	1.7	3	0.37	3	0.37	46	28	6	9
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	7.5	4.5	11.7	3.1	1.0	372	0.33	9.4	6.4	2.4	1.4	254	0.48	70	70	0.20	TRUE	22	100	3.0	0.8	9.9	27	1.0	3	0.56	3	0.57	32	14	5	11
BRB-2.00	3	A.2 to A	1	**1925**	1	7.5	4.5	11.7	3.1	1.0	372	0.33	9.4	6.4	2.4	1.4	254	0.48	70	70	0.20	TRUE	20	99	3.0	0.9	9.9	26	1.0	3	0.56	3	0.57	32	14	5	11

A_{gt} = Area gross of stiffeners at lugs at end connection
$A_{e,L\&t}$ = Net area of lugs and stiffener at end connection
U = Shear lag factor (AISC 360, Table D3.1)
$A_{nv,g}\&A_{nv,L}$ = Net shear area of gusset & lug
$A_{gt,g}\&A_{gt,L}$ = Gross tensile area of gusset & lug
$A_{nt,g}\&A_{nt,L}$ = Net tensile area of gusset & lug
$A_{gv,g}\&A_{gv,L}$ = Gross shear area of gusset & lug
U_{bs} = Reduction coefficient for block rupture (1.0 for uniform loading, 0.5 otherwise)

F_{exx} = Filler metal classification strength
L_{wL} = Length of weld lug to main core PL
F_{wL} = Force that must be transferred to the lug in at the tapered down section.
$R_{n,g}\&R_{n,L}$ = Capacity of gusset & lug

PSE Operational Training Center

Calculation Submittal Package

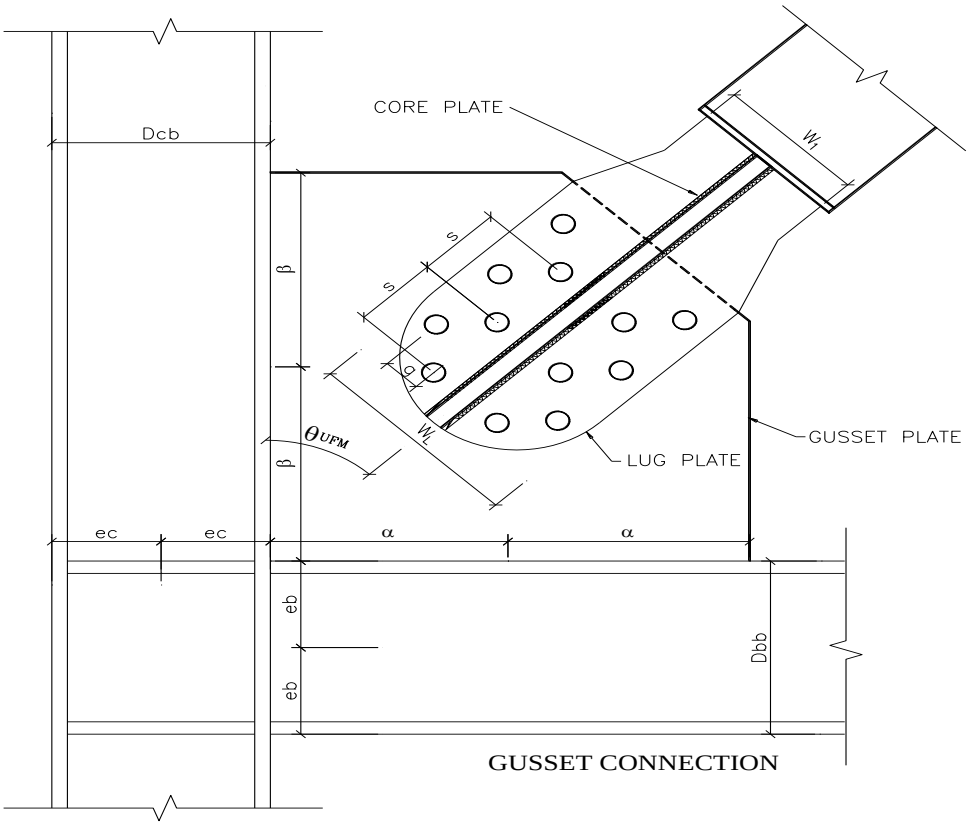
Description

Section 4. **Bottom Gusset Beam to Column Flange (Strong-Axis) Connection Sample Calculation**
Top and Bottom Connection Summary Tables

Bottom Gusset Connection

(Top Connection Similar)

Example Mark #: 1910
Line E, Grid 3.8 to 4.1, Level Low Roof



Uniform Force Method - AISC 360 - Bracing Section

4.0 DESIGN CRITERIA

Area of Yielding Steel Core	A_{sc}:	2.00 in²	*(1290 mm²)*
Maximum Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Compresssion Strength Adjustment Factor	β:	1.12	
Strain Hardening Adjustment Factor	ω:	1.34	
Connection Strain Hardening Factor	CF:	1.00	
Adjusted Brace Strength (Design Axial Load) in Compression ($CF \cdot \beta\omega F_{y\text{-}max}A_{sc}$)	P_{uc}:	138.1 kip	*(614 kN)*
Adjusted Brace Strength (Design Axial Load) in Tension ($CF \cdot \omega F_{y\text{-}max}A_{sc}$)	P_{ut}:	123.3 kip	*(548 kN)*
Thickness of Yielding Core	$t_{sc:}$	0.50 in	*(13 mm)*
Width of Lug	W_L:	6.00 in	*(152 mm)*
Column Depth	D_{cb}:	6.00 in	*(152 mm)*
Column Web Thickness	t_{wc}:	1.25 in	*(32 mm)*
Column Flange Thickness	t_{fc}:	0.63 in	*(16 mm)*
Column Flange Width	b_{fc}:	6.00 in	*(152 mm)*
Column Web Doubler Plate Thickness (one side)	t_{wcPL}:	0.00 in	*(0 mm)*
Beam Depth	D_{bb}:	11.90 in	*(302 mm)*
Nominal Depth of Beam	DN_{bb}:	11.90 in	*(302 mm)*
Beam Web Thickness	t_{wb}:	0.30 in	*(7 mm)*
Beam Flange Thickness	t_{fb}:	0.52 in	*(13 mm)*
Beam Flange Width	b_{fb}:	8.01 in	*(203 mm)*
Beam Distance from Outer Face of Flange to Toe of Fillet	k_{desb}:	1.02 in	*(26 mm)*
Column Distance from Outer Face of Flange to Toe of Fillet	k_{desc}:	1.00 in	*(25 mm)*
Beam Web Doubler Plate Thickness (one side)	t_{wbPL}:	0.00 in	*(0 mm)*
Angle Between the Beam and Brace CL	θ_{CB}:	0.434 rad	*24.9°*
Angle Between the Column and Brace CL	θ_{UFM}:	1.136 rad	*65.1°*
Min Clear Distance from Face of Beam to Edge of Lug	$b_{bot\text{-}Bm}$:	2.38 in	*(60 mm)*
Min Clear Distance from Face of Column to Edge of Lug	$b_{bot\text{-}Col}$:	1.00 in	*(25 mm)*
Distance from Last Bolt to Start of Radius on Lug	b_r:	0.80 in	*(20 mm)*
Bolt Edge Distance	e:	1.19 in	*(30 mm)*
Provided Stroke Distance at Each End of Brace	c:	3.00 in	*(76 mm)*
Distance Between End of Core and Gusset	a:	4.00 in	*(102 mm)*

4.1.0 GEOMETRY CALCULATIONS - UNIFORM FORCE METHOD

Length from WP to Bottom Tip of Brace			
Length from WP to Outside Edge of Col along WorkLine			
$L_{cb} = (D_{cb}/2)/COS(\theta_{CB})$	L_{cb}:	3.31 in	*(84 mm)*
Length from Edge of Column to Tip of CB along WL			
$L_{1cb} = [b_{bot\text{-}Col} + (W_L/2)]/COS(\theta_{CB}) - (e + b_r)$	L_{1cb}:	2.43 in	*(62 mm)*
Length from WP to Top Edge of Beam along WL			
$L_{bb} = (DN_{bb}/2)/SIN(\theta_{CB})$	L_{bb}:	14.14 in	*(359 mm)*
Length from Edge of Beam to Tip of CB along WL			
$L_{1bb} = [b_{bot\text{-}Bm} + (W_L/2)]/SIN(\theta_{CB}) - (e + b_r)$	L_{1bb}:	10.80 in	*(274 mm)*
Controling Length is $MAX(L_{cb}+L_{1cb}, L_{bb}+L_{1bb})$	L_{tb}:	24.94 in	*(634 mm)*
Length from Square Projection to Edge of Gusset (CB Lap on Gusset)	L_g:	5.88 in	*(149 mm)*
Horizontal Distance from Column to WP ($D_{cb}/2$)	e_c:	0.00 in	*(0 mm)*
For HSS columns, set e_c to 0" and slot the gusset through the column, welding on both sides. This allows the resultent of the weld group to be concentric with the work point and eliminates horizontal forces and moments from being applied to the relatively flexible face of the HSS column.			
Vertical Distance from Beam to WP ($DN_{bb}/2$)	e_b:	5.95 in	*(151 mm)*

Minimum Weld on Column from Geometry

$L_{wc_min} = (L_{tb} + L_g)*SIN(\theta_{CB}) + (W_L/2 + 1)*COS(\theta_{CB}) - DN_{bb}/2$ | L_{wc_min}: | 10.65 in | *(270 mm)*

Minimum Weld on Beam from Geometry

$L_{wb_min} = (L_{tb} + L_g)*COS(\theta_{CB}) + (W_L/2 + 1)*SIN(\theta_{CB}) - D_{cb}/2$ | L_{wb_min}: | 26.64 in | *(677 mm)*

Dist from Face of Col Fl to Centriod of Gusset-to-Beam Connection (UFM)

$\alpha_{min} = L_{wb_min}/2$ | α_{min} | 13.32 in | *(338 mm)*

α_{Hand} = Hand Input Value to Force | α_{Hand} | 10.51 in | *(267 mm)*

If Hand Input Value is Different from α_{min} use Hand Input Value | α_{min}: | 10.51 in | *(267 mm)*

Inside Weld Deducts: | $WD_{Bm,In}$: | 1.50 in | *(38 mm)*

Outside Weld Deducts: | $WD_{Bm,Out}$: | 0.50 in | *(13 mm)*

α Dist for Weld (1/2 of the actual weld length used for design) | α_g: | 9.51 in | *(242 mm)*

α Dist from face of column to mid point on beam welds

$\alpha_{bar} = WD_{Bm,In} + \alpha_g$ | α_{bar}: | 11.01 in | *(280 mm)*

Dist from Face of Beam Fl to Centriod of Gusset-to-Column Connection (UFM)

$\beta_{min} = L_{wc_min}/2$ | β_{min} | 5.32 in | *(135 mm)*

β_{Hand} = Hand Input Value to Force | β_{Hand} | 5.32 in | *(135 mm)*

If Hand Input Value is Different from β_{min} use Hand Input Value | β_{min}: | 5.32 in | *(135 mm)*

Inside Weld Deducts: | $WD_{Col,In}$: | 1.50 in | *(38 mm)*

Outside Weld Deducts: | $WD_{Col,Out}$: | 0.50 in | *(13 mm)*

β Dist for Weld (1/2 of the actual weld length used for design) | β_g: | 4.32 in | *(110 mm)*

β from face of beam to mid point on column welds

$\beta_{bar} = WD_{Col,In} + \beta_g$ | β_{bar}: | 5.82 in | *(148 mm)*

Final Gusset-Beam Weld Length *(note that welds sized on 2 α g only)*

$L_{wbu} = ROUNDUP(2\alpha_q)$ | L_{wbu}: | 20.00 in | *(508 mm)*

Final Gusset-Column Weld Length *(note that welds sized on 2βg only)*

$L_{wcu} = ROUNDUP(2\beta_g)$ | L_{wcu}: | 9.00 in | *(229 mm)*

Constants for Connections not in Equilibrium

$K = e_b TAN(\theta_{UFM}) - e_c$ | K: | 12.83 in | *(326 mm)*

$K' = \alpha_{bar}[TAN(\theta_{UFM}) + \alpha_{bar}/\beta_{bar}]$ | K': | 44.55 in | *(1132 mm)*

$D = (TAN(\theta_{UFM}))^2 + (\alpha_{bar}/\beta_{bar})^2$ | D: | 8.22

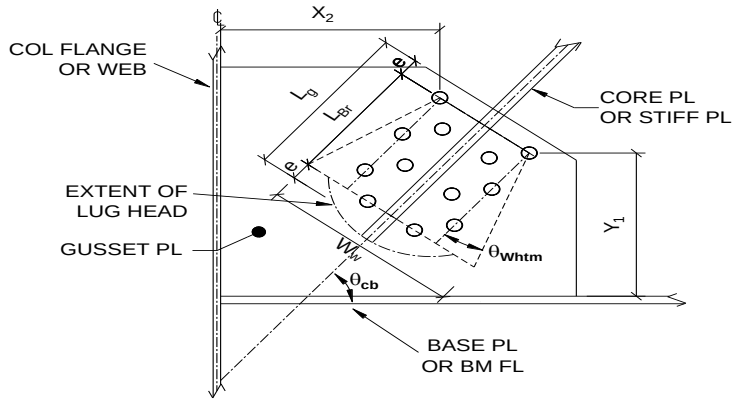
Final values of α and β

$\alpha_{nE} = [K'*TAN(\theta_{UFM}) + K(\alpha_{bar}/\beta_{bar})^2]/D$ | α_{nE}: | 17.26 in | *(438 mm)*

$\beta_{nE} = [K' - K*TAN(\theta_{UFM})]/D$ | β_{nE}: | 2.05 in | *(52 mm)*

$r = \sqrt{((\alpha_{nE} + e_c)^2 + (\beta_{nE} + e_b)^2)}$ | r: | 19.02 in | *(483 mm)*

4.2.0 GUSSET STRESS CALCULATIONS - AISC 360



4.2.1 WHITMORE SECTION STRESS CHECK

LRFD Resistance Factor	ϕ_W:	0.90	
Number of Bolts in Inside Row	n_i:	2	
Number of Bolts in Outside Row	n_o:	0	
Total Number of Bolts at Each End $2(n_i + n_o)$	n_b:	4	
Bolt Spacing	s:	3.50 in	*(89 mm)*
Lug Width	W_L:	6.00 in	*(152 mm)*
Minimum Yield Strength of Gusset	F_{yg}:	50 ksi	*(345 MPa)*
Minimum Tensile Strength of Gusset	F_{ug}:	65 ksi	*(448 MPa)*
Thickness of Gusset Plate	$t_{q:}$	0.75 in	*(19 mm)*
Thickness of Repad Plate for Design:	$t_{r:}$	0.00 in	*(0 mm)*
Whitmore Angle	θ_{Whtm}:	28.0°	*0.489 rad*
Total Length Between Outer Bolt Holes $L_{Br} = L_q - 2e$	L_{Br}:	3.50 in	*(89 mm)*
Vertical Distance to Top Bolt on Beam Side of CL $Y_1 = L_{wc\text{-}min} - (W_L + 1 - e)\cdot COS(\theta_{CB}) - e\cdot SIN(\theta_{CB})$	Y_1:	4.87 in	*(124 mm)*
Horizontal Distance to Top Bolt on Column Side of CL $X_2 = L_{wb\text{-}min} - (W_L + 1 - e)\cdot SIN(\theta_{CB}) - e\cdot COS(\theta_{CB})$	X_2:	23.12 in	*(587 mm)*
Whitmore Length if Not Limited by Beam or Column $h_{Br} = L_{Br}/COS(\theta_{Whtm})$	h_{Br}:	3.96 in	*(101 mm)*
Gusset Condition: FHG - Full Height Gusset NFG - Non Full Height Gusset	FHG:	TRUE	
Whitmore Length if Limited by Beam IF — Then FHG = TRUE — $h_{Bm} = h_{Br}$ FHG = FALSE — $h_{Bm} = Y_1/SIN(\theta_{CB} + \theta_{Whtm})$	h_{Bm}:	3.96 in	*(101 mm)*
Whitmore Length if Limited by Column $h_{Col} = X_2/COS(\theta_{CB} - \theta_{Whtm})$	h_{Col}:	23.15 in	*(588 mm)*
Constrain Whitmore Section within Gusset Plate?	WSG:	FALSE	
Whitmore Area IF — Then WSG = TRUE — $A_w = [2\cdot\min(h_{Br},h_{Bm},h_{Col})\cdot SIN(\theta_{Whtm})]\cdot t_g + (W_L - 2e)\cdot(t_g + 2t_r)$ WSG = FALSE — $A_w = [2\cdot L_{BR}\cdot TAN(\theta_{Whtm})]\cdot t_q + (W_L - 2e)\cdot(t_q + 2t_r)$	A_W =	5.51 in²	*(3555 mm²)*

Whitmore Capacity $\phi R_{n\text{-}W} = \phi_W \cdot A_W \cdot F_{yg}$	$\phi R_{n\text{-}W}$:	248.0 kip	*(1103 kN)*
Whitmore Stress Ratio			
$DCR_W = P_{ut}/\phi R_{n\text{-}W}$	DCR_W:	0.50	

4.2.2 Gusset Plate Buckling

LRFD Resistance Factor	ϕ_{gb}:	0.85	
Modulus of Elasticity	E:	29000 ksi	*(199955 MPa)*
Effective Length Factor for Gusset Buckling	K_{gb}:	1.00	
Average Buckling Length *Average of L_1, L_2, & L_3. If average is less than zero, zero is used (Gusset is Elastic).*	L':	12.39 in	*(315 mm)*
Radius of Gyration of Gusset $r_g = \sqrt{(t_g^2/12)}$	r_g:	0.22 in	*(5 mm)*
Gusset Slenderness Parameter $\lambda = K_{gb} \cdot L'/(r_g \cdot \pi) \cdot \sqrt{(F_{yg}/E)}$	λ:	0.76	
Gusset Buckling Capacity $\phi R_{n\text{-}gb} = \phi_{gb} \cdot 0.658^{\wedge}(\lambda_c^2) \cdot F_{yg} \cdot A_w$	$\phi R_{n\text{-}gb}$:	184.3 kip	*(820 kN)*
Gusset Buckling Capacity Ratio			
$DCR_{gb} = P_{uc}/\phi R_{n\text{-}gb}$	DCR_{gb}:	0.75	

4.2.3 Gusset Plate Buckling (Out-of-Plane)

A. Consider Self Weight of Brace Out-of-Plane Acting on Gusset

Assumed Spectral Acceleration	S_A:	1.02 g	
Factor on S_A	F_{SA}	0.40	
Importance Factor	I_p:	1.00	
Brace Weight	Wt_{br}:	0.72 kip	*(3.2 kN)*
Additional Out-of-Plane Force on Gusset *(when present)*.	$F_{Add'l\text{-}OOP/End}$:	0.00 kip	*(0.0 kN)*
Out of Plane Force at Each End of Brace due to BRB Self Weight SW $F_{OOP} = F_{SA} \cdot S_A \cdot I_p \cdot Wt_{br}/2 + F_{Add'l\text{-}OOP/End}$	F_{OOP}:	0.147 kip	*(1 kN)*
Moment Arm $M_{Arm_OOP} = L_g + a + 2 \cdot C$	M_{Arm_OOP}:	15.88 in	*(403 mm)*
Resulting Self Weight Out-of-Plane Moment SW $M_{OOP} = F_{OOP} \cdot M_{Arm_OOP}$	M_{OOP}:	2.3 kip-in	*(263 kN-mm)*

B. Consider Adjusted Brace Strength at Out Of Plane Frame Deformation

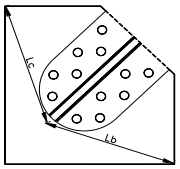
Story Drift Factor *(Usually 2x, But if considering 100% of ABS, Use only 1/3 of this)*	F_{SD}:	0.67	
Story Drift (See Stiffness Section for Calculation)	SD:	1.00%	
Drift Angle $\theta_{SD} = ATAN(SD \cdot F_{SD})$	θ_{SD}:	0.0067	(0.38°)
Percentage of Adjusted Brace Strength to Consider *Use either 100% ABS and 1/3 of 2xSD, or 30% ABS and 2xSD*	F_{ABS}:	100%	
Out of Plane component of F_{ABS}xAdjusted Brace Strength $P_H = F_{ABS} \cdot P_{uc} \cdot SIN(\theta_{SD})$	P_H:	0.92 kip	*(4.1 kN)*
Moment Arm (consider PH applied at centroid of BRB-gusset connection) $M_{Arm_PH} = L_{Lg}/2$	M_{Arm_PH}:	2.94 in	*(75 mm)*
Resulting Horizontal Moment $M_{PH} = P_H \cdot M_{Arm_PH}$	M_{PH}:	2.70 k-in	*(306 kN-mm)*

C. Consider Total Moment from Part A and B

Total Out of Plane Moment

$M_u = M_{OOP} + M_{PH}$ — M_u: 5 k-in *(569 kN-mm)*

Length of potential yielding line (disregarding concrete where occurs)



To Intersection with Column — L_c: 7.2 in *(183 mm)*

To Intersection with Beam/BP — L_b: 4.7 in *(120 mm)*

Total Length — L_t: 11.9 in *(303 mm)*

Plastic Modulus

$Z_q = L_t \cdot t_q^2/4$ — Z_q: 1.68 in³ *(27469 mm³)*

Design Flexural Strength

$\phi M_n = 0.9 \cdot Z_R \cdot F_{yR}$ — ϕM_n: 75 k-in *(8524 kN-mm)*

Gusset Flexure Capacity Ratio

$DCR_{gf} = M_u/\phi M_n$ — DCR_{gf}: 0.07

Combined Gusset Buckling & Flexure DCR

IF $DCR_{gb} \geq 0.2$, $DCR_{gb+f} = DCR_{gb} + (8/9)DCR_{gf}$ — DCR_{gb+f}: 0.81

IF $DCR_{gb} < 0.2$, $DCR_{gb+f} = (1/2)DCR_{gb} + DCR_{gf}$ — DCR_{gb+f}: -

4.3.0 FORCE CALCULATIONS - AISC 360 BRACING SECTION

Force at the Column Face

Vertical Force $V_{uc} = P_{uc} * \beta_{nE}/r$ — V_{uc}: 14.9 kip *(66 kN)*

See Section 4.4.2 for definitions of R_{ub} and $\phi_{OGC,Below}$

Eccentricity of Beam Reaction (at Full Height Gusset Only)

ecc_{Rub}=ROUNDUP(2·α min,0)+D_{cb}/2 — ecc_{Rub}: 25.0 in *(635 mm)*

Vertical force Couple from Moment Caused by Eccentric Reaction from Beam at FHG

FHG FC=$(R_{ub}/\phi_{OGC,Below}) \cdot ecc_{Rub}/D_{cb}$ — FHG FC: 66.04 kip *(293.7 kN)*

Portion of the FHG Force Couple Resisted Along the Gusset Height, Outside Beam Depth

FC_c=(FHG FC)·$(2 \cdot \beta_g)/(2 \cdot \beta_g + D_{bb}/\phi_{OGC,Below})$ — FC_c: 38.24 kip *(170.1 kN)*

Portion of the FHG Force Couple Resisted Through the Beam Depth

$FC_{c,g}$=(FHG FC)·$(D_{bb}/\phi_{OGC,Below})/(2 \cdot \beta_g + D_{bb}/\phi_{OGC,Below})$ — $FC_{c,g}$: 27.80 kip *(123.7 kN)*

Adjusted Vertical Force in Gusset Outside Beam Depth

$V_{uc}' = V_{uc} + FC_c$ — V_{uc}': 53.2 kip *(236 kN)*

Horizontal Force $H_{uc} = P_{uc} * e_c/r$ — H_{uc}: 0.0 kip *(0 kN)*

Moment at Column $M_{uc} = H_{uc} * |\beta_{nE} - \beta_{bar}|$ — M_{uc}: 0.0 kip-in *(0 kN-mm)*

Force at Beam Face

Vertical Force $V_{ub} = P_{uc} * e_b/r$ — V_{ub}: 43.2 kip *(192 kN)*

Horizontal Force $H_{ub} = P_{uc} * \alpha_{nE}/r$ — H_{ub}: 125.3 kip *(557 kN)*

Moment at Beam $M_{ub} = V_{ub} * |\alpha_{nE} - \alpha_{bar}|$ — M_{ub}: 269.8 kip-in *(30489 kN-mm)*

Equivalent Stress for Mu

$H_{uc_eq} = 6 \cdot M_{uc}/(2 \cdot \beta_g) + H_{uc}$ — H_{uc_eq}: 0.0 kip *(0 kN)*

$V_{ub_eq} = 6 \cdot M_{ub}/(2 \cdot \alpha_q) + V_{ub}$ — V_{ub_eq}: 128.3 kip *(571 kN)*

Where $2\beta_g = L_{wc}$, $2\alpha_g = L_{wb}$

Stresses at the interface between Gusset Plate and Column:

$f_{vc} = V_{uc}/2\beta_q$ — f_{vc}: 1.72 k/in *(0.3 kN/mm)*

$f_{Hc} = H_{uc}/2\beta_q$ — f_{Hc}: 0.00 k/in *(0.0 kN/mm)*

$f_{bc} = 6M_{uc}/(2\beta_q)^2$ — f_{bc}: 0.00 k/in *(0.0 kN/mm)*

Stresses at the interface between Gusset Plate and Beam:

$f_{vb} = V_{ub}/2\alpha_g$ — f_{vb}: 2.27 k/in *(0.4 kN/mm)*

$f_{Hb} = H_{ub}/2\alpha_q$ — f_{Hb}: 6.59 k/in *(1.2 kN/mm)*

$f_{bb} = 6M_{ub}/(2\alpha_q)^2$ — f_{bb}: 4.48 k/in *(0.8 kN/mm)*

4.4.0 WELD DESIGN & STRESS CHECKS - AISC 360

Weld Material Minimum Yield Strength	F_{exx}:	70 ksi	*(483 MPa)*
Minimum Yield Strength of Beam ASTM	F_{yBm}:	50 ksi	*(345 MPa)*
Minimum Tensile Strength of Beam ASTM	F_{uBm}:	65 ksi	*(448 MPa)*
Minimum Yield Strength of Col ASTM	F_{yCol}:	46 ksi	*(317 MPa)*
Minimum Tensile Strength of Col ASTM	F_{uCol}:	58 ksi	*(400 MPa)*
Weld Ductility Factor	μ_F:	1.25	

4.4.1 INITIAL FILLET WELD CALCULATIONS

Angle of Resultant Demand on Column $\theta_{wc} = \tan^{-1}(H_{uc_eq}/V_{uc})$	θ_{wc}:	0.00 rad	*0.0°*
Weld Capacity Increase Factor for Rotation at Column			
$C_c = 1+0.5(\sin(\theta wc))^{1.5}$	C_c:	1.00	
Angle of Resultant Demand on Beam $\theta_{wb} = \tan^{-1}(V_{ub_eq}/H_{ub})$	θ_{wb}:	0.80 rad	*45.7°*
Weld Capacity Increase Factor for Rotation at Beam			
$C_b = 1+0.5(\sin(\theta wb))^{1.5}$	C_b:	1.30	
Initial Weld Required at Beam and Column (16^{ths})			
Peak Stresses at the interface between Gusset Plate and Column:			
$f_{peak_c} = \sqrt{(f_{bc}+f_{Hc})^2+f_{vc}^2}$	f_{peak_c}:	1.72 k/in	*(0.3 kN/mm)*
Average Stresses at the interface between Gusset Plate and Column:			
$f_{avg_c} = (\sqrt{(f_{bc}-f_{Hc})^2+f_{vc}^2} + f_{peak_c})/2$	f_{avg_c}:	1.72 k/in	*(0.3 kN/mm)*
Control Stresses at the interface between Gusset Plate and Column:			
$f_{cont_c} = \text{Max}(\mu_F f_{avg_c}, f_{peak_c})$	f_{cont_c}:	2.16 k/in	*(0.4 kN/mm)*
Peak Stresses at the interface between Gusset Plate and Beam:			
$f_{peak_b} = \sqrt{(f_{bb}+f_{vb})^2+f_{Hb}^2}$	f_{peak_b}:	9.43 k/in	*(1.7 kN/mm)*
Average Stresses at the interface between Gusset Plate and Beam:			
$f_{avg_b} = (\sqrt{(f_{bb}-f_{vb})^2+f_{Hb}^2})+f_{peak_b})/2$	f_{avg_b}:	8.19 k/in	*(1.4 kN/mm)*
Control Stresses at the interface between Gusset Plate and Beam:			
$f_{cont_b} = \text{Max}(\mu_F f_{avg_b}, + f_{peak_b})$	f_{cont_b}:	10.23 k/in	*(1.8 kN/mm)*
Initial Weld Required at Beam and Column (16^{ths})			
$D_{wc1} = \dfrac{f_{cont_c}}{0.75\frac{(1in)0.7071}{16}0.6F_{eex}(2Lines)C_c}$	D_{wc1}:	0.77 (16ths)	*(1 mm)*
$D_{wb1} = \dfrac{f_{cont_b}}{0.75\frac{(1in)0.7071}{16}0.6F_{eex}(2Lines)C_b}$	D_{wb1}:	2.82 (16ths)	*(4 mm)*

4.4.2. BEAM/COLUMN STRESS CHECKS

Gusset and Opposing Brace Conditions			
Opposing Gusset Case - BELOW (for Beam):	OGC_{Below}:	Yes	
"Yes" - There is a gusset plate directly below this plate.			
"No" - There is not a gusset plate directly below this plate.			
$V_{ub,OGC}$: *(For equal capacity oposing brace = V_{ub}/β)*	$V_{ub,OGC}$:	38.6 kip	*(172 kN)*
Apportionment Factor: $\phi_{OGC,Below} = V_{ub,OGC}/V_{ub} + 1$	$\phi_{OGC,Below}$:	1.9	
Opposing Gusset Case - ACROSS (for Column):	OGC_{Across}:	No	
"Yes" - There is a gusset plate directly across from this plate.			
"No" - There is not a gusset plate directly across from this plate.			
$\phi_{OGC,Across}$: = 1 if OGC = YES	$\phi_{OGC,Across}$:	0	
= 0 otherwise			
Gusset Condition:	FHG:	TRUE	
FHG - Full Height Gusset			
NFG - Non Full Height Gusset			
Assumed Beam Reaction (EOR to Verify)	R_{ub}:	30.0 kip	*(133 kN)*
Beam Reaction Adjusted for OCG $R'_{ub} = R_{ub}/\phi_{OGC,Below}$	R'_{ub}:	15.8 kip	*(70 kN)*
Consider half of reaction if OCG = YES because only half of beam shear capacity is considered.			
Other half is considered in the design of the opposing gusset.			
Beam/Column Web Capacity			
t_{wbb}: = t_g if FHG	t_{wbb}:	0.75 in	*(19 mm)*
= t_{wb} if NFG			

Pseudo Thickness of Beam Web (Amount to use to calc weld to column for FHG) — t'_{wbb}: 0.75 in *(19 mm)*

t_{wbb1}: $= t'_{wbb}$ if $t'_{wbb} \neq 0$ AND FHG = TRUE; $= t_{wbb}$ Otherwise — t_{wbb1}: 0.75 in *(19 mm)*

Beam and Column Shear Capacities

$\phi V_{nb} = 0.6 \cdot F_{yBm} \cdot (\phi_{Vb} \cdot t_{wbb1} + 0.9 \cdot t_{wbPL}) \cdot D_{bb} / \phi_{OGC,Below}$ — ϕV_{nb}: 141.5 kip *(629 kN)*

$\phi_{Vb} =$ 1.00

ϕV_{nbc} = Shear Capacity of Beam at Col Connection — ϕV_{nbc}: 127.3 kip *(566 kN)*

$\phi V_{nc} = \phi_{Vc} \cdot \phi_{Vc,BP} \cdot 0.6 \cdot F_{yCol} \cdot (t_{wc} + t_{wbPL}) \cdot D_{cb}$ — ϕV_{nc}: 186.3 kip *(829 kN)*

$\phi_{Vc} =$ 0.90

$\phi_{Vc,BP} =$ 1.00 *Accounts for shear cap reduction at BP if needed. (Includes removal of WAH, etc where occurs.)*

Beam Web Check

$S_{rb} = (R'_{ub} + V_{ub}) / \text{Min}(\phi V_{nb}, \phi V_{nbc})$ — S_{rb}: 0.46

Transfer Force if Greater than 1.0

Vertical Force in Excess of Beam Web (or Connection) Capacity

ΔV_{ub}: $= 0$ kip if $t_{wbb} = 0$; $= 0$ kip if $R'_{ub} + V_{ub} - \min(\phi V_{nb}, \phi V_{nbc}) < 0$; $= R'_{ub} + V_{ub} - \min(\phi V_{nb}, \phi V_{nbc})$ otherwise — ΔV_{ub}: 0.0 kip *(0 kN)*

See Resultant Moment Shear Check on Beam/Col at End of Revised Weld Calculations

Column Web Shear Check

Point Load on Column from Opposing Gusset — $H_{uc,OGC}$: 0.0 kip *(0 kN)*

For equal capacity opposing brace = (Huc/β) $\phi_{OGC,Across}$*

$DCR_{CWV} = (H_{uc} + H_{uc,OGC}) / \phi V_{nc}$ — DCR_{cwv}: 0.00

If this DCR is >1.0 then column web must be reinforced or thickened.

4.5.0 REVISED FORCE CALCULATIONS TO ACCOUNT FOR FORCE TRANSFER TO COLUMN WELD

$\Delta M_{ub} = \Delta V_{ub} \cdot \alpha_{bar}$ (Zero if no force transferred to weld) — ΔM_{ub}: 0.0 kip-in *(0 kN-mm)*

Moment Demand on Weld at Beam:

$M_{ub2} = V_{ub} \cdot |\alpha_{nE} - \alpha_{bar}|$ — M_{ub2}: 269.8 kip-in *(30489 kN-mm)*

Equivalent Vertical Demand on Weld from M_{ub}:

$V_{ub_eq2} = 6 (M_{ub2} + \Delta M_{ub}) / (2\alpha_q) + (V_{ub} - \Delta V_{ub})$ — V_{ub_eq2}: 128.3 kip *(571 kN)*

Stresses at the interface between Gusset Plate and Column:

$f'_{vc} = (V_{uc} + \Delta V_{ub}) / 2\beta_g$ — f'_{vc}: 1.72 k/in *(0.3 kN/mm)*

$f'_{Hc} = H_{uc} / 2\beta_q$ — f'_{Hc}: 0.00 k/in *(0.0 kN/mm)*

$f'_{bc} = 6M_{uc} / (2\beta_q)^2$ — f'_{bc}: 0.00 k/in *(0.0 kN/mm)*

Stresses at the interface between Gusset Plate and Beam:

$f_{vb} = (V_{ub} - \Delta V_{ub}) / 2\alpha_q$ — f_{vb}: 2.27 k/in *(0.4 kN/mm)*

$f_{Hb} = H_{ub} / 2\alpha_g$ — f_{Hb}: 6.59 k/in *(1.2 kN/mm)*

$f_{bb} = 6(M_{ub2} + \Delta M_{ub}) / (2\alpha_q)^2$ — f_{bb}: 4.48 k/in *(0.8 kN/mm)*

4.6.0 WELD DESIGN/STRESS CHECKS FOR REVISED FORCES

6.1 FINAL FILLET WELD CALCULATIONS

Angle of Resultant Demand on Column:

$\theta_{wc} = \text{TAN}^{-1}[H_{uc_eq} / (V_{uc} + \Delta V_{ub})]$ — θ_{wc}: 0.000 rad *0.0°*

Weld Capacity Increase Factor for Angle at Column

$C_{wc} = 1 + 0.5[\text{SIN}(\theta_{wc})]^{1.5}$ — C_{wc}: 1.000

Angle of Resultant Demand on Beam:

$\theta_{wb} = \text{TAN}^{-1}(V_{ub_eq2} / H_{ub})$ — θ_{wb}: 0.797 rad *45.7°*

Weld Capacity Increase Factor for Angle at Beam

$C_{wb} = 1 + 0.5[\text{SIN}(\theta_{wb})]^{1.5}$ — C_{wb}: 1.303

Peak Stresses at the interface between Gusset Plate and Column:

$f'_{peak_c} = \sqrt{(f'_{bc} + f'_{Hc})^2 + f'^2_{vc}}$ — f'_{peak_c}: 1.72 k/in *(0.3 kN/mm)*

Average Stresses at the interface between Gusset Plate and Column:

$f'_{avg_c} = (\sqrt{(f'_{bc} - f'_{Hc})^2 + f'^2_{vc}} + f'_{peak_c}) / 2$ — f'_{avg_c}: 1.72 k/in *(0.3 kN/mm)*

Control Stresses at the interface between Gusset Plate and Column:

$f'_{cont_c} = \text{Max}(\mu_F f'_{avg_c}, f'_{peak_c})$ — f'_{cont_c}: 2.16 k/in *(0.4 kN/mm)*

Peak Stresses at the interface between Gusset Plate and Beam:

$f'_{peak_b} = \sqrt{(f'_{bb}+f'_{vb})^2+f'^2_{Hb}}$ — f'_{peak_b}: 9.43 k/in *(1.7 kN/mm)*

Average Stresses at the interface between Gusset Plate and Beam:

$f'_{avg_b} = (\sqrt{(f'_{bb}-f'_{vb})^2+f'^2_{Hb}})+f'_{peak_b})/2$ — f'_{avg_b}: 8.19 k/in *(1.4 kN/mm)*

Control Stresses at the interface between Gusset Plate and Beam:

$f'_{cont_b} = Max(\mu_F f'_{avg_b,} + f'_{peak_b})$ — f'_{cont_b}: 10.23 k/in *(1.8 kN/mm)*

Final Weld Required at Beam and Column (16ths)

$$D_{wc2} = \frac{f'_{cont_c}}{0.75\frac{(1in)0.7071}{16}0.6F_{eex}(2Lines)C_{wc}}$$

D_{wc2}: 0.77 (16ths) *(1 mm)*

$$D_{wb2} = \frac{f'_{cont_b}}{0.75\frac{(1in)0.7071}{16}0.6F_{eex}(2Lines)C_{wb}}$$

D_{wb2}: 2.82 (16ths) *(4 mm)*

Min Weld Size for Gusset — $D_{w\text{-}min}$: 4.00 (16ths) *(6 mm)*

If: $t_g \le 0.50"$, $D_{w\text{-}min} = 3/16"$
$0.50" < t_g \le 0.75"$, $D_{w\text{-}min} = 1/4"$
$t_g > 0.75"$, $D_{w\text{-}min} = 5/16"$

Final Weld Size to Use:

$D_{wc} = MAX(D_{wc1}, D_{wc2}, D_{w\text{-}min})$ — D_{wc}: 4.00 (16ths) *(6 mm)*
Rounded Up: D_{wc}: 4.00 (16ths) *(6 mm)*
Use: D_{wc}: 1/4 " *(6 mm)*

$D_{wb} = MAX(D_{wb1}, D_{wb2}, D_{w\text{-}min})$ — D_{wb}: 4.00 (16ths) *(6 mm)*
Rounded Up: D_{wb}: 4.00 (16ths) *(6 mm)*
Use: D_{wb}: 1/4 " *(6 mm)*

Gusset Weld Comparison (*Based on Non-Rounded Dwb & Dwc)*

$DCR_{wbmbg} = 2/\sqrt{2}\cdot(D_{wb}/16)\cdot F_{exx}/(t_g\cdot F_{ug})$ — DCR_{wbmbg}: 0.51

$DCR_{wbmcg} = 2/\sqrt{2}\cdot(D_{wc}/16)\cdot F_{exx}/(t_g\cdot F_{ug})$ — DCR_{wbmcg}: 0.51

Beam and Column Weld Filler Base Metal Compatiblity Check

$DCR_{wbm,Bm} = \sqrt{2}/2\cdot F_{exx}/F_{uBm}$ — $DCR_{wbm,Bm}$: 0.76
$DCR_{wbm,Col} = \sqrt{2}/2\cdot F_{exx}/F_{uCol}$ — $DCR_{wbm,Col}$: 0.85

4.7.0 Col & Bm Web Yielding and Crippling - AISC 360 J10

7.1 Web Yield Check - EQ J10-3

Beam Distance from Outer Face of the Flange to the Web Toe of the Fillet — k_{desb}: 1.02 in *(26 mm)*

Column Distance from Outer Face of the Flange to the Web Toe of the Fillet — k_{desc}: 1.00 in *(25 mm)*

Beam Web Local Yielding Capacity

$\phi R_{nyb} = (2.5k_{desb} + \alpha_g)\cdot(t_{wbb} + t_{wbPL})\cdot F_{yBm}$ — ϕR_{nyb}: 452.3 kip *(2012 kN)*

Beam Web Yielding Unity Check

$DCR_{wyb} = (max(V_{ub_eq}, V_{ub_eq2})/2)/\phi R_{nyb}$ — DCR_{wyb}: 0.14

Provide Stiffener if $DCR_{wyb} > 1.0$

Column Web Local Yielding Capacity

$\phi R_{nyc} = (2.5k_{desc} + \beta_q)\cdot(t_{wcb} + t_{wcPL})\cdot F_{yCol}$ — ϕR_{nyc}: 392.3 kip *(1745 kN)*

Column Web Yielding Unity Check

$DCR_{wyc} = (H_{uc_eq}/2)/\phi R_{nyc}$ — DCR_{wyc}: 0.00

Provide Stiffener if $DCR_{wyc} > 1.0$

4.7.2 Web Crippling Check - EQ J10-5b

LRFD Resistance Factor — ϕ_c: 0.75

Modulus of Elasticity of Steel — E: 29000 ksi *(199955 MPa)*

Beam Web Crippling Capacity

$$\phi R_{ncb} = \phi_c 0.4(t_{wbb} + 2t_{wbPL})^2 \left[1 + \left(\frac{4\alpha_g}{D_{bb}} - 0.2\right)\left(\frac{t_{wbb} + 2t_{wbPL}}{t_{fbb}}\right)^{1.5}\right]\sqrt{\frac{F_{yBm} t_{fbb} E}{t_{wbb} + 2t_{wbPL}}}$$

ϕR_{ncb}: 1055.2 kip *(4694 kN)*

Beam Web Crippling Unity Check

$DCR_{wcb} = (\max(V_{ub_eq}, V_{ub_eq2})/2)/\phi R_{ncb}$ — DCR_{wcb}: 0.06

Provide Stiffener if $DCR_{wcb} > 1.0$

Column Web Crippling Capacity

$$\phi R_{ncc} = \phi_c 0.4(t_{wcb} + t_{wcPL})^2 \left[1 + \left(\frac{4\beta_g}{D_{cb}} - 0.2\right)\left(\frac{t_{wcb} + t_{wcPL}}{t_{fcb}}\right)^{1.5}\right]\sqrt{\frac{F_{yCol} t_{fcb} E}{t_{wcb} + t_{wcPL}}}$$

ϕR_{ncc}: 3287.2 kip *(14622 kN)*

Column Web Crippling Unity Check

$DCR_{wcc} = (H_{uc_eq}/2)/\phi R_{ncc}$ — DCR_{wcc}: 0.00

Provide Stiffener if $DCR_{wcb} > 1.0$

4.7.3 Required Stiffener Thickness

Beam Stiffener Required?

Required if $DCR_{wwb} > 1.0$ or $DCR_{wcb} > 1.0$ — FALSE

Column Stiffener Required?

Required if $DCR_{wyc} > 1.0$ or $DCR_{wcc} > 1.0$ — FALSE

4.8.0 Summary

4.2.1 Whitmore Section Stress	DCR_W:	0.50
4.2.2 Gusset Plate Buckling	DCR_{qb}:	0.75
4.2.3 Gusset Plate Combined Buckling & Flexure	DCR_{qb+f}:	0.81
4.4.2 Column Web Shear Check	DCR_{cwv}:	0.00
4.6.1A Gusset Weld Base Metal Check at Beam (Gusset)	DCR_{wbmbq}:	0.51
Gusset Weld Base Metal Check at Beam (Flange)	DCR_{wbmbf}:	0.74
4.6.1B Gusset Weld Base Metal Check at Column (Gusset)	DCR_{wbmcq}:	0.51
Gusset Weld Base Metal Check at Column (Flange)	DCR_{wbmcf}:	0.68
4.6.1C Beam Weld Filler Material Base Metal Compatability Check	$DCR_{wbm,Bm}$:	0.76
Column Weld Filler Material Base Metal Compatability Check	$DCR_{wbm,Col}$:	0.85
4.7.1 Beam Web Yield Check	DCR_{wyb}:	0.14
4.7.1 Column Web Yield Check	DCR_{wyc}:	0.00
4.7.2 Beam Web Crippling Check	DCR_{wcb}:	0.06
4.7.2 Column Web Crippling Check	DCR_{wcc}:	0.00

Provide Stiffener if DCR_{wyb} or DCR_{wcb} > 1.0

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																			Constrained UFM Geometry																				Whitmore Tension Fracture																			
EOR-ID	Line	Grids	Lvls	Mark	Qty	n_i	n_o	s	θ_{CB}	θ_{UFM}	L_{tt}	L_{2t}	e	D_{ct}	D_{bt}	DN_{bt}	e_{Col}	e_{Bm}	W_L	Whtm Ang	l_{wc} min	l_{wb} min	Rot_c	α min	Y1	$WD_{Bm,In}$	$WD_{Bm,Out}$	α_g	α_{bar}	β min	X2	$WD_{Col,In}$	$WD_{Col,Out}$	β_g	β_{bar}	t_g	t_{r_Des}	L_{Br}	h_{Br}	h_{Bm}	h_{Col}	W'_{wh}	A'_{wh}	A_{wh}	P_{uc}	β	P_{ut}	F_{yg}	F_{ug}	Constrain	$\underline{P_{ut}}$
#		#	#	#	#	#	#	in	rad	rad	in	in	in	in	in	in	in	in	in	deg	in	in	deg	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	kip		kip	ksi	ksi	Whitmore	ϕR_n
BRB-2.00	4.1	D.3 to D(+)	Low Roof	1901	1	2	0	3.50	0.48	1.093	24.53	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	30	9.34	25.83	0	12.92	3.63	1.50	0.50	11.92	13.42	4.67	22.11	1.50	0.50	3.67	5.17	0.63	0.00	3.50	4.04	4.04	22.13	7.67	4.79	4.79	149	1.17	127	50	65	NO	0.59
BRB-2.00	4.1	D(+) to C.6	Low Roof	1901	1	2	0	3.50	0.48	1.093	24.53	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	30	9.34	25.83	0	12.92	3.63	1.50	0.50	11.92	13.42	4.67	22.11	1.50	0.50	3.67	5.17	0.63	0.00	3.50	4.04	4.04	22.13	7.67	4.79	4.79	149	1.17	127	50	65	NO	0.59
BRB-2.00	5	E to D.5	1	1903	1	2	0	3.50	0.63	0.941	19.02	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	30	9.69	19.47	0	9.74	4.29	1.50	0.50	8.74	10.24	4.84	15.09	1.50	0.50	3.84	5.34	0.63	0.00	3.50	4.04	4.69	15.18	7.67	4.79	4.79	134	1.11	121	50	65	NO	0.56
BRB-2.00	C	2.8 to 3(+)	Low Roof	1904	1	2	0	3.50	0.39	1.185	30.83	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	26	9.32	32.51	0	16.25	3.49	1.50	0.50	15.25	16.75	4.66	29.22	1.50	0.50	3.66	5.16	0.75	0.00	3.50	3.89	3.89	29.29	7.04	5.28	5.28	146	1.16	126	50	65	NO	0.53
BRB-2.00	C	3(+) to 3.2	Low Roof	1904	1	2	0	3.50	0.39	1.185	30.83	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	26	10.25	32.51	0	16.25	3.49	1.50	0.50	15.25	16.75	5.12	29.22	1.50	0.50	4.12	5.62	0.75	0.00	3.50	3.89	3.89	29.29	7.04	5.28	5.28	146	1.16	126	50	65	NO	0.53
BRB-2.00	C.2	3.3 to 3.7	Low Roof	1906	1	2	0	3.50	0.27	1.299	41.28	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	25	13.60	43.50	0	21.75	2.38	1.50	0.50	20.75	22.25	6.80	40.80	1.50	0.50	5.80	7.30	0.88	0.00	3.50	3.86	3.86	41.36	6.89	6.03	6.03	134	1.11	121	50	65	NO	0.44
BRB-2.00	C.2	3.7 to 4.1	Low Roof	1907	1	2	0	3.50	0.31	1.261	41.88	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	26	13.98	43.70	0	21.85	4.27	1.50	0.50	20.85	22.35	6.99	40.80	1.50	0.50	5.99	7.49	0.88	0.00	3.50	3.89	3.89	41.23	7.04	6.16	6.16	134	1.11	121	50	65	NO	0.43
BRB-2.00	E	4.7 to 5	1	1909	1	2	0	3.50	0.67	0.906	14.82	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	9.97	15.75	0	7.88	4.67	1.50	0.50	6.88	8.38	4.99	11.23	1.50	0.50	3.99	5.49	0.63	0.00	3.50	4.04	4.04	11.34	7.67	4.79	4.79	134	1.11	121	50	65	NO	0.56
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	2	0	3.50	0.43	1.136	20.72	5.88	1.188	8.0	11.9	11.9	0.0	6.0	6.00	30	8.87	21.81	0	10.91	3.10	1.50	0.50	9.91	11.41	4.44	18.29	1.50	0.50	3.44	4.94	0.75	0.00	3.50	4.04	4.04	18.36	7.67	5.75	5.75	138	1.12	123	50	65	NO	0.48
BRB-3.00	E	4.1 to 3.8	1	1911	1	3	0	3.50	0.88	0.695	12.31	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	13.27	21.02	0	10.51	8.64	1.50	0.50	9.51	11.01	6.64	8.73	1.50	0.50	5.64	7.14	0.75	0.00	7.00	8.08	8.08	9.30	11.71	8.78	8.78	199	1.17	170	50	65	NO	0.43
BRB-2.00	4	A.8 to A.99	1	1912	1	2	0	3.50	0.93	0.642	12.03	5.88	1.188	6.0	13.8	13.8	0.0	6.9	6.00	30	9.84	10.93	0	5.47	5.40	1.50	0.50	4.47	5.97	4.92	5.57	1.50	0.50	3.92	5.42	0.63	0.00	3.50	4.04	4.04	6.06	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	2	D to C.6	Low Roof	1915	1	2	0	3.50	0.27	1.297	43.57	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	20	9.97	45.68	0	22.84	3.09	1.50	0.50	21.84	23.34	4.98	42.97	1.50	0.50	3.98	5.48	1.00	0.00	3.50	3.72	3.72	43.09	6.17	6.17	6.17	134	1.11	121	50	65	NO	0.43
BRB-3.00	2	D to C.6	1	1916	1	3	0	3.50	0.67	0.899	28.64	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	20.84	29.25	0	14.63	15.55	1.50	0.50	13.63	15.13	10.42	24.71	1.50	0.50	9.42	10.92	1.00	0.00	7.00	8.08	8.08	24.98	11.71	11.71	11.71	197	1.17	168	50	65	NO	0.32
BRB-2.00	3.2	D to C.6	Low Roof	1917	1	2	0	3.50	0.24	1.326	59.31	5.88	1.188	6.0	21.6	21.6	0.0	10.8	6.00	20	12.73	61.21	0	30.61	2.93	1.50	0.50	29.61	31.11	6.37	58.66	1.50	0.50	5.37	6.87	1.00	0.00	3.50	3.72	3.72	58.98	6.17	6.17	6.17	134	1.11	121	50	65	NO	0.43
BRB-2.00	3.2	C.6 to C.2	Low Roof	1917	1	2	0	3.50	0.24	1.326	59.31	5.88	1.188	6.0	21.6	21.6	0.0	10.8	6.00	20	12.73	61.21	0	30.61	2.93	1.50	0.50	29.61	31.11	6.37	58.66	1.50	0.50	5.37	6.87	1.00	0.00	3.50	3.72	5.23	58.98	6.17	6.17	6.17	134	1.11	121	50	65	NO	0.43
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	2	0	3.50	0.34	1.227	32.44	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	23	8.47	34.42	0	17.21	2.60	1.50	0.50	16.21	17.71	4.24	31.35	1.50	0.50	3.24	4.74	0.75	0.00	3.50	3.80	3.80	31.40	6.60	4.95	4.95	134	1.11	121	50	65	NO	0.54
BRB-2.50	2	A.2 to A	1	1921	1	3	0	3.50	0.86	0.706	13.20	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	13.82	14.69	0	7.35	9.15	1.50	0.50	6.35	7.85	6.91	9.50	1.50	0.50	5.91	7.41	0.63	0.00	7.00	8.08	8.08	10.08	11.71	7.32	7.32	167	1.11	151	50	65	NO	0.46
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	3	0	3.50	0.29	1.276	40.49	9.38	1.188	6.0	16.4	16.4	0.0	8.2	6.00	20	10.09	45.88	0	22.94	4.19	1.50	0.50	21.94	23.44	5.05	43.06	1.50	0.50	4.05	5.55	1.00	0.00	7.00	7.45	7.45	43.12	8.72	8.72	8.72	167	1.11	151	50	65	NO	0.38
BRB-3.50	A	3 to 2.7	1	1923	1	3	0	3.50	0.68	0.892	29.26	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	21.42	29.58	0	14.79	16.15	1.50	0.50	13.79	15.29	10.71	25.01	1.50	0.50	9.71	11.21	1.00	0.00	7.00	8.08	8.08	25.31	11.71	11.71	11.71	232	1.17	198	50	65	NO	0.38
BRB-2.00	3	A.2 to A	Low Roof	1924	1	2	0	3.50	0.31	1.256	28.10	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	22	8.36	30.55	0	15.27	2.47	1.50	0.50	14.27	15.77	4.18	27.62	1.50	0.50	3.18	4.68	1.25	0.00	3.50	3.77	3.83	27.69	6.45	8.07	8.07	136	1.11	122	50	65	NO	0.34
BRB-2.00	3	A.2 to A	1	1925	1	2	0	3.50	0.69	0.883	27.56	5.88	1.188	6.0	24.5	24.5	0.0	12.3	6.00	30	12.06	25.38	0	12.69	6.81	1.50	0.50	11.69	13.19	6.03	20.78	1.50	0.50	5.03	6.53	1.25	0.00	3.50	4.04	4.04	21.06	7.67	9.58	9.58	135	1.11	121	50	65	NO	0.28

Table of Symbols

n = Number of bolts in a row ($_i$ inside row, $_o$ outside row)
s = Bolt spacing in a row
W_L = Width of lug
θ_{CB} = Angle of Cb from horizontal
θ_{UFM} = Angle used for uniform force method
L_{tb} = Total length from W.P. to top end of CB
L_{2b} = Length from end of lug to end of gusset
e = Edge distance
D_{cb} = Depth of column at bottom of CB
D_{bb} = Depth of beam at bottom of CB
$l_{wc,min}$ = Minimum possible length of weld on column
$l_{wb,min}$ = Minimum possible length of weld on beam
α min = Center of weld on beam based on geometry constraints
β min = Center of weld on column based on geometry constraints
α_g / β_g = 1/2 of weld length on beam / column, respectively
α_{bar} / β_{bar} = Actual center of weld on beam / column used, respectively
t_g = Thickness of gusset
t_r = Thickness of repad
A_{wm} = Area of whitmore line at gusset
L_{wm} = Width of whitmore section
P_{uc} = Ultimate CB compressive demand
β = Compression strength adjustment factor
P_{ut} = Ultimate CB tensile demand
F_{yg} = Yield stress of gusset
ϕR_n = Capacity of whitmore section
L' = Average buckling length of gusset
r = Radius of gyration of gusset
λ_c = Gusset slenderness parameter
f_{cr} = Buckling stress demand on gusset
ϕF_{cr} = Buckling stress capacity of gusset
K = UFM factor
K' = UFM reduced moment factor
D = UFM reduced moment factor
α = Center of weld on column
β = Center of weld on beam
r = Resultant length of **α** & **β**

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

															Gusset Buckling																	
EOR-ID	**Line**	**Grids**	**Lvls**	**Mark**	**Qty**	**L'**	**r**	**K_{gb}**	**λ_c**	**$\frac{f_{ez}}{\phi F_{cr}}$**	**S_A**	Factor	I_p	Wt_{BRB}	SW $F_{OOP\ (EA\ End)}$	$M_{Arm\text{-}OOP}$	SW M_{OOP}	SD	Factor	Drift Angle	Factor	P_H	M_{Arm_PH}	M_{PH}	L_b	L_c	Z_g	ϕ_b	ϕMn	M_r	$\frac{Mr}{\phi Mn}$	**M_r/M_c +**
#		#	#	#	#	in	in				(SDS)	on S_A		kips	kips	in	k-in	%	on SD	RAD	on ABS	kips	in	k-in	in	in	in^3		k-in	k-in		**P_r/P_c**
BRB-2.00	4.1	D.3 to D(+)	Low Roof	1901	1	9.58	0.18	1.00	0.70	0.90	1.02	0.40	1.00	0.60	0.12	15.88	1.94	1.00%	0.67	0.01	100%	0.99	2.94	2.91	8.38	7.57	1.56	0.90	70.09	4.85	0.07	0.96
BRB-2.00	4.1	D(+) to C.6	Low Roof	1901	1	9.58	0.18	1.00	0.70	0.90	1.02	0.40	1.00	0.60	0.12	15.88	1.94	1.00%	0.67	0.01	100%	0.99	2.94	2.91	8.38	7.57	1.56	0.90	70.09	4.85	0.07	0.96
BRB-2.00	5	E to D.5	1	1903	1	7.00	0.18	1.00	0.51	0.73	1.02	0.40	1.00	1.49	0.30	15.88	4.84	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.28	9.02	1.69	0.90	76.02	7.46	0.10	0.82
BRB-2.00	C	2.8 to 3(+)	Low Roof	1904	1	13.05	0.22	1.00	0.80	0.85	1.02	0.40	1.00	0.62	0.13	15.88	2.01	1.00%	0.67	0.01	100%	0.97	2.94	2.86	8.45	6.80	2.14	0.90	96.49	4.88	0.05	0.89
BRB-2.00	C	3(+) to 3.2	Low Roof	1904	1	13.05	0.22	1.00	0.80	0.85	1.02	0.40	1.00	0.62	0.13	15.88	2.01	1.00%	0.67	0.01	100%	0.97	2.94	2.86	8.45	7.80	2.28	0.90	102.82	4.88	0.05	0.89
BRB-2.00	C.2	3.3 to 3.7	Low Roof	1906	1	17.31	0.25	1.00	0.91	0.74	1.02	0.40	1.00	0.84	0.17	15.88	2.72	1.04%	0.67	0.01	100%	0.93	2.94	2.72	8.14	11.42	3.74	0.90	168.43	5.45	0.03	0.77
BRB-2.00	C.2	3.7 to 4.1	Low Roof	1907	1	19.42	0.25	1.00	1.02	0.79	1.02	0.40	1.00	0.89	0.18	15.88	2.88	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.87	10.21	3.65	0.90	164.30	5.50	0.03	0.82
BRB-2.00	E	4.7 to 5	1	1909	1	5.59	0.18	1.00	0.41	0.70	1.02	0.40	1.00	1.56	0.32	15.88	5.07	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.30	9.41	1.73	0.90	77.80	7.69	0.10	0.79
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	7.87	0.22	1.00	0.48	0.62	1.02	0.40	1.00	0.72	0.15	15.88	2.33	1.00%	0.67	0.01	100%	0.92	2.94	2.70	8.27	7.20	2.18	0.90	97.89	5.03	0.05	0.67
BRB-3.00	E	4.1 to 3.8	1	1911	1	2.80	0.22	1.00	0.17	0.54	1.02	0.40	1.00	1.30	0.27	19.38	5.16	1.00%	0.67	0.01	100%	1.32	4.69	6.21	17.01	11.36	3.99	0.90	179.54	11.37	0.06	0.60
BRB-2.00	4	A.8 to A.99	1	1912	1	3.14	0.18	1.00	0.23	0.68	1.02	0.40	1.00	1.18	0.24	15.88	3.83	1.00%	0.67	0.01	100%	0.90	2.94	2.64	7.58	8.69	1.59	0.90	71.52	6.47	0.09	0.76
BRB-2.00	2	D to C.6	Low Roof	1915	1	19.52	0.29	1.00	0.89	0.71	1.02	0.40	1.00	0.95	0.19	15.88	3.09	1.14%	0.67	0.01	100%	1.02	2.94	2.99	8.39	6.93	3.83	0.90	172.37	6.07	0.04	0.74
BRB-3.00	2	D to C.6	1	1916	1	18.09	0.29	1.00	0.83	0.53	1.02	0.40	1.00	1.96	0.40	19.38	7.76	1.00%	0.67	0.01	100%	1.31	4.69	6.16	15.47	12.26	6.93	0.90	311.90	13.92	0.04	0.57
BRB-2.00	3.2	D to C.6	Low Roof	1917	1	25.33	0.29	1.00	1.16	0.90	1.02	0.40	1.00	0.73	0.15	15.88	2.38	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.34	9.72	4.51	0.90	203.12	5.00	0.02	0.92
BRB-2.00	3.2	C.6 to C.2	Low Roof	1917	1	25.33	0.29	1.00	1.16	0.90	1.02	0.40	1.00	0.73	0.15	15.88	2.38	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.34	9.72	4.51	0.90	203.12	5.00	0.02	0.92
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	13.30	0.22	1.00	0.81	0.84	1.02	0.40	1.00	1.14	0.23	15.88	3.69	1.14%	0.67	0.01	100%	1.02	2.94	2.99	8.19	6.47	2.06	0.90	92.74	6.68	0.07	0.90
BRB-2.50	2	A.2 to A	1	1921	1	3.62	0.18	1.00	0.27	0.55	1.02	0.40	1.00	2.50	0.51	19.38	9.91	1.00%	0.67	0.01	100%	1.11	4.69	5.23	10.33	11.59	2.14	0.90	96.35	15.13	0.16	0.69
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	16.55	0.29	1.00	0.76	0.57	1.02	0.40	1.00	0.95	0.19	19.38	3.76	1.04%	0.67	0.01	100%	1.16	4.69	5.44	11.57	7.15	4.68	0.90	210.60	9.20	0.04	0.61
BRB-3.50	A	3 to 2.7	1	1923	1	18.85	0.29	1.00	0.86	0.64	1.02	0.40	1.00	1.99	0.41	19.38	7.88	1.00%	0.67	0.01	100%	1.54	4.69	7.24	15.85	12.38	7.06	0.90	317.53	15.12	0.05	0.68
BRB-2.00	3	A.2 to A	Low Roof	1924	1	12.22	0.36	1.00	0.45	0.43	1.02	0.40	1.00	0.83	0.17	15.88	2.69	1.00%	0.67	0.01	100%	0.91	2.94	2.66	8.16	6.24	5.62	0.90	253.12	5.35	0.02	0.45
BRB-2.00	3	A.2 to A	1	1925	1	11.98	0.36	1.00	0.44	0.36	1.02	0.40	1.00	1.52	0.31	15.88	4.92	1.00%	0.67	0.01	100%	0.90	2.94	2.64	9.11	9.66	7.33	0.90	329.81	7.56	0.02	0.38

V_{uc} = Vertical demand component on weld at column
H_{uc} = Horizontal demand component on weld at column
H_{ub} = Horizontal demand component on weld at beam
V_{ub} = Vertical demand component on weld at beam
M_{uc} = Moment demand on weld at column
M_{ub} = Moment demand on weld at beam
H_{uc}' = Equivalent horizontal demand on weld from Muc
V_{ub}' = Equivalent vertical demand on weld from Mub
θ_{wc} = Angle of resultant demand on column

θ_{wb} = Angle of resultant demand on beam
C_c = Weld capacity increase factor for rotation at column
C_b = Weld capacity increase factor for rotation at beam
μ_F = Ductility Factor
D_{wc} = # of sixteenths of weld required at column
D_{wb} = # of sixteenths of weld required at beam
$D_{wc,u}$ = # of sixteenths of weld actually used at column
$D_{wb,u}$ = # of sixteenths of weld actually used at beam
t_{wbb} = Thickness of beam web

$t_{wbb,PL}$ = Thickness of doubler plate at beam web
ϕV_{nb} = Shear capacity of beam
R_{ub} = Maximum shear in beam from Live & Dead Loads
ϕV_{nbc} = Shear capacity of beam at column connection
ΔV_{ub} = Amount shear needs to be reduced in beam
F_{ug} = Nominal min temsile stress of gusset

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

| | | | | | | Constrianed UFM with Minimized Eccentricity at Both Column and Beam | | | | | |

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

| | | | | | | Beam & Column Shear Capacity | | | | | |

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Constrained UFM with Reduced Shear in Beam																														
EOR-ID	Line	Grids	Lvls	Mark	Qty	$V_{uc}+\Delta V_{ub}$	H_{uc}	H_{ub}	$V_{ub}-\Delta V_{ub}$	M_{uc}	$M_{ub}+\Delta M_{ub}$	H_{uc}'	V_{ub}'	θ_{wc}	θ_{wb}	C_c	C_b	f'_{vc}	f'_{Hc}	f'_{bc}	f'_{vb}	f'_{Hb}	f'_{bb}	f'_{peak_c}	f'_{avg_c}	f'_{cont_c}	f'_{peak_b}	f'_{avg_b}	f'_{cont_b}	Fillet			
#		#	#	#	#	kip	kip	kip	kip	k-in	k-in	kip	kip	rad	rad			kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	D_{wc}	$D_{wc,u}$	D_{wb}	$D_{wb,u}$
BRB-2.00	4.1	D.3 to D(+)	Low Roof	1901	1	63	0	132	51	0	403	0	152	0.00	0.86	1.00	1.33	8.53	0.00	0.00	2.12	5.53	4.26	8.53	8.53	10.66	8.44	7.19	8.98	3.83	4	2.43	4
BRB-2.00	4.1	D(+) to C.6	Low Roof	1901	1	63	0	132	51	0	403	0	152	0.00	0.86	1.00	1.33	8.53	0.00	0.00	2.12	5.53	4.26	8.53	8.53	10.66	8.44	7.19	8.98	3.83	4	2.43	4
BRB-2.00	5	E to D.5	1	1903	1	22	0	108	56	0	311	0	163	0.00	0.98	1.00	1.38	2.93	0.00	0.00	3.22	6.19	6.10	2.93	2.93	3.66	11.19	9.01	11.26	1.31	4	2.93	4
BRB-2.00	C	2.8 to 3(+)	Low Roof	1904	1	69	0	135	41	0	421	0	124	0.00	0.74	1.00	1.28	9.49	0.00	0.00	1.35	4.44	2.72	9.49	9.49	11.86	6.02	5.33	6.67	4.26	5	1.87	4
BRB-2.00	C	3(+) to 3.2	Low Roof	1904	1	74	0	135	41	0	422	0	124	0.00	0.74	1.00	1.28	8.99	0.00	0.00	1.35	4.44	2.72	8.99	8.99	11.24	6.02	5.33	6.67	4.04	5	1.87	4
BRB-2.00	C.2	3.3 to 3.7	Low Roof	1906	1	104	0	129	29	0	408	0	88	0.00	0.60	1.00	1.21	8.97	0.00	0.00	0.70	3.11	1.42	8.97	8.97	11.22	3.76	3.47	4.34	4.03	5	1.29	5
BRB-2.00	C.2	3.7 to 4.1	Low Roof	1907	1	110	0	127	30	0	379	0	84	0.00	0.58	1.00	1.20	9.20	0.00	0.00	0.71	3.06	1.31	9.20	9.20	11.50	3.66	3.39	4.24	4.13	5	1.26	5
BRB-2.00	E	4.7 to 5	1	1909	1	69	0	105	52	0	190	0	135	0.00	0.91	1.00	1.35	8.61	0.00	0.00	3.79	7.65	6.04	8.61	8.61	10.76	12.45	10.22	12.77	3.87	4	3.40	4
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	52	0	125	42	0	269	0	123	0.00	0.78	1.00	1.29	7.58	0.00	0.00	2.11	6.32	4.12	7.58	7.58	9.47	8.87	7.75	9.69	3.40	4	2.69	4
BRB-3.00	E	4.1 to 3.8	1	1911	1	126	0	127	69	0	6	0	71	0.00	0.51	1.00	1.17	11.21	0.00	0.00	3.64	6.68	0.10	11.21	11.21	14.01	7.66	7.61	9.51	5.03	6	2.92	4
BRB-2.00	4	A.8 to A.99	1	1912	1	65	0	81	68	0	151	0	170	0.00	1.13	1.00	1.43	8.33	0.00	0.00	7.62	9.04	11.38	8.33	8.33	10.41	21.04	15.41	21.04	3.74	4	5.29	6
BRB-2.00	2	D to C.6	Low Roof	1915	1	89	0	129	28	0	412	0	84	0.00	0.58	1.00	1.20	11.13	0.00	0.00	0.63	2.95	1.30	11.13	11.13	13.91	3.52	3.27	4.09	5.00	5	1.22	5
BRB-3.00	2	D to C.6	1	1916	1	139	0	154	50	0	166	0	86	0.00	0.51	1.00	1.17	7.39	0.00	0.00	1.82	5.66	1.34	7.39	7.39	9.24	6.48	6.08	7.60	3.32	5	2.33	5
BRB-2.00	3.2	D to C.6	Low Roof	1917	1	114	0	130	26	0	585	0	86	0.00	0.58	1.00	1.20	10.62	0.00	0.00	0.44	2.19	1.00	10.62	10.62	13.28	2.63	2.44	3.05	4.77	5	0.91	5
BRB-2.00	3.2	C.6 to C.2	Low Roof	1917	1	6	0	130	26	0	585	0	86	0.00	0.58	1.00	1.20	0.57	0.00	0.00	0.44	2.19	1.00	0.57	0.57	0.71	2.63	2.44	3.05	0.26	5	0.91	5
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	64	0	126	35	0	414	0	112	0.00	0.72	1.00	1.27	9.87	0.00	0.00	1.08	3.88	2.36	9.87	9.87	12.34	5.19	4.64	5.80	4.43	5	1.64	4
BRB-2.50	2	A.2 to A	1	1921	1	108	0	109	65	0	139	0	130	0.00	0.88	1.00	1.34	9.09	0.00	0.00	5.09	8.55	5.18	9.09	9.09	11.37	13.36	10.96	13.69	4.08	5	3.68	4
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	94	0	160	35	0	482	0	101	0.00	0.56	1.00	1.20	11.62	0.00	0.00	0.81	3.65	1.50	11.62	11.62	14.53	4.32	4.01	5.02	5.22	6	1.51	5
BRB-3.50	A	3 to 2.7	1	1923	1	155	0	180	58	0	189	0	99	0.00	0.50	1.00	1.17	7.96	0.00	0.00	2.10	6.54	1.49	7.96	7.96	9.95	7.46	7.01	8.77	3.57	5	2.70	5
BRB-2.00	3	A.2 to A	Low Roof	1924	1	11	0	129	31	0	284	0	90	0.00	0.61	1.00	1.22	1.77	0.00	0.00	1.08	4.52	2.09	1.77	1.77	2.21	5.52	5.08	6.35	0.80	5	1.87	5
BRB-2.00	3	A.2 to A	1	1925	1	56	0	104	63	0	447	0	178	0.00	1.04	1.00	1.40	5.58	0.00	0.00	2.69	4.46	4.90	5.58	5.58	6.97	8.80	6.89	8.80	2.50	5	2.26	5

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																				UFM Geometry																	Whitmore Tension Fracture																				
EOR-ID	Line	Grids	Lvls	Mark	Qty	n_i	n_o	s	θ_{CB}	θ_{UFM}	L_{tb}	L_{2b}	e	D_{cb}	D_{bb}	DN_{bb}	e_{Col}	e_{Bm}	W_L	Whtm Ang	l_{wc} min	l_{wb} min	Rot$_c$	α min	Y1	$WD_{Bm,In}$	$WD_{Bm,Out}$	α_g	α_{bar}	β min	X2	$WD_{Col,In}$	$WD_{Col,Out}$	β_g	β_{bar}	t_g	t_{r_Des}	L_{Br}	h_{Br}	h_{Bm}	h_{Col}	W'_{wh}	A'_{wh}	A_{wh}	P_{uc}	β	P_{ut}	F_{yg}	F_{ug}	Constrain	P_{ut}
#		#	#	#	#	#	#	in	rad	rad	in	in	in	in	in	in	in	in	in	in	deg	in	in	deg	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in^2	in^2	kip		kip	ksi	ksi	Whitmore	ϕR_n
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	2	0	3.50	0.90	0.674	10.05	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	14.94	10.07	0	5.03	10.39	1.50	0.50	4.03	5.53	7.47	4.79	1.50	0.50	6.47	7.97	0.63	0.00	3.50	4.04	10.50	5.14	7.67	4.79	4.79	136	1.11	122	50	65	NO	0.57
BRB-2.00	4.1	D(+) to C.6	1	1902	1	2	0	3.50	0.90	0.674	10.05	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	14.94	10.07	0	5.03	10.39	1.50	0.50	4.03	5.53	7.47	4.79	1.50	0.50	6.47	7.97	0.63	0.00	3.50	4.04	10.50	5.14	7.67	4.79	4.79	136	1.11	122	50	65	NO	0.57
BRB-2.00	5	E to D.5	1	1903	1	2	0	3.50	0.63	0.941	7.31	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	11.00	10.01	0	5.01	5.60	1.50	0.50	4.01	5.51	5.50	5.63	1.50	0.50	4.50	6.00	0.63	0.00	3.50	4.04	6.12	5.66	7.67	4.79	4.79	134	1.11	121	50	65	NO	0.56
BRB-2.00	C	2.8 to 3(+)	1	1905	1	2	0	3.50	0.85	0.722	9.06	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.85	9.87	0	4.93	9.12	1.50	0.50	3.93	5.43	6.93	4.72	1.50	0.50	5.93	7.43	0.63	0.00	3.50	4.04	9.30	4.98	7.67	4.79	4.79	136	1.11	122	50	65	NO	0.57
BRB-2.00	C	3(+) to 3.2	1	1905	1	2	0	3.50	0.85	0.722	9.06	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.85	9.87	0	4.93	9.12	1.50	0.50	3.93	5.43	6.93	4.72	1.50	0.50	5.93	7.43	0.63	0.00	3.50	4.04	9.30	4.98	7.67	4.79	4.79	136	1.11	122	50	65	NO	0.57
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	2	0	3.50	0.72	0.853	9.56	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.16	11.26	0	5.63	8.00	1.50	0.50	4.63	6.13	6.58	6.54	1.50	0.50	5.58	7.08	0.63	0.00	3.50	4.04	8.46	6.67	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	2	0	3.50	0.72	0.853	9.56	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.16	11.26	0	5.63	8.00	1.50	0.50	4.63	6.13	6.58	6.54	1.50	0.50	5.58	7.08	0.63	0.00	3.50	4.04	8.46	6.67	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	E	4.7 to 5	1	1909	1	2	0	3.50	0.67	0.906	7.19	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	11.21	9.75	0	4.88	5.91	1.50	0.50	3.88	5.38	5.61	5.23	1.50	0.50	4.61	6.11	0.63	0.00	3.50	4.04	6.37	5.28	7.67	4.79	4.79	134	1.11	121	50	65	NO	0.56
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	2	0	3.50	0.43	1.136	24.94	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	28	10.65	26.64	0	10.51	4.87	1.50	0.50	9.51	11.01	5.32	23.12	1.50	0.50	4.32	5.82	0.75	0.00	3.50	3.96	3.96	23.15	7.35	5.51	5.51	138	1.12	123	50	65	NO	0.50
BRB-3.00	E	4.1 to 3.8	1	1911	1	3	0	3.50	0.88	0.695	10.94	9.38	1.188	8.0	0.0	0.0	0.0	0.0	6.00	30	18.17	12.08	0	6.04	13.54	1.50	0.50	5.04	6.54	9.08	6.85	1.50	0.50	8.08	9.58	0.75	0.00	7.00	8.08	13.74	7.30	10.92	8.19	8.78	199	1.17	170	50	65	NO	0.43
BRB-2.00	4	A.8 to A.99	1	1912	1	2	0	3.50	0.93	0.642	10.32	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	15.36	9.90	0	4.95	10.93	1.50	0.50	3.95	5.45	7.68	4.54	1.50	0.50	6.68	8.18	0.63	0.00	3.50	4.04	11.00	4.94	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	B	5 to 4.7	1	1913	1	2	0	3.50	0.72	0.850	7.94	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	12.12	10.01	0	5.01	6.97	1.50	0.50	4.01	5.51	6.06	5.28	1.50	0.50	5.06	6.56	0.63	0.00	3.50	4.04	7.36	5.39	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	B	4.7 to 4.4	1	1914	1	2	0	3.50	0.72	0.850	7.94	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	12.12	10.01	0	5.01	6.97	1.50	0.50	4.01	5.51	6.06	5.28	1.50	0.50	5.06	6.56	0.63	0.00	3.50	4.04	7.36	5.39	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	2	D to C.6	Low Roof	1915	1	2	0	3.50	0.27	1.297	45.46	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	22	14.66	47.50	0	23.75	5.85	1.50	0.50	22.75	24.25	7.33	44.79	1.50	0.50	6.33	7.83	1.00	0.00	3.50	3.77	3.77	45.06	6.45	6.45	6.45	134	1.11	121	50	65	NO	0.42
BRB-3.00	2	D to C.6	1	1916	1	3	0	3.50	0.67	0.899	8.69	9.38	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	14.37	13.63	0	6.81	9.08	1.50	0.50	5.81	7.31	7.18	9.08	1.50	0.50	6.18	7.68	1.00	0.00	7.00	8.08	9.76	9.18	11.71	11.71	11.71	197	1.17	168	50	65	NO	0.32
BRB-2.00	3.2	D to C.6	1	1918	1	2	0	3.50	0.71	0.864	9.07	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	12.75	10.96	0	5.48	7.56	1.50	0.50	4.48	5.98	6.37	6.28	1.50	0.50	5.37	6.87	0.63	0.00	3.50	4.04	8.02	6.39	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	3.2	C.6 to C.2	1	1919	1	2	0	3.50	0.71	0.864	9.07	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	12.75	10.96	0	5.48	7.56	1.50	0.50	4.48	5.98	6.37	6.28	1.50	0.50	5.37	6.87	0.63	0.00	3.50	4.04	8.02	6.39	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	2	0	3.50	0.34	1.227	34.02	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	15.02	35.91	0	17.95	5.38	1.50	0.50	16.95	18.45	7.51	32.83	1.50	0.50	6.51	8.01	0.75	0.00	3.50	4.04	4.04	33.37	7.67	5.75	5.75	134	1.11	121	50	65	NO	0.47
BRB-2.50	2	A.2 to A	1	1921	1	3	0	3.50	0.86	0.706	11.41	9.38	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	18.41	13.53	0	6.77	13.74	1.50	0.50	5.77	7.27	9.21	8.34	1.50	0.50	8.21	9.71	0.63	0.00	7.00	8.08	13.97	8.85	11.71	7.32	7.32	167	1.11	151	50	65	NO	0.46
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	3	0	3.50	0.29	1.276	40.40	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	23	15.19	45.79	0	22.90	6.41	1.50	0.50	21.90	23.40	7.59	42.97	1.50	0.50	6.59	8.09	1.00	0.00	7.00	7.60	7.60	43.22	9.57	9.57	9.57	167	1.11	151	50	65	NO	0.35
BRB-3.50	A	3 to 2.7	1	1923	1	3	0	3.50	0.68	0.892	7.69	9.38	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.83	12.79	0	6.40	8.56	1.50	0.50	5.40	6.90	6.91	8.22	1.50	0.50	5.91	7.41	1.00	0.00	7.00	8.08	9.17	8.32	11.71	11.71	11.71	232	1.17	198	50	65	NO	0.38
BRB-2.00	3	A.2 to A	Low Roof	1924	1	2	0	3.50	0.31	1.256	69.96	5.88	1.188	6.0	24.5	24.5	0.0	12.3	6.00	24	20.71	70.36	0	35.18	9.11	1.50	0.50	34.18	35.68	10.36	67.43	1.50	0.50	9.36	10.86	1.25	0.00	3.50	3.83	3.83	67.80	6.74	8.43	8.43	136	1.11	122	50	65	NO	0.32
BRB-2.00	3	A.2 to A	1	1925	1	2	0	3.50	0.69	0.883	7.56	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	11.62	9.92	0	4.96	6.37	1.50	0.50	3.96	5.46	5.81	5.32	1.50	0.50	4.81	6.31	1.25	0.00	3.50	4.04	6.81	5.39	7.67	9.58	9.58	135	1.11	121	50	65	NO	0.28

Table of Symbols

n = Number of bolts in a row (i inside row, o outside row)
s = Bolt spacing in a row
W_L = Width of lug
θ_{CB} = Angle of Cb from horizontal
θ_{UFM} = Angle used for uniform force method
L_{tb} = Total length from W.P. to top end of CB
L_{2b} = Length from end of lug to end of gusset
e = Edge distance
D_{cb} = Depth of column at bottom of CB
D_{bb} = Depth of beam at bottom of CB
$l_{wc,min}$ = Minimum possible length of weld on column
$l_{wb,min}$ = Minimum possible length of weld on beam
α min = Center of weld on beam based on geometry constraints
β min = Center of weld on column based on geometry constraints
α_g / β_g = 1/2 of weld length on beam / column, respectively
α_{bar} / β_{bar} = Actual center of weld on beam / column used, respectively
t_g = Thickness of gusset
t_r = Thickness of repad
A_{wm} = Area of whitmore line at gusset
L_{wm} = Width of whitmore section
P_{uc} = Ultimate CB compressive demand
β = Compression strength adjustment factor
P_{ut} = Ultimate CB tensile demand
F_{yg} = Yield stress of gusset
ϕR_n = Capacity of whitmore section
L' = Average buckling length of gusset
r = Radius of gyration of gusset
λ_c = Gusset slenderness parameter
f_{cr} = Buckling stress demand on gusset
ϕF_{cr} = Buckling stress capacity of gusset
K = UFM factor
K' = UFM reduced moment factor
D = UFM reduced moment factor
α = Center of weld on column
β = Center of weld on beam
r = Resultant length of **α** & **β**

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Gusset Buckling																														
EOR-ID	Line	Grids	Lvls	Mark	Qty	L'	r	K_{gb}	λ_c	f_{cr}	S_A	Factor	I_p	Wt_{BRB}	SW $F_{OOP\ (EA\ End)}$	$M_{Arm\text{-}OOP}$	SW M_{OOP}	SD	Factor	Drift Angle	Factor	P_H	M_{Arm_PH}	M_{PH}	L_b	L_c	Z_g	ϕ_b	ϕMn	M_r	Mr	M_r/M_c +
#		#	#	#	#	in	in	in		ϕF_{cr}	(SDS)	on S_A		kips	kips	in	k-in	%	on SD	RAD	on ABS	kips	in	k-in	in	in	in^3		k-in	k-in	ϕMn	P_r/P_c
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	5.42	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.22	0.25	15.88	3.94	1.00%	0.67	0.01	100%	0.905	2.938	2.660	9.507	8.312	1.740	0.90	78.303	6.604	0.084	0.787
BRB-2.00	4.1	D(+) to C.6	1	1902	1	5.42	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.22	0.25	15.88	3.94	1.00%	0.67	0.01	100%	0.905	2.938	2.660	9.507	8.312	1.740	0.90	78.303	6.604	0.084	0.787
BRB-2.00	5	E to D.5	1	1903	1	3.34	0.18	1.00	0.24	0.67	1.02	0.40	1.00	1.49	0.30	15.88	4.84	1.00%	0.67	0.01	100%	0.892	2.938	2.620	8.748	7.583	1.595	0.90	71.767	7.455	0.104	0.766
BRB-2.00	C	2.8 to 3(+)	1	1905	1	4.64	0.18	1.00	0.34	0.70	1.02	0.40	1.00	1.32	0.27	15.88	4.28	1.00%	0.67	0.01	100%	0.905	2.938	2.660	9.670	8.150	1.740	0.90	78.313	6.938	0.089	0.779
BRB-2.00	C	3(+) to 3.2	1	1905	1	4.64	0.18	1.00	0.34	0.70	1.02	0.40	1.00	1.32	0.27	15.88	4.28	1.00%	0.67	0.01	100%	0.905	2.938	2.660	9.670	8.150	1.740	0.90	78.313	6.938	0.089	0.779
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	5.52	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.56	0.32	15.88	5.05	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.631	8.292	1.750	0.90	78.762	7.694	0.098	0.796
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	5.52	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.56	0.32	15.88	5.05	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.631	8.292	1.750	0.90	78.762	7.694	0.098	0.796
BRB-2.00	E	4.7 to 5	1	1909	1	3.21	0.18	1.00	0.24	0.67	1.02	0.40	1.00	1.56	0.32	15.88	5.07	1.00%	0.67	0.01	100%	0.892	2.938	2.620	8.763	7.631	1.601	0.90	72.044	7.687	0.107	0.767
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	12.39	0.22	1.00	0.76	0.75	1.02	0.40	1.00	0.72	0.15	15.88	2.33	1.00%	0.67	0.01	100%	0.920	2.938	2.704	4.724	7.196	1.676	0.90	75.431	5.033	0.067	0.809
BRB-3.00	E	4.1 to 3.8	1	1911	1	3.99	0.22	1.00	0.24	0.55	1.02	0.40	1.00	1.30	0.27	19.38	5.16	1.00%	0.67	0.01	100%	1.324	4.688	6.206	12.357	10.803	3.257	0.90	146.557	11.367	0.078	0.615
BRB-2.00	4	A.8 to A.99	1	1912	1	5.50	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.18	0.24	15.88	3.83	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.156	8.321	1.707	0.90	76.805	6.469	0.084	0.783
BRB-2.00	B	5 to 4.7	1	1913	1	3.88	0.18	1.00	0.28	0.68	1.02	0.40	1.00	1.45	0.30	15.88	4.69	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.054	7.867	1.652	0.90	74.362	7.334	0.099	0.772
BRB-2.00	B	4.7 to 4.4	1	1914	1	3.88	0.18	1.00	0.28	0.68	1.02	0.40	1.00	1.45	0.30	15.88	4.71	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.054	7.867	1.652	0.90	74.362	7.346	0.099	0.773
BRB-2.00	2	D to C.6	Low Roof	1915	1	26.79	0.29	1.00	1.23	0.92	1.02	0.40	1.00	0.95	0.19	15.88	3.09	1.14%	0.67	0.01	100%	1.016	2.938	2.985	9.807	8.933	4.685	0.90	210.830	6.074	0.029	0.942
BRB-3.00	2	D to C.6	1	1916	1	3.31	0.29	1.00	0.15	0.40	1.02	0.40	1.00	1.96	0.40	19.38	7.76	1.00%	0.67	0.01	100%	1.313	4.688	6.156	11.646	10.056	5.425	0.90	244.146	13.917	0.057	0.450
BRB-2.00	3.2	D to C.6	1	1918	1	5.04	0.18	1.00	0.37	0.70	1.02	0.40	1.00	1.56	0.32	15.88	5.06	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.422	8.140	1.715	0.90	77.177	7.703	0.100	0.790
BRB-2.00	3.2	C.6 to C.2	1	1919	1	5.04	0.18	1.00	0.37	0.70	1.02	0.40	1.00	1.57	0.32	15.88	5.08	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.422	8.140	1.715	0.90	77.177	7.721	0.100	0.790
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	18.34	0.22	1.00	1.12	0.93	1.02	0.40	1.00	1.14	0.23	15.88	3.69	1.14%	0.67	0.01	100%	1.017	2.938	2.987	9.385	10.465	2.791	0.90	125.616	6.679	0.053	0.973
BRB-2.50	2	A.2 to A	1	1921	1	5.56	0.18	1.00	0.41	0.58	1.02	0.40	1.00	2.50	0.51	19.38	9.91	1.00%	0.67	0.01	100%	1.115	4.688	5.226	12.583	11.150	2.318	0.90	104.293	15.134	0.145	0.705
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	21.12	0.29	1.00	0.97	0.61	1.02	0.40	1.00	0.95	0.19	19.38	3.76	1.04%	0.67	0.01	100%	1.160	4.688	5.439	12.380	10.150	5.633	0.90	253.464	9.202	0.036	0.641
BRB-3.50	A	3 to 2.7	1	1923	1	2.31	0.29	1.00	0.11	0.47	1.02	0.40	1.00	1.99	0.41	19.38	7.88	1.00%	0.67	0.01	100%	1.545	4.688	7.240	11.397	9.883	5.320	0.90	239.401	15.124	0.063	0.524
BRB-2.00	3	A.2 to A	Low Roof	1924	1	39.87	0.36	1.00	1.46	0.93	1.02	0.40	1.00	0.83	0.17	15.88	2.69	1.00%	0.67	0.01	100%	0.905	2.938	2.660	11.958	12.241	9.453	0.90	425.366	5.348	0.013	0.938
BRB-2.00	3	A.2 to A	1	1925	1	3.56	0.36	1.00	0.13	0.33	1.02	0.40	1.00	1.52	0.31	15.88	4.92	1.00%	0.67	0.01	100%	0.899	2.938	2.640	8.894	7.743	6.499	0.90	292.438	7.564	0.026	0.356

V_{uc} = Vertical demand component on weld at column
H_{uc} = Horizontal demand component on weld at column
H_{ub} = Horizontal demand component on weld at beam
V_{ub} = Vertical demand component on weld at beam
M_{uc} = Moment demand on weld at column
M_{ub} = Moment demand on weld at beam
H_{uc}' = Equivalent horizontal demand on weld from Muc
V_{ub}' = Equivalent vertical demand on weld from Mub
θ_{wc} = Angle of resultant demand on column

θ_{wb} = Angle of resultant demand on beam
C_c = Weld capacity increase factor for rotation at column
C_b = Weld capacity increase factor for rotation at beam
μ_F = Ductility Factor
D_{wc} = # of sixteenths of weld required at column
D_{wb} = # of sixteenths of weld required at beam
$D_{wc,u}$ = # of sixteenths of weld actually used at column
$D_{wb,u}$ = # of sixteenths of weld actually used at beam
t_{wbb} = Thickness of beam web

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

| | | | | | | Constrained UFM with Minimized Eccentricity at Both Column and Beam | | | | | |

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Beam & Column Shear Capacity																				t_q & Basemetal Check						Col & Bm Web Yielding & Cripling													
EOR-ID	Line	Grids	Lvls	Mark	Qty	Full Ht	t_{wbb}	t'_{wbb}	$t_{wbb,PL}$	Guss	ϕ_{vb}	ϕV_{nb}	$V_{ub\text{-}OGC}$	Aprnment	R_{ub}	R_{ub}'	ϕV_{nbc}	$V_{ub}+R_{ub}$	Trans	ΔV_{ub}	ϕ_{vc}	$\phi_{vc,BP}$	ϕV_{nc}	H_{uc}	F_{yBm}	F_{uBm}	F_{yCol}	F_{uCol}	$F_{ub,min}$	$F_{uc,min}$	$t_{ubt,min}$	$t_{pc,min}$	t_{fbt}	ϕR_{myb}	V_{ub}'	ϕR_{ncb}	V_{ub}'	B Stiff	t_{fc}	ϕR_{nyc}	H_{uc}'	ϕR_{ncc}	H_{uc}'	C Stiff
#		#	#	#	#	Guss?	in	in	in	Below		kips	kip	Factor	kip	kip	kip	$\phi V_{nb\ or\ nbc}$	V?	kip			kips	ϕV_{nc}	ksi	ksi	ksi	ksi	F_{ubBm}	F_{uCol}	t_g	t_g	in	kip	ϕR_{myb}	kip	ϕR_{ncb}	Req?	in	kip	ϕR_{nyc}	kip	ϕR_{ncc}	Req?
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.72	0.61	0.00	1634	-	NA	-	n.a.	0.63	516	0.00	4837	0.00	no
BRB-2.00	4.1	D(+) to C.6	1	1902	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.72	0.61	0.00	1634	-	NA	-	n.a.	0.63	516	0.00	4837	0.00	no
BRB-2.00	5	E to D.5	1	1903	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.92	0.61	0.00	1626	-	NA	-	n.a.	0.63	402	0.00	3413	0.00	no
BRB-2.00	C	2.8 to 3(+)	1	1905	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.78	0.61	0.00	1608	-	NA	-	n.a.	0.63	484	0.00	4444	0.00	no
BRB-2.00	C	3(+) to 3.2	1	1905	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.78	0.61	0.00	1608	-	NA	-	n.a.	0.63	484	0.00	4444	0.00	no
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.75	0.61	0.00	1783	-	NA	-	n.a.	0.63	465	0.00	4196	0.00	no
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.75	0.61	0.00	1783	-	NA	-	n.a.	0.63	465	0.00	4196	0.00	no
BRB-2.00	E	4.7 to 5	1	1909	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.93	0.61	0.00	1594	-	NA	-	n.a.	0.63	409	0.00	3492	0.00	no
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	yes	0.750	0.75	0.00	Yes	1.0	127	39	1.9	30.0	57.8	127	0.58	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.51	0.51	0.52	452	0.14	1055	0.06	no	0.63	392	0.00	3287	0.00	no
BRB-3.00	E	4.1 to 3.8	1	1911	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	248	0.00	50	65	46	58	0.76	0.85	0.72	0.54	0.00	1884	-	NA	-	n.a.	0.63	609	0.00	4543	0.00	no
BRB-2.00	4	A.8 to A.99	1	1912	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.70	0.61	0.00	1613	-	NA	-	n.a.	0.63	528	0.00	4988	0.00	no
BRB-2.00	B	5 to 4.7	1	1913	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.86	0.61	0.00	1627	-	NA	-	n.a.	0.63	435	0.00	3820	0.00	no
BRB-2.00	B	4.7 to 4.4	1	1914	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.86	0.61	0.00	1627	-	NA	-	n.a.	0.63	435	0.00	3820	0.00	no
BRB-2.00	2	D to C.6	Low Roof	1915	1	yes	1.000	1.00	0.00	Yes	1.0	169	20	1.9	30.0	74.4	169	0.36	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.48	0.48	0.52	1265	0.02	5483	0.00	no	0.63	508	0.00	4734	0.00	no
BRB-3.00	2	D to C.6	1	1916	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.57	0.48	0.00	2078	-	NA	-	n.a.	0.63	499	0.00	4631	0.00	no
BRB-2.00	3.2	D to C.6	1	1918	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.78	0.61	0.00	1745	-	NA	-	n.a.	0.63	453	0.00	4046	0.00	no
BRB-2.00	3.2	C.6 to C.2	1	1919	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.78	0.61	0.00	1745	-	NA	-	n.a.	0.63	453	0.00	4046	0.00	no
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	yes	0.750	0.75	0.00	No	1.0	241	0	1.0	30.0	123.1	241	0.63	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.51	0.52	0.52	731	0.05	1796	0.02	no	0.63	518	0.00	4866	0.00	no
BRB-2.50	2	A.2 to A	1	1921	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.64	0.61	0.00	2066	-	NA	-	n.a.	0.63	616	0.00	6090	0.00	no
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	yes	1.000	1.00	0.00	Yes	1.0	169	26	1.9	30.0	71.5	169	0.39	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.48	0.48	0.52	1222	0.03	5282	0.01	no	0.63	523	0.00	4926	0.00	no
BRB-3.50	A	3 to 2.7	1	1923	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.71	0.53	0.00	1974	-	NA	-	n.a.	0.63	484	0.00	4434	0.00	no
BRB-2.00	3	A.2 to A	Low Roof	1924	1	yes	1.250	0.50	0.00	Yes	1.0	174	26	1.9	30.0	109.4	174	0.50	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.38	0.38	0.96	2364	0.02	4449	0.01	no	0.63	682	0.00	6920	0.00	no
BRB-2.00	3	A.2 to A	1	1925	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.45	0.38	0.00	1616	-	NA	-	n.a.	0.63	420	0.00	3638	0.00	no

$t_{wbb,PL}$ = Thickness of doubler plate at beam web
ϕV_{nb} = Shear capacity of beam
R_{ub} = Maximum shear in beam from Live & Dead Loads
ϕV_{nbc} = Shear capacity of beam at column connection
ΔV_{ub} = Amount shear needs to be reduced in beam
F_{ug} = Nominal min temsile stress of gusset

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Constrained UFM with Reduced Shear in Beam																															
EOR-ID	Line	Grids	Lvls	Mark	Qty	$V_{uc}+\Delta V_{ub}$	H_{uc}	H_{ub}	$V_{ub}-\Delta V_{ub}$	M_{uc}	$M_{ub}+\Delta M_{ub}$	H_{uc}'	V_{ub}'	θ_{wc}	θ_{wb}	C_c	C_b	f'_{vc}	f'_{Hc}	f'_{bc}	f'_{vb}	f'_{Hb}	f'_{bb}	f'_{peak_c}	f'_{avg_c}	f'_{cont_c}	f'_{peak_b}	f'_{avg_b}	f'_{cont_b}	Fillet			
#		#	#	#	#	kip	kip	kip	kip	k-in	k-in	kip	kip	rad	rad			kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	D_{wc}	$D_{wc,u}$	D_{wb}	$D_{wb,u}$
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	106	0	85	0	0	0	0	0	0.00	0.00	1.00	1.00	8.20	0.00	0.00	0.00	10.51	0.00	8.20	8.20	10.25	10.51	10.51	13.13	3.68	4	4.72	5
BRB-2.00	4.1	D(+) to C.6	1	1902	1	106	0	85	0	0	0	0	0	0.00	0.00	1.00	1.00	8.20	0.00	0.00	0.00	10.51	0.00	8.20	8.20	10.25	10.51	10.51	13.13	3.68	4	4.72	5
BRB-2.00	5	E to D.5	1	1903	1	79	0	108	0	0	0	0	0	0.00	0.00	1.00	1.00	8.76	0.00	0.00	0.00	13.50	0.00	8.76	8.76	10.94	13.50	13.50	16.87	3.93	4	6.06	7
BRB-2.00	C	2.8 to 3(+)	1	1905	1	102	0	90	0	0	0	0	0	0.00	0.00	1.00	1.00	8.60	0.00	0.00	0.00	11.41	0.00	8.60	8.60	10.75	11.41	11.41	14.26	3.86	4	5.12	6
BRB-2.00	C	3(+) to 3.2	1	1905	1	102	0	90	0	0	0	0	0	0.00	0.00	1.00	1.00	8.60	0.00	0.00	0.00	11.41	0.00	8.60	8.60	10.75	11.41	11.41	14.26	3.86	4	5.12	6
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	89	0	102	0	0	0	0	0	0.00	0.00	1.00	1.00	7.94	0.00	0.00	0.00	10.97	0.00	7.94	7.94	9.92	10.97	10.97	13.71	3.56	4	4.92	5
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	89	0	102	0	0	0	0	0	0.00	0.00	1.00	1.00	7.94	0.00	0.00	0.00	10.97	0.00	7.94	7.94	9.92	10.97	10.97	13.71	3.56	4	4.92	5
BRB-2.00	E	4.7 to 5	1	1909	1	83	0	105	0	0	0	0	0	0.00	0.00	1.00	1.00	8.96	0.00	0.00	0.00	13.58	0.00	8.96	8.96	11.20	13.58	13.58	16.97	4.02	5	6.10	7
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	53	0	125	43	0	270	0	128	0.00	0.80	1.00	1.30	6.15	0.00	0.00	2.27	6.59	4.48	6.15	6.15	7.68	9.43	8.19	10.23	2.76	4	2.82	4
BRB-3.00	E	4.1 to 3.8	1	1911	1	153	0	127	0	0	0	0	0	0.00	0.00	1.00	1.00	9.44	0.00	0.00	0.00	12.62	0.00	9.44	9.44	11.80	12.62	12.62	15.77	4.24	5	5.66	6
BRB-2.00	4	A.8 to A.99	1	1912	1	108	0	81	0	0	0	0	0	0.00	0.00	1.00	1.00	8.08	0.00	0.00	0.00	10.22	0.00	8.08	8.08	10.10	10.22	10.22	12.77	3.63	4	4.59	5
BRB-2.00	B	5 to 4.7	1	1913	1	89	0	101	0	0	0	0	0	0.00	0.00	1.00	1.00	8.79	0.00	0.00	0.00	12.63	0.00	8.79	8.79	10.99	12.63	12.63	15.79	3.95	4	5.67	6
BRB-2.00	B	4.7 to 4.4	1	1914	1	89	0	101	0	0	0	0	0	0.00	0.00	1.00	1.00	8.79	0.00	0.00	0.00	12.63	0.00	8.79	8.79	10.99	12.63	12.63	15.79	3.95	4	5.67	6
BRB-2.00	2	D to C.6	Low Roof	1915	1	104	0	129	22	0	235	0	53	0.00	0.39	1.00	1.12	8.21	0.00	0.00	0.48	2.83	0.68	8.21	8.21	10.27	3.06	2.95	3.69	3.69	5	1.19	5
BRB-3.00	2	D to C.6	1	1916	1	123	0	154	0	0	0	0	0	0.00	0.00	1.00	1.00	9.91	0.00	0.00	0.00	13.26	0.00	9.91	9.91	12.39	13.26	13.26	16.58	4.45	5	5.95	6
BRB-2.00	3.2	D to C.6	1	1918	1	88	0	102	0	0	0	0	0	0.00	0.00	1.00	1.00	8.15	0.00	0.00	0.00	11.44	0.00	8.15	8.15	10.18	11.44	11.44	14.30	3.66	4	5.14	6
BRB-2.00	3.2	C.6 to C.2	1	1919	1	88	0	102	0	0	0	0	0	0.00	0.00	1.00	1.00	8.15	0.00	0.00	0.00	11.44	0.00	8.15	8.15	10.18	11.44	11.44	14.30	3.66	4	5.14	6
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	119	0	126	28	0	233	0	69	0.00	0.50	1.00	1.17	9.14	0.00	0.00	0.83	3.71	1.22	9.14	9.14	11.42	4.24	3.99	4.98	4.10	5	1.53	4
BRB-2.50	2	A.2 to A	1	1921	1	127	0	109	0	0	0	0	0	0.00	0.00	1.00	1.00	7.75	0.00	0.00	0.00	9.41	0.00	7.75	7.75	9.69	9.41	9.41	11.76	3.48	4	4.22	5
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	107	0	160	29	0	284	0	67	0.00	0.40	1.00	1.12	8.14	0.00	0.00	0.65	3.65	0.89	8.14	8.14	10.18	3.97	3.81	4.77	3.66	5	1.53	5
BRB-3.50	A	3 to 2.7	1	1923	1	145	0	180	0	0	0	0	0	0.00	0.00	1.00	1.00	12.30	0.00	0.00	0.00	16.71	0.00	12.30	12.30	15.37	16.71	16.71	20.89	5.52	6	7.50	8
BRB-2.00	3	A.2 to A	Low Roof	1924	1	128	0	129	29	0	547	0	77	0.00	0.54	1.00	1.18	6.85	0.00	0.00	0.42	1.89	0.70	6.85	6.85	8.57	2.20	2.06	2.57	3.08	5	0.78	5
BRB-2.00	3	A.2 to A	1	1925	1	86	0	104	0	0	0	0	0	0.00	0.00	1.00	1.00	8.89	0.00	0.00	0.00	13.15	0.00	8.89	8.89	11.12	13.15	13.15	16.44	3.99	5	5.90	6

PSE Operational Training Center

Calculation Submittal Package

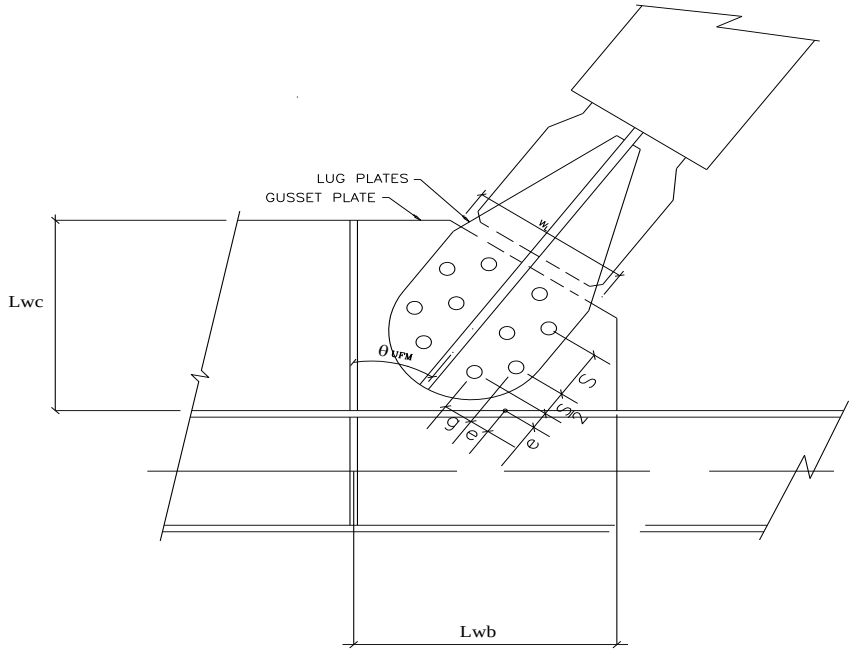
Description

Section 6. **V Gusset Connection Sample Calculation with V and Chevron Connection Summary Tables**

V Gusset Connection

(Chevron Connection Similar)

Example Mark #: 1901
Line 4.1, Grid D.3 to D(+), Level Low Roof



Uniform Force Method - AISC 360 - Bracing Section

6.0 DESIGN CRITERIA

Area of Yielding Steel Core	A_{sc}:	2.00 in²	*(1290 mm²)*
Maximum Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Compresssion Strength Adjustment Factor	β:	1.17	
Strain Hardening Adjustment Factor	ω:	1.38	
Connection Strain Hardening Factor	CF:	1.00	
Axial Design Load Compression ($CF \cdot \beta\omega F_{y\text{-}max}A_{sc}$)	P_{uc}:	148.5 kip	*(661 kN)*
Axial Design Load Tension ($CF \cdot \omega F_{y\text{-}max}A_{sc}$)	P_{ut}:	127.0 kip	*(565 kN)*
Width of Lug	W_L:	6.00 in	*(152 mm)*
Stiffener Depth (Thickness)	D_{cb}:	0.50 in	*(13 mm)*
Beam Depth	D_{bb}:	16.40 in	*(417 mm)*
Nominal Depth of Beam	DN_{bb}:	16.40 in	*(417 mm)*
Beam Web Thickness	t_{wb}:	0.43 in	*(11 mm)*
Beam Flange Thickness	t_{fb}:	0.72 in	*(18 mm)*
Beam Flange Width	b_{fb}:	7.12 in	*(181 mm)*
Beam k-Zone Height	k_{des}:	1.12 in	*(28 mm)*
Angle Between the Beam and Brace CL	θ_{CB}:	0.478 rad	*27.4°*
Angle Between the Column and Brace CL	θ_{UFM}:	1.093 rad	*62.6°*
Min Clear Distance from Face of Beam to Edge of Lug	$b_{bot\text{-}Bm}$:	5.50 in	*(140 mm)*
Min Clear Distance from Face of Column to Edge of Lug	$b_{bot\text{-}Col}$:	1.00 in	*(25 mm)*
Thickness of Gusset Plate	$t_{g:}$	0.63 in	*(16 mm)*
Distance from Last Bolt to Start of Radius on Lug	b_r:	0.80 in	*(20 mm)*
Bolt Edge Distance	e:	1.19 in	*(30 mm)*

6.1.0 GEOMETRY CALCULATIONS - UNIFORM FORCE METHOD

Length from WP to Bottom Tip of Brace			
Length from WP to Outside Edge of Col along WorkLine			
$L_{cb} = (D_{cb}/2)/COS(\theta_{CB})$	L_{cb}:	0.28 in	*(7 mm)*
Length from Edge of Column to Tip of CB along WL			
$L_{1cb} = [b_{bot\text{-}Col} + (W_L/2)]/COS(\theta_{CB}) - (e + b_r)$	L_{1cb}:	2.52 in	*(64 mm)*
Length from WP to Top Edge of Beam along WL			
$L_{bb} = (DN_{bb}/2)/SIN(\theta_{CB})$	L_{bb}:	17.82 in	*(453 mm)*
Length from Edge of Beam to Tip of CB along WL			
$L_{1bb} = [b_{tot\text{-}Bm} + (W_L/2)]/SIN(\theta_{CB}) - (e + b_r)$	L_{1bb}:	16.49 in	*(419 mm)*
Controling Length is $MAX(L_{cb}+L_{1cb}\ ,\ L_{bb}+L_{1bb})$	L_{tb}:	34.31 in	*(871 mm)*
Length from Square Projection to Edge of Gusset (CB Lap on Gusset)	L_g:	5.88 in	*(149 mm)*
Horizontal Distance from Column to WP ($D_{cb}/2$)	e_c:	0.25 in	*(6 mm)*
Vertical Distance from Beam to WP ($DN_{bb}/2$)	e_b:	8.20 in	*(208 mm)*
Minimum Weld on Column from Geometry			
$L_{wc_min} = (L_{tb} + L_g)*SIN(\theta_{CB}) + (W_L/2 + 1)*COS(\theta_{CB}) - DN_{bb}/2$	L_{wc_min}:	13.84 in	*(352 mm)*
Minimum Weld on Beam from Geometry			
$L_{wb_min} = (L_{tb} + L_g)*COS(\theta_{CB}) + (W_L/2 + 1)*SIN(\theta_{CB}) - D_{cb}/2$	L_{wb_min}:	37.27 in	*(947 mm)*

6.2.0 WHITMORE CAPACITY CHECK

LRFD Resistance Factor	ϕ_W:	0.90	
Lug Width	W_L:	6.00 in	*(152 mm)*
Minimum Yield Strength of Gusset	F_{yg}:	50 ksi	*(345 MPa)*
Minimum Tensile Strength of Gusset	F_{ug}:	65 ksi	*(448 MPa)*
Thickness of Repad Plate for Design:	$t_{r:}$	0.00 in	*(0 mm)*
Whitmore Angle	θ_{Whtm}:	30.0°	*0.524 rad*
Total Length Between Outer Bolt Holes $L_{Br} = L_q - 2e$	L_{Br}:	3.50 in	*(89 mm)*
Whitmore Width $W_w = 2 \cdot L_{Br} \cdot TAN(\theta_{Whtm}) + (W_L - 2 \cdot e)$	W_w:	7.67 in	*(195 mm)*
Whitmore Area $A_w = W_w \cdot t_q$	A_W =	4.79 in²	*(3091 mm²)*
Whitmore Capacity $\phi R_{n\text{-}W} = \phi_W \cdot A_W \cdot F_{yg}$	$\phi R_{n\text{-}W}$:	215.6 kip	*(959 kN)*
Whitmore Stress Ratio			
$DCR_W = P_{ut}/\phi R_{n\text{-}W}$	DCR_W:	0.59	

6.3.0 GUSSET BUCKLING CHECKS

LRFD Resistance Factor	ϕ_{gb}:	0.90	
Modulus of Elasticity	E:	29000 ksi	(199955 MPa)
Buckling Length *Conservative Since Based on Edges of Lug Rather than Edges of Whitmore Section*	L_1:	17.68 in	(449 mm)
Radius of Gyration of Gusset $r_g = \sqrt{(t_g^2/12)}$	r_g:	0.18 in	(5 mm)
Effective Length Factor	K_v:	0.65 in	
Elastic Buckling Stress $F_e = \pi^2 \cdot E/(K_v L_1/r_g)^2$	F_e	70.6 kip	(314 kN)
Critical Euler Buckling Stress $F_{cr} = IF(F_y/F_e<2.25, (0.658\text{^}F_y/F_e)F_y, 0.877F_e)$	F_{cr}	37.2 kip	(165 kN)
Gusset Buckling Capacity $\phi R_{n\text{-}gb} = \phi_{gb} \cdot F_{cr} \cdot A_w$	$\phi R_{n\text{-}gb}$:	160.3 kip	(713 kN)
Gusset Buckling Demand Capacity Ratio $DCR_{gb} = P_{uc}/\phi R_{n\text{-}gb}$ *Provide Stiffener if DCR_{gb} >1 .0*	DCR_{gb}:	0.93	

6.4.0 FORCE CALCULATIONS - AISC 360 BRACING SECTION (Typical AISC Method)

Dist from Face of Col Fl to Centriod of Gusset-to-Beam Connection (UFM)						
$\alpha'_{min} = L_{wb_min}/2$	α'_{min}	18.63 in	*(473 mm)*			
α_{Hand} = Hand Input Value to Force	α_{Hand}	18.63 in	*(473 mm)*			
If Hand Input Value is Different from α_{min} use Hand Input Value				α_{min}:	18.63 in	*(473 mm)*
Dist from Face of Beam Fl to Centriod of Gusset-to-Column Connection (UFM)						
$\beta'_{min} = L_{wc_min}/2$	β'_{min}	6.92 in	*(176 mm)*			
β_{Hand} = Hand Input Value to Force	β_{Hand}	6.92 in	*(176 mm)*			
If Hand Input Value is Different from β_{min} use Hand Input Value				β_{min}:	6.92 in	*(176 mm)*
Beam Gusset Length						
$L_{wb} = INT(2\alpha_{min})$				L_{wb}:	37.00 in	*(940 mm)*
Gusset Stiffener Length						
$L_{wc} = INT(2\beta_{min})$				L_{wc}:	13.00 in	*(330 mm)*
Vertical Force from Brace in Compression						
$V_{u\text{-}c} = P_{uc} \cdot SIN(\theta_{CB})$				$V_{u\text{-}c}$:	68.4 kip	*(304 kN)*
Vertical Force from Brace in Tension						
$V_{u\text{-}t} = P_{ut} \cdot SIN(\theta_{CB})$				$V_{u\text{-}t}$:	58.4 kip	*(260 kN)*
Net Vertical Force at the Beam						
$V_b = V_{u\text{-}c} - V_{u\text{-}t}$				V_b:	9.9 kip	*(44 kN)*
Horizontal Force from Brace in Compression						
$H_{u\text{-}c} = P_{uc} \cdot COS(\theta_{CB})$				$H_{u\text{-}c}$:	131.9 kip	*(587 kN)*
Horzontal Force from Brace in Tension						
$H_{u\text{-}t} = P_{ut} \cdot COS(\theta_{CB})$				$H_{u\text{-}t}$:	112.7 kip	*(501 kN)*
Net Horizontal Force at the Beam						
$H_b = H_{u\text{-}c} + H_{u\text{-}t}$				H_b:	244.6 kip	*(1088 kN)*
Resultant Force on Beam						
$R_{ub} = \sqrt{(V_b^2 + H_b^2)}$				R_{ub}:	244.8 kip	*(1089 kN)*
Moment at Beam from Horizontal Loads						
$M_u = H_b \cdot (DN_{bb}/2)$				M_u:	2005.7 kip-in	*(226649 kN-mm)*
Stresses at the interface between Gusset Plate and Beam:						
$f_v = V_b/2L_{wb}$				f_v:	0.13 k/in	*(0.0 kN/mm)*
$f_H = H_b/2L_{wb}$				f_H:	3.31 k/in	*(0.6 kN/mm)*
$f_b = 6M_u/(2L_{wb})^2$				f_b:	2.20 k/in	*(0.4 kN/mm)*

6.5.0 WELD DESIGN & STRESS CHECKS - AISC 360

Weld Material Minimum Yield Strength	F_{exx}:	70 ksi	*(483 MPa)*
Minimum Yield Strength of Beam ASTM	F_{yBm}:	50 ksi	*(345 MPa)*
Minimum Tensile Strength of Beam ASTM	F_{uBm}:	65 ksi	*(448 MPa)*
Weld Stress Distribution Factor (Ductility Factor)	μ_F:	1.00	

6.6.0 BEAM SHEAR AND CHEVRON EFFECTS CHECKS

General

Maximum Unbalanced Vert Shear in Connection Region: $V_{ub} = (P_{uc} - P_{ut})\cdot SIN(\theta_{CB})$	V_{ub}:	9.9 kip	*(44.18 kN)*
Maximum Horizontal Shear in Connection Region: $H_{ub} = (P_{ut} + P_{uc})\cdot COS(\theta_{CB})$	H_{ub}:	244.6 kip	*(1088.04 kN)*
LRFD Resistance Factor	ϕ_{bv}:	1.00	
Gusset and Opposing Brace Conditions Opposing Gusset Case: "Yes" - There is a gusset plate directly below this plate. "No" - There is not a gusset plate directly below this plate.	OGC:	Yes	
$H_{ub,OGC}$: *(For Equal Braces Below, Equal to H_{ub})*	$H_{ub,OGC}$:	244.6 kip	*(1088 kN)*
Apportionment Factor: $\phi_{OGC} = H_{ub,OGC}/H_{ub} + 1$	ϕ_{OGC}:	2.0	
Moment on Beam: $M_{ub} = H_{ub}\cdot e_b\cdot\phi_{OGC}$	M_{ub}:	4011 kip-in	*(453219 kN-mm)*
Beam Web Shear Capacity: $\phi V_n = \phi_{bv}\cdot 0.6\cdot F_{yBm}\cdot t_{wb}\cdot D_b$	ϕV_n:	211.6 kip	*(941 kN)*
Actual Gusset Length $L_{g\text{-}act} = 4\cdot\alpha_{min}$	$L_{g\text{-}act}$:	74.5 in	*(1893 mm)*
Min Weld Size for Gusset If: $t_g \le 0.50"$, $D_{w\text{-}min} = 3/16"$ $0.50" < t_g \le 0.75"$, $D_{w\text{-}min} = 1/4"$ $t_g > 0.75"$, $D_{w\text{-}min} = 5/16"$	$D_{w\text{-}min}$:	4 (16ths)	*(7 mm)*
Weld Size to Develop Gusset: $D_{w\text{-}max} = 0.6\cdot t_g\cdot F_{ug}/(0.6\cdot\sqrt{2}/2\cdot F_{EXX}/16\cdot 2)$	$D_{w\text{-}max}$:	6.57 (16ths)	*(11 mm)*

Standard Chevron Effects Method w/Dist Load Over Each Gusset Half (Uniform Stress Method)

Shear Demand Based on Chevron Effect: $V_{u\text{-}CE} = 2\cdot M_{ub}/(L_{q\text{-}act})$	$V_{u\text{-}CE}$:	107.6 kip	*(479 kN)*
Min Length for No Reinforcement: $L_{CE} = 2\cdot M_{ub}/\phi V_n$	L_{CE}:	37.9 in	*(963 mm)*
Applicability of Std Chevron Effect Method w/out Reinforcement: $L_{CE}/L_{q\text{-}act} \le 1.0$	$L_{CE}/L_{q\text{-}act}$:	0.51	No Reinf Req'd

Doubler Plate and Stiffener Plate Requirements (where needed for Std Chev Method)

Shear Stress to be Taken by Doubler PL: $V_{dpl} = V_{u\text{-}CE} - \phi V_n \ge 0$	V_{dpl}:	0.0 kip	*(0 kN)*
Doubler Plate Height: $h_{Dblr,nom}$ = **1** x Beam Depth	H_{dpl}:	-	-
Calculated Thickness of Doubler Plate: $t_{dpl} = V_{dpl}/(\phi_{bv}\cdot 0.6\cdot F_{yBm}\cdot H_{dpl})$	t_{dpl}:	-	-
Doubler Plate Actual Thickness:	t_{dpl}:	-	-
Length of Doubler Plate to Develop Shear: $L_{dpl\text{-}V} = (1-\phi V_n/V_{u\text{-}CE})\cdot L_{q\text{-}act}$	$L_{dpl\text{-}V}$:	-	-
Doubler Plate Weld Size: *A larger weld may be specified if needed to meet minimums.*	D_{dpl}:	-	-
Length of Doubler Plate to Develop Force: $L_{dpl\text{-}F} = 2\cdot V_{dpl}/[\phi_w\cdot 0.6\cdot F_{exx}\cdot 0.7071\cdot D_{dpl}/16\cdot(2Lines)]$ *Doubler shear must be developed over half of doubler length. Considers only top and bottom welds.*	$L_{dpl\text{-}F}$:	-	-

Checks to Develop Beam Shear Capacity over 1/2 Gusset Length (as Point Load):

Web Local Yielding Check (AISC J10.2)

LRFD Resistance Factor	ϕ_{wyb}:	1.00	
Combined Beam Web and Doubler Thickness	t_{wb+dpl}:	0.430 in	*(11 mm)*
$\phi R_{nyb} = \phi_{wyb}\cdot(5\cdot k_{des} + L_{act}/2)\cdot t_{wb+dpl}\cdot F_{yBm}$	ϕR_{nyb}:	921.6 kip	*(4100 kN)*
$R_{uyb} = V_{u\text{-}CE}$	R_{uyb}:	107.6 kip	*(479 kN)*
$DCR_{wyb} = R_{uyb}/\phi R_{nyb}$ *Provide Stiffener if $DCR_{wyb} > 1.0$*	DCR_{wyb}:	0.12	

Web Local Crippling Check (AISC J10.3)

LRFD Resistance Factor	ϕ_c:	0.75	
$\phi R_{ncb} = \phi_c\cdot 0.80\cdot t_{wb+dpl}^2[1+3\cdot(0.5\cdot L_{q\text{-}act}/D_b)\cdot(t_{wb+dpl}/t_{fb})^{1.5}]\cdot\sqrt{(E\cdot F_{yBm}\cdot t_{fb}/t_{wb+dpl})}$	ϕR_{ncb}:	720.0 kip	*(3203 kN)*
$R_{ucb} = V_{u\text{-}CE}$	R_{ucb}:	107.6 kip	*(479 kN)*
$DCR_{wcb} = R_{ucb}/\phi R_{ncb}$	DCR_{wcb}:	0.15	

Provide Stiffener if DCR_{wcb} > 1.0

Shear Capacity to be Taken by Stiffener (If Required) $V_{stiff} = \max[\phi R_{nyb}(DCR_{wyb}-1),\phi R_{ncb}(DCR_{wcb}-1),0]$ *Applicable only if $L_{CE\text{-}Alt}/L_{act}$ <= 1.0*	V_{stiff}:	0.0 kip	*(0 kN)*
Required Stiffener Area $A_{st} = (V_{stiff}/2)/(\phi_{bv}\cdot F_{yBm})$	A_{st}:	0.00 in²	*(0 mm²)*
Required Stiffener Thickness $t_{st} = A_{st}/[(b_{fb} - t_{wb})/2-t_{dpl}]$	t_{st}:	0.00 in	*(0 mm)*

Required Weld Size for Standard Method

Vertical Load from Tension and Compression Braces $V_{method\ 1} = V_{ub}/L_{q,act} + V_{u,CE}/(L_{q,act}/2)$ *Note that $V_{u,CE}/(L_{q,act}/2)$ is the add'l load from the force couple and exists on both halfs fo the gussset.*	$V_{mthd\ 1}$:	3.02 k/in	*(0.53 kN/mm)*
Horzontal Load from Tension and Compression Braces $H_{method\ 1} = H_{ub}/L_{q,act}$	$H_{mthd\ 1}$:	3.28 k/in	*(0.57 kN/mm)*
Resultant Load on Weld: $R_{method\ 1} = \sqrt{(V_{method\ 1}^2 + H_{method\ 1}^2)}$	$R_{mthd\ 1}$:	4.46 k/in	*(0.78 kN/mm)*
Angle of Resultant Demand on Beam $\theta_{wc} = TAN^{-1}(V_{method\ 1}/H_{method\ 1})$	θ_{wc}:	0.744 rad	*42.6°*
Weld Capacity Increase Factor for Angle at Beam $C_{\theta R} = 1+0.5[SIN(\theta_{wc})]^{1.5}$	$C_{\theta R}$:	1.279	
Size of Weld at Beam: $D_{req}=R_{method\ 1}/[(2Lines)\cdot 0.75\cdot 0.6\cdot(1in)\cdot F_{EXX}\cdot\sqrt{2}/2\cdot C_{\theta R}/16]$	D_{req}:	1.25 (16ths)	*(2 mm)*

Chevron Effects Method with Distributed Loads at Gusset Edges over Length 'z', (Concentrated Stress Method)

Min Length for Alt Method: $L_{CE\text{-}Alt} = M_{ub}/(\phi V_n-0.5V_{ub}) + (\phi V_n-0.5V_{ub})/(\phi_{bv}\cdot F_{yBm}\cdot t_{wb})$	$L_{CE\text{-}Alt}$:	29.0 in	*(737 mm)*
Applicability of Alt Method: $L_{CE\text{-}Alt}/L_{g\text{-}act} \le 1.0$	$L_{CE\text{-}Alt}/L_{g\text{-}act}$:	0.39	
Length of Dist Load on Bm at End of Gusset: $z' = L_{q-act}/2-\sqrt{[L_{q-act}^2/4-M_{ub}/(\phi_{bv}\cdot F_{yBm}\cdot MIN(t_{wbt},t_q))]}$ Round z' up to nearest 0.25"	z': z:	2.59 in 2.75 in	*(66 mm)* *(70 mm)*

Checks to Develop Beam Shear Capacity over z Length (as Point Load):

Web Local Yielding Check (AISC J10.2)

$\phi R_{nyb} = \phi_{wyb}\cdot(5\cdot k_{des} + z)\cdot t_{wb}\cdot F_{yBm}$	ϕR_{nyb}:	179.5 kip	*(799 kN)*
$R_{uyb} = \phi V_n-0.5V_{ub}$	R_{uyb}:	206.6 kip	*(919 kN)*
$DCR_{wyb} = R_u/\phi R_{nyb}$ *Provide Stiffener if DCR_{wyb} > 1.0*	DCR_{wyb}:	1.15	

Web Local Crippling Check (AISC J10.3)

$\phi R_{ncb} = \phi_c\cdot 0.80\cdot t_{wb}^2[1+3\cdot(z/D_b)\cdot(t_{wb}/t_{fb})^{1.5}]\cdot\sqrt{(E\cdot F_{yBm}\cdot t_{fb}/t_{wb})}$	ϕR_{ncb}:	212.7 kip	*(946 kN)*
$R_{ucb} = \phi V_n-0.5V_{ub}$	R_{ucb}:	206.6 kip	*(919 kN)*
$DCR_{wcb} = R_{ucb}/\phi R_{ncb}$ *Provide Stiffener if DCR_{wcb} > 1.0*	DCR_{wcb}:	0.97	
Shear Capacity to be Taken by Stiffener (If Required) $V_{stiff\text{-}alt} = \max[\phi R_{nyb}(DCR_{wyb}-1),\phi R_{ncb}(DCR_{wcb}-1),0]$ *Applicable only if $L_{CE\text{-}Alt}/L_{act}$ <= 1.0*	$V_{stiff\text{-}alt}$:	27.1 kip	*(120 kN)*
Required Stiffener Area at z $A_{st} = (V_{stiff\text{-}Alt}/2)/(\phi_{bv}\cdot F_{yBm})$	A_{st}:	0.27 in²	*(175 mm²)*
Required Stiffener Thickness at z $t_{st} = A_{st}/[(b_{fb} - t_{wb})/2]$	t_{st}:	0.08 in	*(2 mm)*

Checks to Develop Beam Shear Capacity at center (as Point Load):

Web Local Yielding Check (AISC J10.2)

$\phi R_{nyb} = \phi_{wyb}\cdot(5\cdot k_{des} + z)\cdot t_{wb}\cdot F_{yBm}$	ϕR_{nyb}:	179.5 kip	*(799 kN)*
$R_{uyb} = V_{uc,ub}$	R_{uyb}:	9.9 kip	*(44 kN)*
$DCR_{wyb} = R_u/\phi R_{nyb}$ *Provide Stiffener if DCR_{wyb} > 1.0*	DCR_{wyb}:	0.06	

Web Local Crippling Check (AISC J10.3)

$\phi R_{ncb} = \phi_c\cdot 0.80\cdot t_{wb}^2[1+3\cdot(z/D_b)\cdot(t_{wb}/t_{fb})^{1.5}]\cdot\sqrt{(E\cdot F_{yBm}\cdot t_{fb}/t_{wb})}$	ϕR_{ncb}:	212.7 kip	*(946 kN)*
$R_{ucb} = V_{uc,ub}$	R_{ucb}:	9.9 kip	*(44 kN)*
$DCR_{wcb} = R_{ucb}/\phi R_{ncb}$ *Provide Stiffener if DCR_{wcb} > 1.0*	DCR_{wcb}:	0.05	
Shear Capacity to be Taken by Stiffener (If Required) $V_{stiff\text{-}alt,cntr} = \max[\phi R_{nyb}(DCR_{wyb}-1),\phi R_{ncb}(DCR_{wcb}-1),0]$ *Applicable only if $L_{CE\text{-}Alt}/L_{act}$ <= 1.0*	$V_{stiff\text{-}alt,cntr}$:	0.0 kip	*(0 kN)*
Required Stiffener Area at Center $A_{st,cntr} = (V_{stiff\text{-}Alt}/2)/(\phi_{bv}\cdot F_{yBm})$	$A_{st,cntr}$:	0.00 in²	*(0 mm²)*

Required Stiffener Thickness at Center $t_{st,cntr} = A_{st}/[(b_{fb} - t_{wb})/2]$	$t_{st,cntr}$:	0.00 in	*(0 mm)*

Required Weld Size for Concentrated Stress Method

Uniformly Distributed Horizontal Load On Gusset: $H_{qusset} = H_{ub}/L_{g-act}$	H_{qusset}:	3.28 k/in	*(0.57 kN/mm)*
Required Beam Weld in z-Region			
Vertical Load from Unbalanced Moment Resolved in z-Region			
$V_z = M_{ub}/((L_{g-act}-z')\cdot z')$	V_z:	21.50 k/in	*(3.77 kN/mm)*
Resultant Load on Weld: $R_z = \sqrt{(V_z^2 + H_{qusset}^2)}$	R_z:	21.75 k/in	*(3.81 kN/mm)*
Angle of Resultant Demand on Beam			
$\theta_{wc} = TAN^{-1}(V_z/H_{qusset})$	θ_{wc}:	1.419 rad	*81.3°*
Weld Capacity Increase Factor for Angle at Beam			
$C_{\theta R} = 1+0.5[SIN(\theta_{wc})]^{1.5}$	$C_{\theta R}$:	1.491	
Size of Weld at z-Region			
$D_{req-z}=R_z/[(2Lines)\cdot 0.75\cdot 0.6\cdot (1in)\cdot F_{EXX}\cdot\sqrt{2}/2\cdot C_{\theta R}/16]$	D_{req-z}:	5.24 (16ths)	*(9 mm)*
Required Beam Weld Center Region			
Vertical Load from Tension and Compression Braces			
$V_{cntr}=V_{ub}/(L_{g-act}-2\cdot z')$	V_{cntr}:	0.14 k/in	*(0.03 kN/mm)*
Resultant Load on Weld: $R_{cntr\ 1} = \sqrt{(V_{cntr}^2 + H_{gusset}^2)}$	R_{cntr}:	3.28 k/in	*(0.58 kN/mm)*
Angle of Resultant Demand on Beam			
$\theta_{wc} = TAN^{-1}(V_{cntr}/H_{gusset})$	θ_{wc}:	0.044 rad	*2.5°*
Weld Capacity Increase Factor for Angle at Beam			
$C_{\theta R} = 1+0.5[SIN(\theta_{wc})]^{1.5}$	$C_{\theta R}$:	1.005	
Size of Weld at Cntr Region: $D_{req}=R_{cntr}/[(2Lines)\cdot 0.75\cdot 0.6\cdot (1in)\cdot F_{EXX}\cdot\sqrt{2}/2\cdot C_{\theta R}/16]$	$D_{req-cntr}$:	1.17 (16ths)	*(2 mm)*

Summary

If L_{CE}/L_{act} > 1.0 Then Must Reinforce	Result:	**No Reinf Req'd**		
Doubler Plates will be used if L_{CE}/L_{act} > 1.0 and L_{CE-Alt}/L_{act} > 1.0:	Result:	**No Doubler Plate Req'd**		
If Reinforcing, Doubler Plate Thickness Equal to:		t_{dpl}:	-	-
If Reinforcing, Min Doubler Plate Length Equal to:		$L_{dpl-min}$:	-	-
If Reinforcing, Min Doubler Plate Weld Equal to:		D_{dpl}:	-	-
If Reinforcing, Min Stiffener Plate Thickness Equal to:		t_{st}:	-	-
If Reinforcing, Weld Size Required at Gusset to Beam:		D_{req}:	4 (16ths)	*(7 mm)*
If L_{CE-Alt}/L_{act} > 1.0 Then Cannot Use Alt Method	Result:	**No Doubler Plate Req'd**		
Stiffener Plates will be used at z if $V_{stiff-Alt}$ > 0	Result:	**Stiffener Plate Req'd at z**		
If Using Alt Method, Size Weld to Develop Gusset Strength Over Length:		z:	-	-
If Using Alt Method, Required Stiffener Thickness at z:		t_{st}:	-	-
If Reinforcing, Weld Size Required at Gusset to Beam in z-Region:		D_{req-z}:	-	-
If Reinforcing, Weld Size Required at Gusset to Beam in Center Region:		$D_{req-cntr}$:	-	-
If weld sizes in z-region and center-regions are nearly the same size, the larger size may be used over the entire region.				
Stiffener Plates will be used at cntr if $V_{stiff-Alt,cntr}$ > 0	Result:	**No Stiffener Plate Req'd at center**		
If Using Alt Method, Required Stiffener Thickness at Center:		$t_{st,cntr}$:	-	-

ALL OTHER CHECKS OK BY COMPARISON TO CONNECTION AT OPPOSITE END OF BRACE

V Beam Connection Bottom

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																				Whitmore Tension Fracture									Gusset Buckling								
EOR-ID	Line	Grids	Lvls	Mark	Qty	n_i	n_o	s	θ_{CB}	θ_{UFM}	L_{tb}	L_{2b}	e	D_{cb}	D_{bb}	$l_{wc,u}$	$l_{wb,u}$	β_{min}	α_{min}	t_g	t_{r_Des}	W_L	A_{wm}	F_{yg}	P_{uc}	β	P_{ut}	P_{ut}	L_1	r_y	K_{chev}	KL_1	F_e	F_y	F_{cr}	ϕP_{cr}	P_{uc}
#		#	#	#	#	#	#	in	rad	rad	in	in	in	in	in	in	in	in	in	in	in	in	in	in^2	ksi	kip		kip	ϕR_n	in	in		r_y	ksi	F_e	ksi	ksi	ϕP_{cr}
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	2	0	3.50	0.48	1.09	34.31	5.88	1.188	0.50	16.40	13.0	37.0	6.9	18.6	0.63	0.00	6.00	4.79	50	149	1.17	127	0.59	17.68	0.18	0.65	63.68	70.58	0.71	37.17	160.30	0.93
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	2	0	3.50	0.48	1.09	34.31	5.88	1.188	0.50	16.40	13.0	37.0	6.9	18.6	0.63	0.00	6.00	4.79	50	149	1.17	127	0.59	17.68	0.18	0.65	63.68	70.58	0.71	37.17	160.30	0.93
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	2	0	3.50	0.39	1.18	46.37	5.88	1.188	0.50	18.40	15.0	49.0	7.7	24.8	0.75	0.00	6.00	5.17	50	146	1.16	126	0.54	23.11	0.22	0.65	69.39	59.44	0.84	35.16	163.50	0.89
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	2	0	3.50	0.39	1.18	46.37	5.88	1.188	0.50	18.40	15.0	49.0	7.5	24.8	0.75	0.00	6.00	5.17	50	146	1.16	126	0.54	23.11	0.22	0.65	69.39	59.44	0.84	35.16	163.50	0.89
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	2	0	3.50	0.27	1.30	50.97	5.88	1.188	0.50	16.40	14.0	55.0	7.4	27.8	0.88	0.00	6.00	5.65	50	134	1.11	121	0.47	21.58	0.25	0.65	55.53	92.82	0.54	39.91	202.80	0.66
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	2	0	3.50	0.31	1.26	44.60	5.88	1.188	0.50	16.40	14.0	49.0	7.4	24.5	0.88	0.00	6.00	6.03	50	134	1.11	121	0.44	18.89	0.25	0.65	48.60	121.16	0.41	42.07	228.23	0.59
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	2	0	3.50	0.24	1.33	51.33	5.88	1.188	0.50	13.80	15.0	56.0	7.8	28.1	1.00	0.00	6.00	6.31	50	134	1.11	121	0.42	24.00	0.29	0.65	54.04	98.00	0.51	40.39	229.42	0.58
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	2	0	3.50	0.24	1.33	51.33	5.88	1.188	0.50	13.80	15.0	56.0	7.8	28.1	1.00	0.00	6.00	6.31	50	134	1.11	121	0.42	24.00	0.29	0.65	54.04	98.00	0.51	40.39	229.42	0.58

Table of Symbols

n = Number of bolts in a row ($_i$ inside row, $_o$ outside row)
s = Bolt spacing in a row
e = Edge distance
θ_{CB} = Angle between brace and beam, rad
θ_{UFM} = Angle used for uniform force method, rad
D_{ct} = Depth of column at top of CB, in
D_{bt} = Depth of beam at top of CB, in
$l_{wc,u}$ = Actual length of weld on column used
$l_{wb,u}$ = Actual length of weld on beam used

α min = Center of weld on beam based on geometry constraints
β min = Center of weld on column based on geometry constraints
t_g = Thickness of gusset
t_r = Thickness of repad
W_L = Width of lug
A_{wm} = Area of whitmore line at gusset
β = Compression strength adjustment factor
P_{uc} = Ultimate CB demand (compression)
P_{ut} = Ultimate CB demand (tension)

K = UFM factor
K' = UFM reduced moment factor
D = UFM reduced moment factor
α' = Center of weld on column with moments
β' = Center of weld on beam with moments
r = Resultant length of **α** & **β**

V Beam Connection Bottom

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Inputs			General										Method 1										Chevron Effects (V)
EOR-ID	Line	Grids	Lvls	Mark	Qty	Brace	b_{fbb}	$k_{des,BM}$	V_{ub}	H_{ub}	$H_{ub\text{-}OGC}$	Aprnment	e_b	M_{ub}	$\phi V_{n\text{-}Bm}$	$L_{g\text{-}act}$	D_{min}	$D_{develop\text{-}tg}$	$V_{u\text{-}CE}$	L_{CE}	$\frac{L_{CE}}{L_{act}}$	V_{stiff}	$A_{st\ rqd}$	$t_{st\ rqd}$	$V_{method\ 1}$	$H_{method\ 1}$	$R_{method\ 1}$	θ_R	$C_{\theta R}$	D_{req}
#		#	#	#	#	Below?	in	in	kip	kip	kip	Factor	in	k-in	kip	in	16ths	16ths	kip	in		kips	in^2	in	k/in	k/in	k/in	rad		16ths
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	Yes	7.12	1.12	9.9	244.6	244.6	2.0	8.20	4011	211.6	74.5	4	6.6	107.64	37.92	0.51	0.0	0.00	-	3.02	3.28	4.46	0.74	1.28	1.3
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	Yes	7.12	1.12	9.9	244.6	244.6	2.0	8.20	4011	211.6	74.5	4	6.6	107.64	37.92	0.51	0.0	0.00	-	3.02	3.28	4.46	0.74	1.28	1.3
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	Yes	7.59	1.15	7.6	252.2	252.2	2.0	9.20	4641	248.4	99.3	4	7.9	93.46	37.37	0.38	0.0	0.00	-	1.96	2.54	3.21	0.66	1.24	0.9
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	Yes	7.59	1.15	7.6	252.2	252.2	2.0	9.20	4641	248.4	99.3	4	7.9	93.46	37.37	0.38	0.0	0.00	-	1.96	2.54	3.21	0.66	1.24	0.9
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	Yes	7.12	1.12	3.6	245.0	245.0	2.0	8.20	4018	211.6	111.2	5	9.2	72.28	37.98	0.34	0.0	0.00	-	1.33	2.20	2.57	0.54	1.19	0.8
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	Yes	7.12	1.12	4.0	242.2	242.2	2.0	8.20	3972	211.6	98.1	5	9.2	80.99	37.55	0.38	0.0	0.00	-	1.69	2.47	2.99	0.60	1.21	0.9
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	Yes	8.03	1.19	3.2	246.7	246.7	2.0	6.90	3405	140.8	112.4	5	10.5	60.56	48.38	0.43	0.0	0.00	-	1.11	2.19	2.46	0.47	1.15	0.8
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	Yes	8.03	1.19	3.2	246.7	246.7	2.0	6.90	3405	140.8	112.4	5	10.5	60.56	48.38	0.43	0.0	0.00	-	1.11	2.19	2.46	0.47	1.15	0.8

V Beam Connection Bottom

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Method 2																		Summary				
EOR-ID	Line	Grids	Lvls	Mark	Qty	$L_{CE\text{-}Alt}$	$\frac{L_{CE\text{-}Alt}}{L_{act}}$	z	$z_{Rounded}$	$V_{stiff\text{-}Alt}$	$t_{st\ rqd,cntr}$	V_z	H_{gusset}	R_z	$\theta_{R\text{-}z}$	$C_{\theta R\text{-}z}$	$D_{Z,Req}$	V_{cntr}	H_{cntr}	R_{cntr}	$\theta_{R\text{-}cntr}$	$C_{\theta R\text{-}cntr}$	$D_{req\text{-}cntr}$	No Reinf	Method 1	Method 2	$t_{st,cntr}$	W_{cntr}
#		#	#	#	#	in	L_{act}	in	in	kips	in	k/in	k/in	k/in	rad	16ths	16ths	k/in	k/in	k/in	rad		16ths	Req'd	(Dblr Plate)	(z Reinf)	in	16ths
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	29.03	0.39	2.59	2.75	0.0	-	21.50	3.28	21.75	1.42	1.49	5.24	0.14	3.28	3.28	0.04	1.00	1.17	✓	✗	✗	0.50	4.00
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	29.03	0.39	2.59	2.75	0.0	-	21.50	3.28	21.75	1.42	1.49	5.24	0.14	3.28	3.28	0.04	1.00	1.17	✓	✗	✗	0.50	4.00
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	29.84	0.30	2.12	2.25	0.0	-	22.50	2.54	22.64	1.46	1.50	5.44	0.08	2.54	2.54	0.03	1.00	0.91	✓	✗	✗	0.50	4.00
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	29.84	0.30	2.12	2.25	0.0	-	22.50	2.54	22.64	1.46	1.50	5.44	0.08	2.54	2.54	0.03	1.00	0.91	✓	✗	✗	0.50	4.00
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	28.91	0.26	1.71	1.75	0.0	-	21.50	2.20	21.61	1.47	1.50	5.19	0.03	2.20	2.20	0.01	1.00	0.79	✓	✗	✗	0.50	5.00
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	28.70	0.29	1.92	2.00	0.0	-	21.50	2.47	21.64	1.46	1.50	5.20	0.04	2.47	2.47	0.02	1.00	0.89	✓	✗	✗	0.50	5.00
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	32.65	0.29	1.81	2.00	0.0	-	17.00	2.19	17.14	1.44	1.49	4.12	0.03	2.19	2.19	0.01	1.00	0.79	✓	✗	✗	0.50	5.00
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	32.65	0.29	1.81	2.00	0.0	-	17.00	2.19	17.14	1.44	1.49	4.12	0.03	2.19	2.19	0.01	1.00	0.79	✓	✗	✗	0.50	5.00

Chevron Beam Connection Top

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																			Whitmore Tension Fracture									Gusset Buckling								
EOR-ID	Line	Grids	Lvls	Mark	Qty	n_i	n_o	s	θ_{CB}	θ_{UFM}	L_{tt}	L_{2t}	e	D_{ct}	D_{bt}	$l_{wc,u}$	$l_{wb,u}$	β_{min}	α_{min}	t_g	t_{r_Des}	W_L	A_{wm}	F_{yg}	P_{uc}	β	P_{ut}	P_{ut}	L_1	r_y	K_{chev}	KL_1/r_y	F_e	F_y/F_e	F_{cr}	ϕP_{cr}	$P_{uc}/\phi P_{cr}$
#		#	#	#	#	#	#	in	rad	rad	in	in	in	in	in	in	in	in	in	in	in	in	in	in^2	ksi	kip		kip	ϕR_n	in	in			ksi		ksi	ksi	
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	2	0	3.50	0.90	0.67	13.95	5.88	1.188	0.5	16.4	9.0	15.0	4.9	7.6	0.63	0.00	6.00	4.79	50	136	1.11	122	0.57	4.64	0.18	0.65	16.72	1023.68	0.05	48.99	211.26	0.64
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	2	0	3.50	0.90	0.67	13.95	5.88	1.188	0.5	16.4	9.0	15.0	4.9	7.6	0.63	0.00	6.00	4.79	50	136	1.11	122	0.57	4.64	0.18	0.65	16.72	1023.68	0.05	48.99	211.26	0.64
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	2	0	3.50	0.85	0.72	15.93	5.88	1.188	0.5	18.4	9.0	17.0	4.9	8.6	0.63	0.00	6.00	4.79	50	136	1.11	122	0.57	4.86	0.18	0.65	17.52	932.94	0.05	48.89	210.84	0.64
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	2	0	3.50	0.85	0.72	15.93	5.88	1.188	0.5	18.4	9.0	17.0	4.9	8.6	0.63	0.00	6.00	4.79	50	136	1.11	122	0.57	4.86	0.18	0.65	17.52	932.94	0.05	48.89	210.84	0.64
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	2	0	3.50	0.72	0.85	18.30	5.88	1.188	0.5	16.4	10.0	20.0	5.4	10.3	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	7.30	0.18	0.65	26.31	413.34	0.12	47.53	204.97	0.66
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	2	0	3.50	0.72	0.85	18.30	5.88	1.188	0.5	16.4	10.0	20.0	5.4	10.3	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	6.72	0.18	0.65	24.19	489.02	0.10	47.91	206.59	0.65
BRB-2.00	B	5 to 4.7	1	**1913**	1	2	0	3.50	0.72	0.85	13.76	5.88	1.188	0.5	11.9	10.0	17.0	5.0	8.6	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	5.71	0.18	0.65	20.59	675.24	0.07	48.47	209.04	0.64
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	2	0	3.50	0.72	0.85	13.03	5.88	1.188	0.5	11.9	10.0	17.0	5.1	8.6	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	5.41	0.18	0.65	19.51	752.20	0.07	48.63	209.70	0.64
BRB-2.00	3.2	D to C.6	1	**1918**	1	2	0	3.50	0.71	0.86	17.82	5.88	1.188	0.5	13.8	11.0	20.0	5.8	10.2	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	8.11	0.18	0.65	29.21	335.46	0.15	46.98	202.58	0.67
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	2	0	3.50	0.71	0.86	16.86	5.88	1.188	0.5	13.8	11.0	20.0	5.8	10.1	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	7.68	0.18	0.65	27.65	374.27	0.13	47.28	203.89	0.66

Table of Symbols

- **n** = Number of bolts in a row ($_i$ inside row, $_o$ outside row)
- **s** = Bolt spacing in a row
- **e** = Edge distance
- θ_{CB} = Angle between brace and beam, rad
- θ_{UFM} = Angle used for uniform force method, rad
- D_{cb} = Depth of column at bottom of CB
- D_{bb} = Depth of beam at bottom of CB
- $l_{wc,u}$ = Actual length of weld on column used
- $l_{wb,u}$ = Actual length of weld on beam used
- **α min** = Center of weld on beam based on geometry constraints
- **β min** = Center of weld on column based on geometry constraints
- t_g = Thickness of gusset
- t_r = Thickness of repad
- W_L = Width of lug
- A_{wm} = Area of whitmore line at gusset
- **β** = Compression strength adjustment factor
- P_{uc} = Ultimate CB demand (compression)
- P_{ut} = Ultimate CB demand (tension)
- **K** = UFM factor
- **K'** = UFM reduced moment factor
- **D** = UFM reduced moment factor
- **α'** = Center of weld on column with moments
- **β'** = Center of weld on beam with moments
- **r** = Resultant length of **α** & **β**

Chevron Beam Connection Top

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Inputs			General										Method 1										Chevron Effects
EOR-ID	Line	Grids	Lvls	Mark	Qty	Brace	b_{fbt}	$k_{des,BM}$	V_{ub}	H_{ub}	$H_{ub\text{-}OGC}$	Aprnment	e_b	M_{ub}	$\phi V_{n\text{-}Bm}$	$L_{g\text{-}act}$	D_{min}	$D_{develop\text{-}tg}$	$V_{u\text{-}CE}$	L_{CE}	$\underline{L_{CE}}$ / L_{act}	V_{stiff}	$A_{st\ rqd}$	$t_{st\ rqd}$	$V_{method\ 1}$	$H_{method\ 1}$	$R_{method\ 1}$	θ_R	$C_{\theta R}$	D_{req}
#		#	#	#	#	Above?	in	in	kip	kip	kip	Factor	in	k-in	kip	in	16ths	16ths	kip	in		kips	in^2	in	k/in	k/in	k/in	rad		16ths
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	Yes	7.12	1.12	10.51	161	161	2.0	8.20	2643	211.56	30.50	4	6.6	173.31	24.99	0.82	0.00	0.00	-	11.71	5.28	12.85	1.15	1.44	3.21
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	Yes	7.12	1.12	10.51	161	161	2.0	8.20	2643	211.56	30.50	4	6.6	173.31	24.99	0.82	0.00	0.00	-	11.71	5.28	12.85	1.15	1.44	3.21
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	Yes	7.59	1.15	10.10	171	171	2.0	9.20	3138	248.40	34.31	4	6.6	182.91	25.27	0.74	0.00	0.00	-	10.96	4.97	12.03	1.14	1.43	3.01
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	Yes	7.59	1.15	10.10	171	171	2.0	9.20	3138	248.40	34.31	4	6.6	182.91	25.27	0.74	0.00	0.00	-	10.96	4.97	12.03	1.14	1.43	3.01
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	Yes	7.12	1.12	8.78	193	193	2.0	8.20	3166	211.56	41.19	4	6.6	153.72	29.93	0.73	0.00	0.00	-	7.68	4.69	8.99	1.02	1.39	2.32
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	Yes	7.12	1.12	8.78	193	193	2.0	8.20	3166	211.56	41.19	4	6.6	153.72	29.93	0.73	0.00	0.00	-	7.68	4.69	8.99	1.02	1.39	2.32
BRB-2.00	B	5 to 4.7	1	**1913**	1	No	8.01	1.02	8.82	192	0	1.0	5.95	1145	105.32	34.27	4	6.6	66.83	21.74	0.63	0.00	0.00	-	4.16	5.62	6.99	0.64	1.23	2.04
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	No	8.01	1.02	8.82	192	0	1.0	5.95	1145	105.32	34.50	4	6.6	66.38	21.74	0.63	0.00	0.00	-	4.10	5.58	6.93	0.63	1.23	2.03
BRB-2.00	3.2	D to C.6	1	**1918**	1	Yes	8.03	1.19	8.68	195	195	2.0	6.90	2688	140.76	40.72	4	6.6	132.05	38.20	0.94	0.00	0.00	-	6.70	4.78	8.23	0.95	1.37	2.16
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	Yes	8.03	1.19	8.68	195	195	2.0	6.90	2688	140.76	40.56	4	6.6	132.57	38.20	0.94	0.00	0.00	-	6.75	4.80	8.29	0.95	1.37	2.18

Chevron Beam Connection Top

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Method 2																	Summary				
EOR-ID	Line	Grids	Lvls	Mark	Qty	$L_{CE\text{-}Alt}$	$L_{CE\text{-}Alt}$	z	$z_{Rounded}$	$V_{stiff\text{-}Alt}$	$t_{st\ rqd,cntr}$	V_z	H_{gusset}	R_z	$\theta_{R\text{-}z}$	$C_{\theta R\text{-}z}$	$D_{Z,Req}$	V_{cntr}	H_{cntr}	R_{cntr}	$\theta_{R\text{-}cntr}$	$C_{\theta R\text{-}cntr}$	$D_{req\text{-}cntr}$	No Reinf	Method 1	Method 2	$t_{st,cntr}$	W_{cntr}
#		#	#	#	#	in	L_{act}	in	in	kips	in	k/in	k/in	k/in	rad	16ths	16ths	k/in	k/in	k/in	rad		16ths	Req'd	(Dblr Plate)	(z Reinf)	in	16ths
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	22.41	0.73	4.78	5.00	0.00	-	21.50	5.28	22.14	1.33	1.48	5.38	0.50	5.28	5.31	0.09	1.01	1.88	✓	✗	✗	0.50	4.00
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	22.41	0.73	4.78	5.00	0.00	-	21.50	5.28	22.14	1.33	1.48	5.38	0.50	5.28	5.31	0.09	1.01	1.88	✓	✗	✗	0.50	4.00
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	23.71	0.69	4.71	4.75	0.00	-	22.50	4.97	23.04	1.35	1.48	5.58	0.41	4.97	4.99	0.08	1.01	1.77	✓	✗	✗	0.50	4.00
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	23.71	0.69	4.71	4.75	0.00	-	22.50	4.97	23.04	1.35	1.48	5.58	0.41	4.97	4.99	0.08	1.01	1.77	✓	✗	✗	0.50	4.00
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	24.92	0.60	3.95	4.00	0.00	-	21.50	4.69	22.00	1.36	1.48	5.33	0.26	4.69	4.69	0.06	1.01	1.67	✓	✗	✗	0.50	4.00
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	24.92	0.60	3.95	4.00	0.00	-	21.50	4.69	22.00	1.36	1.48	5.33	0.26	4.69	4.69	0.06	1.01	1.67	✓	✗	✗	0.50	4.00
BRB-2.00	B	5 to 4.7	1	**1913**	1	18.19	0.53	2.44	2.50	0.00	-	14.75	5.62	15.78	1.21	1.45	3.90	0.30	5.62	5.62	0.05	1.01	2.01	✓	✗	✗	0.50	4.00
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	18.19	0.53	2.42	2.50	0.00	-	14.75	5.58	15.77	1.21	1.45	3.90	0.30	5.58	5.59	0.05	1.01	1.99	✓	✗	✗	0.50	4.00
BRB-2.00	3.2	D to C.6	1	**1918**	1	27.73	0.68	4.35	4.50	0.00	-	17.00	4.78	17.66	1.30	1.47	4.31	0.27	4.78	4.79	0.06	1.01	1.71	✓	✗	✗	0.50	4.00
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	27.73	0.68	4.37	4.50	0.00	-	17.00	4.80	17.67	1.30	1.47	4.31	0.27	4.80	4.81	0.06	1.01	1.72	✓	✗	✗	0.50	4.00

PSE Operational Training Center

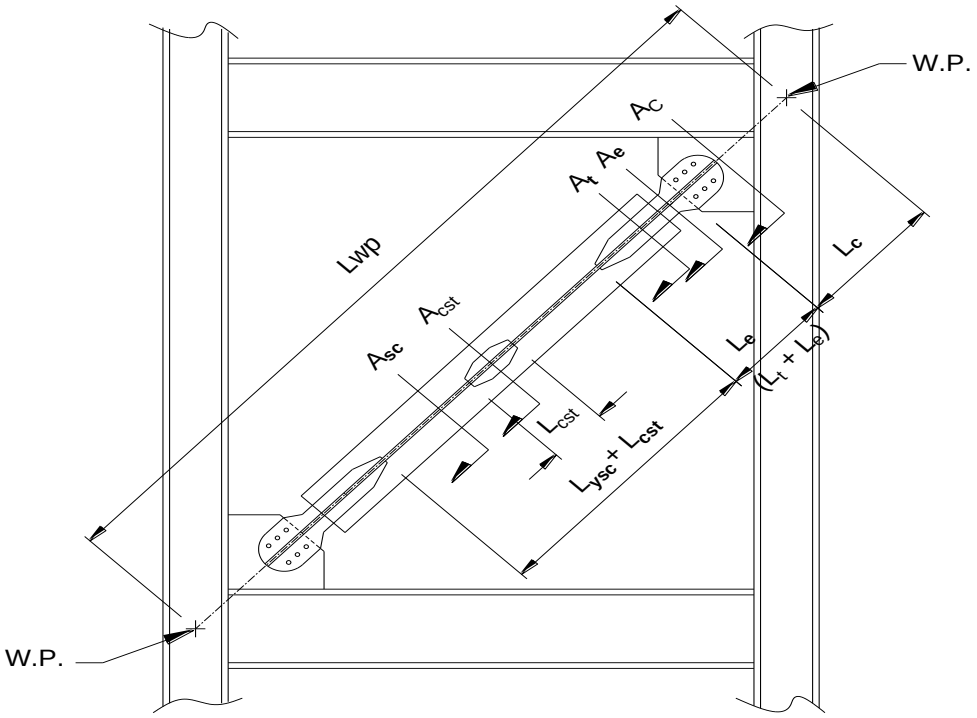
Calculation Submittal Package

Description

Section 7. **Stiffness Sample Calculation**
Stiffness Tables

Stiffness Calculation

Example Mark #: 1901
Line 4.1, Grid D.3 to D(+), Level Low Roof



Stiffness Calculation

7.0 DESIGN CRITERIA

Length Between Work Points at Top and Bottom of Brace	L_{wp}:	173.3 in	*(4402 mm)*
Modulus of Elasticity	E:	29000 ksi	*(199955 MPa)*
Yielding Core Stiffness			
Yielding Core Length	L'_{ysc}:	74.5 in	*(1891 mm)*
Yielding Core Area	A_{ysc}:	2.00 in²	*(1290 mm²)*
Yielding Core Stiffness $K_{ysc} = A_{ysc} \cdot E/L_{ysc}$	K_{ysc}:	779 k/in	*(136 kN/mm)*
End Zone Stiffness			
Length of Stiffener Plate Extension into Casing	L_e:	14.1 in	*(359 mm)*
End Zone Total Length $L_{eT} = 2L_e$	L_{eT}:	28.3 in	*(718 mm)*
End Zone Area	A_e:	5.11 in²	*(3294 mm²)*
End Zone Stiffness $K_e = A_e \cdot E/L_{eT}$	K_e:	5239 k/in	*(917 kN/mm)*
Transition Zone Stiffness (Where Occurs)			
Length from End of Stiffener Plate to Middle of Final Transition	L_t:	0.0 in	*(0 mm)*
Transition Zone Total Length $L_{tT} = 2L_t$	L_{tT}:	0.0 in	*(0 mm)*
Transition Zone Area	A_t:	0.00 in²	*(0 mm²)*
Transition Zone Stiffness $K_t = A_t \cdot E/L_{tT}$	K_t:	--	--
Connection Stiffness			
Length of Connection from Work Point to End of Gusset	L_c:	35.3 in	*(896 mm)*
Connection Region Total Length $L_{cT} = 2 \cdot L_C$	L_{cT}:	70.6 in	*(1793 mm)*
Connection Area	A_c:	15.32 in²	*(9883 mm²)*
Connection Stiffness $K_c = A_c \cdot E/L_{cT}$	K_c:	6294 k/in	*(1102 kN/mm)*
Center Region Stiffness (Not Applicable Where $L_{cst} = 0$)			
Length of Center Region	L_{cst}:	0.0 in	*(0 mm)*
Area of Center Region	A_{cst}:	2.00 in²	*(1290 mm²)*
Center Stiffness $K_{cst} = A_{cst} \cdot E/L_{cst}$	K_{cst}:	--	--
Total Stiffness $K_{eff} = 1/(1/K_{ysc} + 1/K_e + 1/K_t + 1/K_c + 1/K_{cst})$	K_{eff}:	612 k/in	*(107 kN/mm)*
Yielding Core Stiffness WP to WP $K_{LWP} = A_{ysc} \cdot E/L_{WP}$	K_{LWP}:	335 k/in	*(59 kN/mm)*
Stiffness Modification Factor $K_f = K_{eff}/K_{LWP}$	K_f:	1.83	

Length Verification

$$\frac{L_{ysc} + L_{eT} + L_{tT} + L_{cT} + L_{cst}}{L_{WP}} = 1.00$$ *Should be 1.0 if all regions are accounted for.*

COREBRACE STIFFNESS CALCULATIONS

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

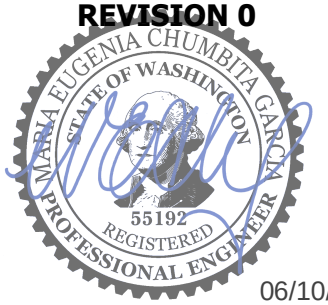
										Core Stiffness		End Stiffness		Connection Stiffness			Transition Stiff		Cntr Stfnr Stff				SMF
EOR-ID	Line	Grids	Lvls	Mark	Qty	L_{wp}	L_g	β	ω	A_{sc}	L'_{ysc}	A_e	L_e	A_{CONN}	A_{conn}	L_{conn}	A_t	L_{tT}	$A_{sc+2cst}$	L_{cst}	K_{Eff}	K_{LWP}	K_{Eff}
#		#	#	#	#	in	in			in^2	in	in^2	in	Ae	in^2	in	in^2	in	in^2	in	k/in	k/in	K_{LWP}
BRB-2.00	4.1	D.3 to D(+)	Low Roof	1901	1	173.31	109.62	1.17	1.38	2.00	74.46	5.11	14.13	3.0	15.32	71	0.00	0.00	2.00	0.00	612	335	1.83
BRB-2.00	4.1	D(+) to C.6	Low Roof	1901	1	173.31	109.62	1.17	1.38	2.00	74.46	5.11	14.13	3.0	15.32	71	0.00	0.00	2.00	0.00	612	335	1.83
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	246.48	217.62	1.11	1.33	2.00	182.46	5.11	14.13	3.0	15.32	36	0.00	0.00	2.00	0.00	293	235	1.24
BRB-2.00	4.1	D(+) to C.6	1	1902	1	246.48	217.62	1.11	1.33	2.00	182.46	5.11	14.13	3.0	15.32	36	0.00	0.00	2.00	0.00	293	235	1.24
BRB-2.00	5	E to D.5	1	1903	1	296.91	265.73	1.11	1.31	2.00	230.57	5.11	14.13	3.0	15.32	38	0.00	0.00	2.00	0.00	235	195	1.20
BRB-2.00	C	2.8 to 3(+)	Low Roof	1904	1	189.30	107.24	1.16	1.37	2.00	72.24	5.67	14.06	3.0	17.00	89	0.00	0.00	2.00	0.00	626	306	2.04
BRB-2.00	C	3(+) to 3.2	Low Roof	1904	1	189.30	107.24	1.16	1.37	2.00	72.24	5.67	14.06	3.0	17.00	89	0.00	0.00	2.00	0.00	626	306	2.04
BRB-2.00	C	2.8 to 3(+)	1	1905	1	265.47	235.63	1.11	1.33	2.00	200.47	5.11	14.13	3.0	15.32	37	0.00	0.00	2.00	0.00	268	218	1.23
BRB-2.00	C	3(+) to 3.2	1	1905	1	265.47	235.63	1.11	1.33	2.00	200.47	5.11	14.13	3.0	15.32	37	0.00	0.00	2.00	0.00	268	218	1.23
BRB-2.00	C.2	3.3 to 3.7	Low Roof	1906	1	242.64	145.52	1.11	1.31	2.00	110.52	5.67	14.06	3.0	17.00	104	0.00	0.00	2.00	0.00	437	239	1.83
BRB-2.00	C.2	3.7 to 4.1	Low Roof	1907	1	245.43	154.09	1.11	1.31	2.00	119.09	5.67	14.06	3.0	17.00	98	0.00	0.00	2.00	0.00	413	236	1.75
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	310.24	277.52	1.11	1.32	2.00	242.36	5.11	14.13	3.0	15.32	40	0.00	0.00	2.00	0.00	224	187	1.20
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	310.24	277.52	1.11	1.32	2.00	242.36	5.11	14.13	3.0	15.32	40	0.00	0.00	2.00	0.00	224	187	1.20
BRB-2.00	E	4.7 to 5	1	1909	1	305.05	278.18	1.11	1.31	2.00	243.02	5.11	14.13	3.0	15.32	34	0.00	0.00	2.00	0.00	224	190	1.18
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	181.06	130.53	1.12	1.34	2.00	95.38	5.11	14.13	3.0	15.32	57	0.00	0.00	2.00	0.00	509	320	1.59
BRB-3.00	E	4.1 to 3.8	1	1911	1	256.62	225.02	1.17	1.23	3.00	184.96	6.67	14.83	3.0	20.00	42	0.00	0.00	3.00	0.00	425	339	1.25
BRB-2.00	4	A.8 to A.99	1	1912	1	238.68	211.47	1.11	1.32	2.00	176.31	5.11	14.13	3.0	15.32	34	0.00	0.00	2.00	0.00	302	243	1.24
BRB-2.00	B	5 to 4.7	1	1913	1	284.61	258.06	1.11	1.32	2.00	222.90	5.11	14.13	3.0	15.32	33	0.00	0.00	2.00	0.00	243	204	1.19
BRB-2.00	B	4.7 to 4.4	1	1914	1	284.61	258.79	1.11	1.32	2.00	223.63	5.11	14.13	3.0	15.32	33	0.00	0.00	2.00	0.00	243	204	1.19
BRB-2.00	2	D to C.6	Low Roof	1915	1	259.13	165.25	1.11	1.31	2.00	130.25	5.67	14.06	3.0	17.00	101	0.00	0.00	2.00	0.00	382	224	1.70
BRB-3.00	2	D to C.6	1	1916	1	318.70	273.02	1.17	1.22	3.00	232.96	6.67	14.83	3.0	20.00	56	0.00	0.00	3.00	0.00	342	273	1.25
BRB-2.00	3.2	D to C.6	Low Roof	1917	1	242.71	127.21	1.11	1.31	2.00	92.21	5.67	14.06	3.0	17.00	122	0.00	0.00	2.00	0.00	498	239	2.08
BRB-2.00	3.2	C.6 to C.2	Low Roof	1917	1	242.71	127.21	1.11	1.31	2.00	92.21	5.67	14.06	3.0	17.00	122	0.00	0.00	2.00	0.00	498	239	2.08
BRB-2.00	3.2	D to C.6	1	1918	1	309.76	278.02	1.11	1.32	2.00	242.86	5.11	14.13	3.0	15.32	39	0.00	0.00	2.00	0.00	224	187	1.20
BRB-2.00	3.2	C.6 to C.2	1	1919	1	309.76	278.98	1.11	1.32	2.00	243.82	5.11	14.13	3.0	15.32	38	0.00	0.00	2.00	0.00	223	187	1.19
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	275.34	204.03	1.11	1.31	2.00	168.87	5.11	14.13	3.0	15.32	78	0.00	0.00	2.00	0.00	305	211	1.45
BRB-2.50	2	A.2 to A	1	1921	1	369.86	336.90	1.11	1.31	2.50	298.00	5.70	14.25	3.0	17.10	43	0.00	0.00	2.50	0.00	229	196	1.17
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	250.78	161.54	1.11	1.31	2.50	122.90	6.25	14.12	3.0	18.74	100	0.00	0.00	2.50	0.00	492	289	1.70
BRB-3.50	A	3 to 2.7	1	1923	1	308.32	263.02	1.17	1.23	3.50	221.48	7.76	15.57	3.0	23.28	56	0.00	0.00	3.50	0.00	416	329	1.26
BRB-2.00	3	A.2 to A	Low Roof	1924	1	252.37	149.45	1.11	1.33	2.00	112.80	5.11	14.88	3.0	15.32	110	0.00	0.00	2.00	0.00	418	230	1.82
BRB-2.00	3	A.2 to A	1	1925	1	310.50	270.52	1.11	1.32	2.00	235.36	5.11	14.13	3.0	15.32	47	0.00	0.00	2.00	0.00	230	187	1.23

Table of Symbols

L_{wp} = Length between W.P.s at top and bottom of CB
L_g = Length between tips of gussets
β = Compression strength adjustment factor
ω = Tension strength adjustment factor
A_{cst} = Area of center stiffener
L_{ysc} = Length of yielding core w/out allowance for Cntr Stiffener
A_{sc} = Area of core plates at yielding section
L_e = Length at end stiffener
A_e = Area at end stiffener
L_{CONN} = Length at end connection
A_{CONN} = Area at end connection
L_{tT} = Transition length of both ends combined
L_{cst} = Length of center stiffeners
A_{cst} = Area of center stiffener at center
K_{LWP} = Theoretical CB stiffness from WP to WP
K_{Eff} = CB stiffness from WP to WP incl transitions & connection regions

PSE Operational Training Center
CALCULATIONS
SUBMITTAL

REVISION 0



06/10/2024

May 29, 2024

CoreBrace Project #5872

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

www.CoreBrace.com

PSE Operational Training Center

Calculation Submittal Package

Description

Section 1 Strain, β, and ω Determination and Summary Tables

Section 2 Buckling Calculation and Summary Tables

Section 3 Brace End Connection Sample Calculation and Summary Tables

Section 4 Bottom Gusset Beam to Column Flange (Strong-Axis) Connection Sample Calculation and Summary Tables

Section 5 Not Used

Section 6 Chevron Gusset Connection Sample Calculation and Summary Tables

Section 7 Stiffness Sample Calculation and Summary Tables

PSE Operational Training Center

Calculation Submittal Package

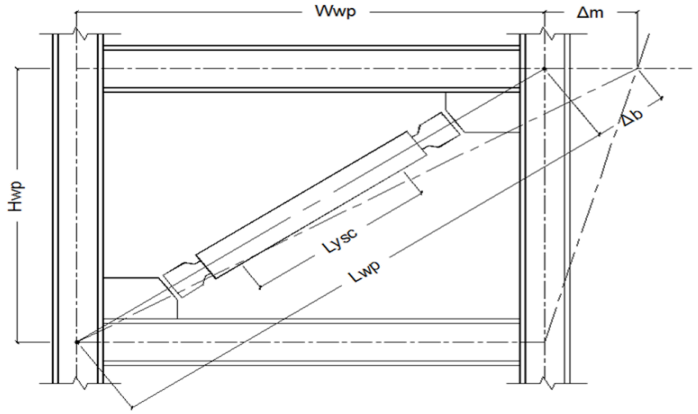
Description

Section 1. Strain, β, and ω Determination and Submittal Tables

Strain and Overstrength Calculation

Example Mark #: 1901

Line 4.1, Grid D.3 to D(+), Level Low Roof



1.0 DESIGN CRITERIA

Width Between Workpoints	W_{wp}:	153.88 in	*(3908 mm)*
Height Between Workpoints	H_{wp}:	79.75 in	*(2026 mm)*
Yielding Core Length	L_{ysc}:	74.46 in	*(1891 mm)*
Workpoint Length Along Diagonal $L_{wp} = \sqrt{(W_{wp}^2+H_{wp}^2)}$	L_{wp}:	173.31 in	*(4402 mm)*
Yield Stress of Core Material for Establishing Area	$F_{y\text{-}min}$:	38 ksi	*(262 MPa)*
Maximum Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Modulus of Elasticity	E:	29000 ksi	*(199955 MPa)*
LRFD Resistance Factor	ϕ_{BRB}:	0.90	
Deflection Amplification Factor	C_d:	5.00	
Demand Capacity Ratio	DCR:	1.00	
Importance Factor	I_E:	1.00	
Redundancy Factor	ρ:	1.00	
Specified Story Drift to Consider (Typically 1.0% Minimum unless NLRHA) *The displacements and strains assocaited with this value will later be multiplied by 2, so 2% minimum is typically being considered.*	SSD:	1.00%	
Area of Yielding Steel Core	A_{sc}:	2.00 in²	*(1290 mm²)*

1.1 STRAIN CALCULATION

Minimum Yield Force in Steel Core $(F_{y\text{-}min}\cdot A_{sc})$	$P_{ysc,min}$:	76 kip	*(338 kN)*
Maximum yield Force in Steel Core $(F_{y\text{-}max}\cdot A_{sc})$	$P_{ysc,max}$:	92 kip	*(409 kN)*
Final Width Between Workpoints after Specified Story Drift			
$W_f = W_{wp}+(SSD\cdot H_{wp})$	W_f:	154.67 in	*(3929 mm)*
$\Delta_{mSSD} = W_f - W_{wp}$ (for reference only)	Δ_{mSSD}:	0.80 in	*(20 mm)*
Final WP Length Along Diagonal After Specified Story Drift			
$L_f = \sqrt{(W_f^2+H_{wp}^2)}$	L_f:	174.02 in	*(4420 mm)*
Yielding Core Elongation at Specified Story Drift $(L_f - L_{wp})$	Δ_{bSSD}:	0.71 in	*(18 mm)*
Core Strain at Considered Story Drift (Δ_{bSSD}/L_{ysc})	ε_{bSSD}:	0.95%	
Core Strain at Design Story Drift (Cd*Yield Strain)			
Force for Elastic Drift Determination $P_d=\phi P_{ysc,min}/(\rho\cdot I)\cdot DCR$	P_d:	68 kip	*(304 kN)*
Stiffness of Yeilding Core $K_{Lysc}=A_{sc}\cdot E/L_{ysc}$	K_{Lysc}:	779 k/in	*(136 kN/mm)*
Core Deformation at Yield $\Delta_{by}=P_d/K_{Lysc}$	Δ_{by}:	0.09 in	*(2 mm)*
Core Deformation at Design Story Drift $\Delta_{bCd}=\Delta_{by}\cdot C_d$	Δ_{bCd}:	0.44 in	*(11 mm)*
Core Strain at Design Story Drift $\varepsilon_{bCd} = \Delta_{bCd}/L_{ysc}$	ε_{bCd}:	0.59%	
Note, identical results are found by calculating the strain with the following equation, $\varepsilon_{bCd} = \phi\cdot C_d\cdot(F_y/E)\cdot DCR/(I_E\cdot\rho)$, and then backing out the deformation, $\Delta_{bCd} = \varepsilon_{bCd}\cdot L_{ysc}$			
$\Delta_{mCd} = \Delta_{bCd}/COS(TAN^{-1}(H_{wp}/W_{wp}))$ (for reference only)	Δ_{mCd}:	0.49 in	*(13 mm)*
Required Stroke at Each End of Brace (½ of 2x Max of Δ_{bCd} & Δ_{bSSD})	$c_{req'd}$:	0.71 in	*(18 mm)*
Provided Stroke Distance at Each End of Brace	c:	3.00 in	*(76 mm)*
Controlling Strain (Max of ε_{bSSD} & ε_{bCd})	$\varepsilon_{b,max}$:	0.95%	
Strain at $2*\varepsilon_{b,max}$	ε_{max}:	1.90%	

1.2 DETERMINE OVERSTRENGTH FACTORS AT ε_{max} - SEE BACKBONE CURVES

Qualifying Similarity Test per AISC 341 K3.3	Similarity (K3.3) Test:	10P	
Yield Force of Test Specimen	P_y:	86 kip	*(382 kN)*
Test Extrapolation Range Downward per AISC 341-16	Extrapolation Downward	83%	
Minimum Qualified Yield Force	$P_{y,min}$:	72 kip	*(318 kN)*
Test Extrapolation Range Upward per AISC 341-16	Extrapolation Upward	333%	
Maximum Qualified Yield Force	$P_{y,max}$:	286 kip	*(1273 kN)*
Compression Strength Adjustment Factor at ε_{max}	$\beta_{K3.3}$	1.17	
Strain Hardening Adjustment Factor at ε_{max}	$\omega_{K3.3}$	1.38	
Qualifying Sub-Assemblage Test per AISC 341 K3.2	Subassemblage (K3.2) Test	3P	
Yield Force of Test Brace	P_y:	376 kip	*(1673 kN)*
Compression Strength Adjustment Factor at ε_{max}	$\beta_{K3.2}$	1.13	
Strain Hardening Adjustment Factor at ε_{max}	$\omega_{K3.2}$	1.32	
Maximum Compression strength adjustment factor at ε_{max}	β_{max}	1.17	
Maximum Strain hardening adjustment factor at ε_{max}	ω_{max}	1.38	

These values may be increased for length effects where applicable. Design values may be larger.

Adjusted Brace Strength in Compression: $ABS_T = A_{sc} \cdot F_{y\text{-}max} \cdot \omega = P_{ysc,max} \cdot \omega$	**P_{uT}:**	**127 kip**	*(564 kN)*
Adjusted Brace Strength in Compression: $ABS_C = A_{sc} \cdot F_{y\text{-}max} \cdot \beta \cdot \omega = P_{ysc,max} \cdot \beta \cdot \omega$	**P_{uC}:**	**148 kip**	*(658 kN)*

1.3 BRACE ROTATIONAL DEMAND

2x Story Drift Rotation = $2*MAX(\Delta_{m1\%}, \Delta_{mCd})/H_{wp}$

$\delta = 2*MAX(\Delta_{m1\%}, \Delta_{mCd})/H_{wp}$ Equal to Assumed (Conservative) Translational Demand	δ:	0.02 rad	

Assumed story drift rotation is considered conservative based on the following:

$\Delta_m = \delta \cdot H$ *Maximum Story Drift for Project*	Δ_m:	1.60 in	*(41 mm)*

$\Delta_t \le \Delta_m$ $\delta_t = \Delta_t / L_{wp}$ *Where Δ_t is the translation of the brace/beam joint and L_{wp} is the length of the brace*

$L_b \ge H$ *Where H is the story height*

$\Delta_m/H = \delta \cdot H/H = \delta =$ 0.02 rad

Since $\Delta_t \le \Delta_m$ and $L_b \ge H$ Then: $\Delta_t/L_b \le \Delta_m/H \rightarrow \delta_t \le \delta$

$\theta_{CB} = \tan^{-1}(H_{wp}/W_{wp})$ *Angle between Horiz and BRB before rotation*	θ_{CB}:	0.478 rad	
$\Delta_t = \Delta_m \cdot \sin(\Theta_{CB})$	Δ_t:	0.73 in	*(19 mm)*
$\delta_t = \Delta_t / L_{wp}$	δ_t:	0.004 rad	

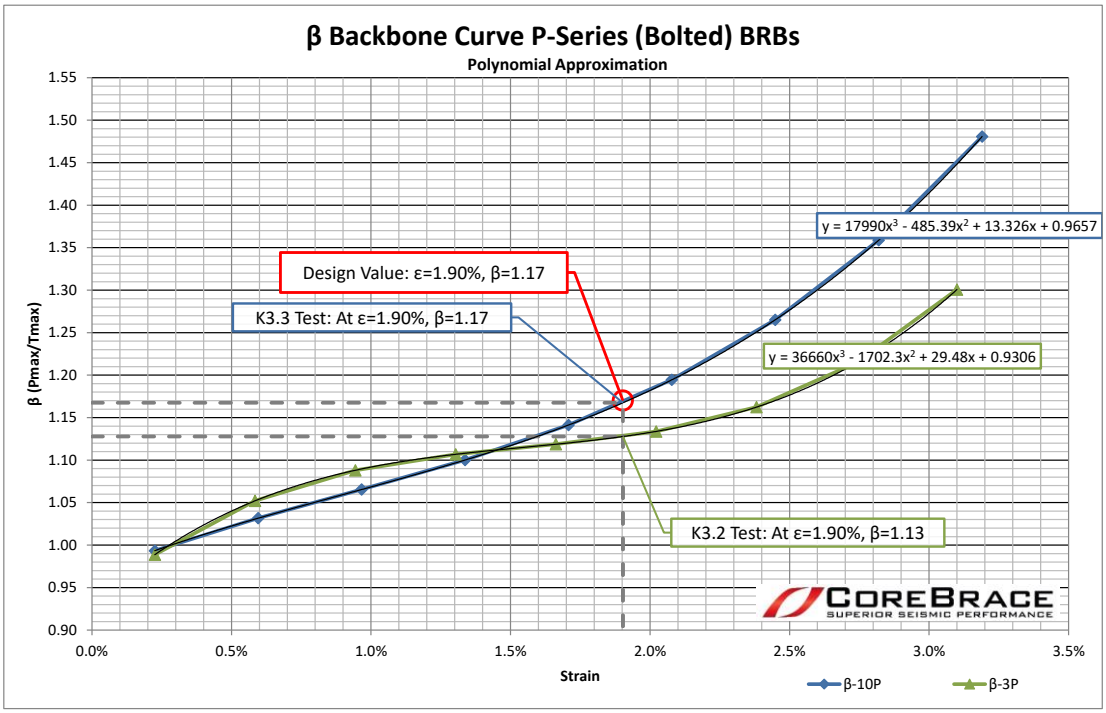
Alternate Method:

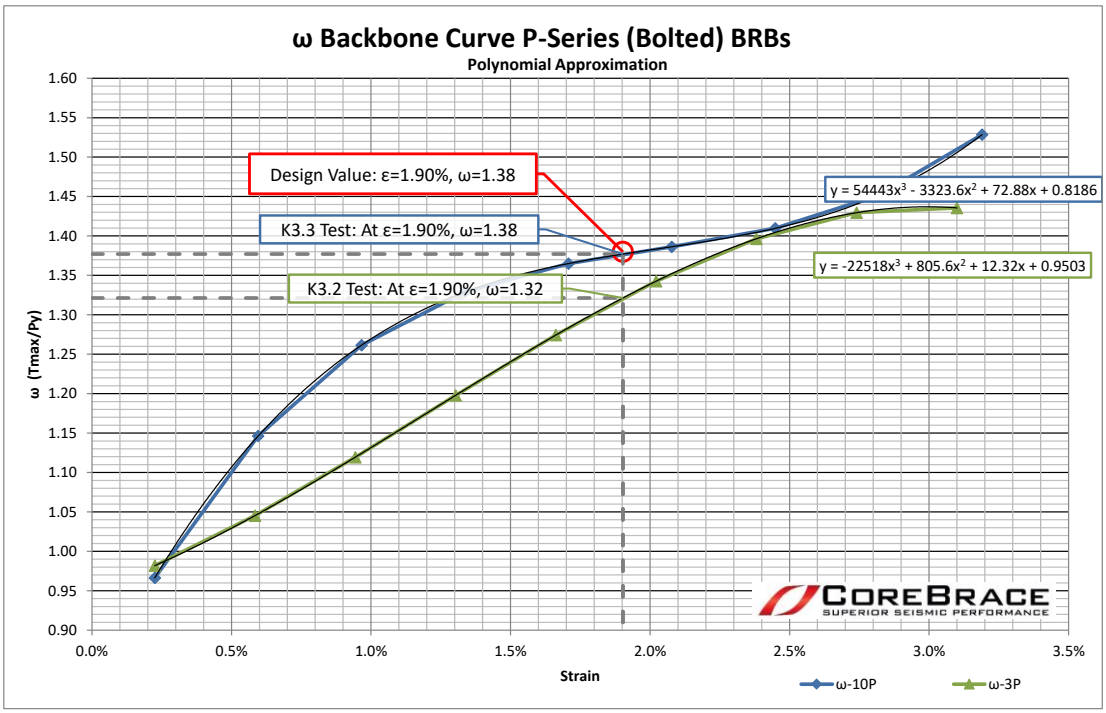
$\theta'_{CB} = \tan^{-1}(H_{wp}/(W_{wp}+\Delta_m))$ *Angle between Horiz and BRB after rotation*	θ_{CB}:	0.474 rad	
$\delta_{t\text{-}alt} = \theta_{CB} - \theta'_{CB}$	δ_t:	0.004 rad	

Therefore 0.02 Radians is Conservative

Tested Capacity from Test Report Must Equal 0.004 Radians. -- CoreBrace OK

1.4 BACKBONE CURVES





COREBRACE STRAIN CALCULATIONS

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

| | | |

PSE Operational Training Center

Calculation Submittal Package

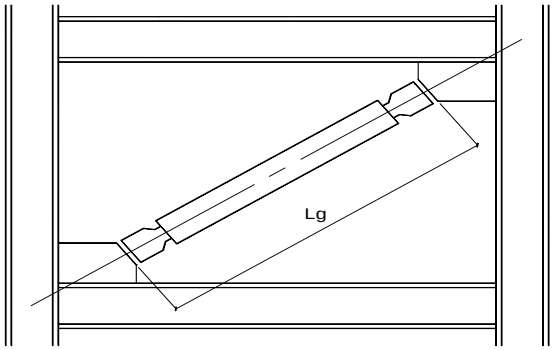
Description

Section 2. **Casing Buckling Calculations**
Casing Buckling Summary Tables

Buckling Calculation

Example Mark #: 1901

Line 4.1, Grid D.3 to D(+), Level Low Roof



2.0 DESIGN CRITERIA

Tip of gusset to tip of gusset is set as buckling length	L_g:	109.62 in	*(2784 mm)*
Compresssion Strength Adjustment Factor	β:	1.17	
Strain Hardening Adjustment Factor	ω:	1.38	
Upper Bound Yield Strength of Brace (A_{sc}·$F_{y\text{-}max}$)	$P_{ysc\text{-}max}$:	92.0 kip	*(409 kN)*
Upper Bound Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Area of Steel Core	A_{sc}:	2.00 in²	*(1290 mm²)*
Ultimate Load (Adjusted Brace Strength in Compression): P_u = ($P_{ysc\text{-}max}$·β·ω) = ABS_C	P_u:	148.5 kip	*(661 kN)*
Modulus of Elasticity	E:	29000 ksi	*(199955 MPa)*
Model Brace as Pinned Both Ends (conservative)	k:	1.0	
Casing Moment of Inertia **t7x1/4**	I_c:	46.5 in⁴	*(1935 cm⁴)*

2.1 Euler Buckling

Solving Euler's buckling equation for required moment of inertia:

$$I_{Ig} = \frac{FS_B \cdot P_u \cdot \left(k \cdot L_g\right)^2}{\pi^2 E}$$

	I_{Ig}:	7.9 in⁴	*(329 cm⁴)*

Where:

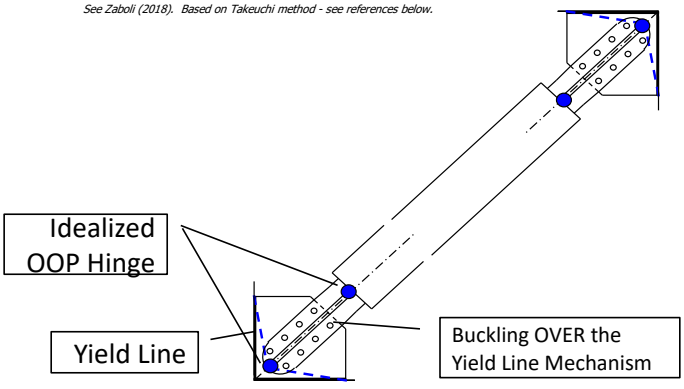
FS_B = Factor of Safety Against Buckling: FS_B: 1.27

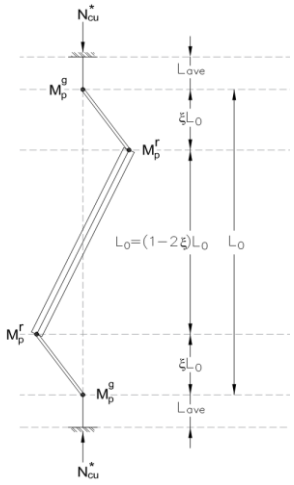
Verified by Testing

Unity Check:	I'_g/I_c:	0.17	**OK**

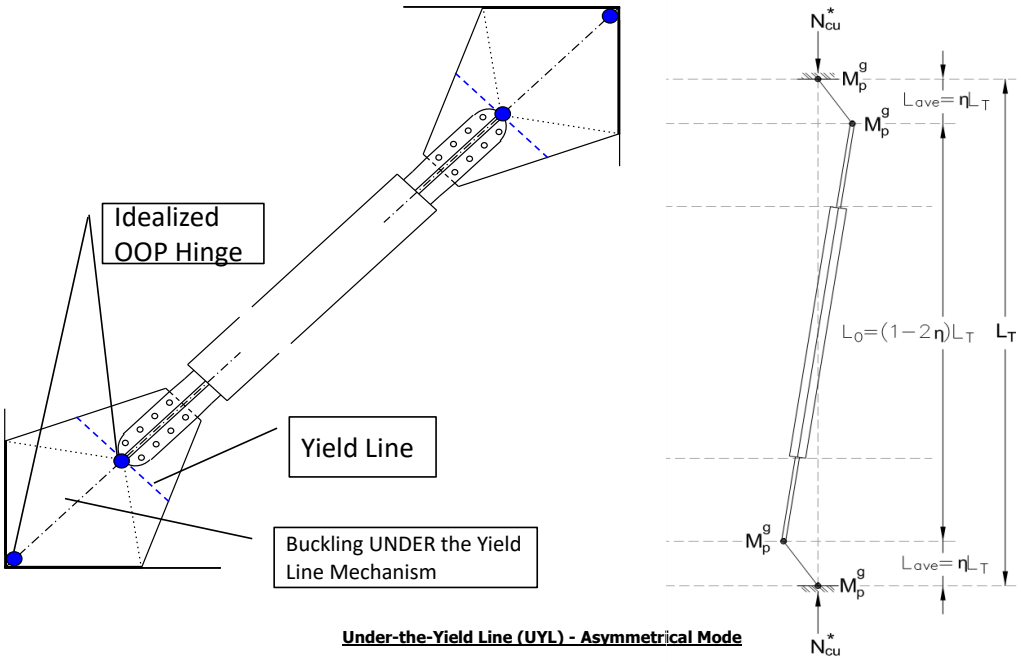
2.2 Global Stability (Notional Load Yield Line Method) - Asymmetrical Modes

See Zaboli (2018). Based on Takeuchi method - see references below.





Over-the-Yield Line (OYL) - Asymmetrical Mode

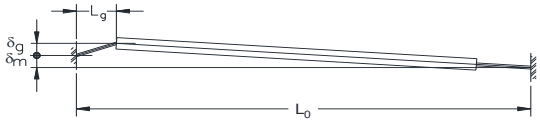


Under-the-Yield Line (UYL) - Asymmetrical Mode

2.2.1 NLYL Method Design Criteria

Overall Brace Length	L_0:	114.48 in	*(2908 mm)*
Additional Out-of-Plane Force on BRB *(half assumed to go to each end)*:	$F_{Add'l\text{-}OOP}$	0.0 kip	*(0 kN)*
Initial Imperfection of Neck Insertion Zone	θ_0:	0.007 rad	
Assumed Out-of-Plumbness of Brace: $\delta_m/L_0 = 1/x_{\delta m}$	$x_{\delta m}$:	500	
Assumed Out-of-Flatness of Gusset Plate: $\delta_g/L_g = 1/x_{\delta g}$	$x_{\delta g}$:	100	

Values of $x_{\delta m}$ and $x_{\delta g}$ per Dowswell (2016) recommendations. Imperfection of Neck per Takeuchi (2014).



Initial Imperfection per Dowswell (2016)

Critical Gusset Dimensions: Top Gusset

Top Gusset is Chev?		$Chev_{Top}$:	FALSE	
Top Gusset is Stiffened?		$Stiff_{Top}$:	FALSE	
Is gusset stiffened sufficiently for Kb to be reduced? Can be "FALSE" even if stiffeners are present.				
Stiffener Width		$W_{stiff,top}$:	-	-
Stiffener Thickness		$t_{stiff,top}$:	-	-
Gusset Thickness		$t_{g,top}$:	0.63 in	*(16 mm)*
Projected Stiffener Plastic Section Modulus *(Proj per Dowswell. All stiff's combined.)*		$Z_{stiff,top}$:	-	-
Yield Strength of Gusset Material		$F_{yg,top}$:	50 ksi	*(345 MPa)*
Ultimate Strength of Gusset Material		$F_{ug,top}$:	65 ksi	*(448 MPa)*
Length from WL Intersection w/Beam or Col along WL to Tip of Brace		a_{top}:	6.71 in	*(170 mm)*
Clear from Col to Lug Edge		b_{top}:	17.54 in	*(446 mm)*
Clear from Beam to Lug Edge		c_{top}:	1.00 in	*(25 mm)*
Controlling Bendline Length, Gusset Edge to Brace Tip:	Bm Side	$L_{b,top}$:	8.38 in	*(213 mm)*
	Col Side	$L_{c,top}$:	7.57 in	*(192 mm)*

Critical Gusset Dimensions: Bottom Gusset

Bottom Gusset is Chev?		V_{Bot}:	TRUE	
Bottom Gusset is Stiffened?		$Stiff_{Bot}$:	FALSE	
Is gusset stiffened sufficiently for Kb to be reduced? Can be "FALSE" even if stiffeners are present.				
Stiffener Width		$W_{stiff,bot}$:	-	-
Stiffener Thickness		$t_{stiff,bot}$:	-	-
Gusset Thickness		$t_{g,bot}$:	0.63 in	*(16 mm)*
Projected Stiffener Plastic Section Modulus *(Proj per Dowswell. All stiff's combined.)*		$Z_{stiff,bot}$:	-	-
Yield Strength of Gusset Material		$F_{yg,bot}$:	50 ksi	*(345 MPa)*
Ultimate Strength of Gusset Material		$F_{ug,bot}$:	65 ksi	*(448 MPa)*
Length from WL Intersection w/Beam or Col along WL to Tip of Brace		a_{bot}:	16.49 in	*(419 mm)*
Clear from Col to Lug Edge		b_{bot}:	28.97 in	*(736 mm)*
Clear from Beam to Lug Edge		c_{bot}:	5.50 in	*(140 mm)*
Controlling Bendline Length, Gusset Edge to Brace Tip:	Bm Side	$L_{b,bot}$:	10.68 in	*(271 mm)*
	Col Side	$L_{c,bot}$:	7.57 in	*(192 mm)*

Core Dimensions and Properties

Ultimate Stress of Core Material	F_{usc}:	66 ksi	*(455 MPa)*
Core Width at Neck Section	W_t:	4.00 in	*(102 mm)*
Core Thickness	t_{sc}:	0.50 in	*(13 mm)*
Neck Insertion Length for Out-of-Plane Buckling Direction	L_{in}:	7.13 in	*(181 mm)*

Note that L_{in}/W_t = Embedment Ratio = 1.78

Lug and Bolt Pattern Dimensions			
Width of Lug Plate	W_L:	6.00 in	*(152 mm)*
Width of Lug at Neck Section	W_1:	3.61 in	*(92 mm)*
Length of Lug on Gusset Measured to Square Projection	L'_{Lg}:	5.88 in	*(149 mm)*
Transition Length, W_L to W_1	a:	4.00 in	*(102 mm)*
Stroke Length, End of Transition to Casing	c:	3.00 in	*(76 mm)*
Lug Thickness	t_L:	0.50 in	*(13 mm)*
Yield Strength of Lug Material	F_{yL}:	50 ksi	*(345 MPa)*
Ultimate Strength of Lug Material	F_{uL}:	65 ksi	*(448 MPa)*
Number of Bolts in Inner Row Along Brace Axis	n_i:	2	
Number of Bolts in Outer Row Along Brace Axis	n_o:	0	
Bolt Spacing	s:	3.50 in	*(89 mm)*
Plate Edge to CL of Bolt	e_{perp}:	1.19 in	*(30 mm)*
Restrainer (Casing) Size and Properties			
Restrainer Section Name	Section:	t7x1/4	
Yield Stress of Casing Material	F_{yc}:	46 ksi	*(317 MPa)*
Youngs Modulus of Casing Material	E_c:	29000 ksi	*(199955 MPa)*
Casing is Square/Rectangular?	Sq_{Cas}:	TRUE	
Casing Height (Dimension Viewed in Elevation)	H_c:	7.00 in	*(178 mm)*
Casing Width (Dimension Viewed in Plan & Overall Dimension for p Sections)	W_c:	7.00 in	*(178 mm)*
Casing Thickness	t_c:	0.25 in	*(6 mm)*
Factor on Adjusted Brace Strength	F_{PU}:	1.0	
Capacity Reduction Factor, ϕ_{NLYL}	ϕ_{NLYL}:	1.0	
Equal to 1.0 per Takeuchi (2014). Lower values can be used.			
Zaboli (2018) is even more conservative than Takeuchi even with ϕ = 1.0.			

2.2.2 NLYL Global Stability Method

Overstrength Compression Force in the Core of the BRB: $N^*_{cu} = F_{Pu} \cdot P_u$	N^*_{cu}:	**148.5 kip**	*(661 kN)*
NLYL Method Uses: N^*_{cu} = Overstrength Compression Capacity of the BRB. This requires an iterative solution.			
The variant used here checks demand vs capacity based on applied load (Pu).			
Length from End of Casing to Yield Line at Tip of Brace: $\xi L_0 = a+c+L'_{LG}$	ξL_0:	12.88 in	*(327 mm)*
$\xi = \xi L_0 / L_0$	ξ:	0.112	
Effective Length Factor for Brace including Gusset Stiffness Effect: k_b	k_b:	1.00	
If $Stiff_{Top}$ AND $Stiff_{Bot}$ = TRUE, k_b = 0.7			
If $Stiff_{Top}$ AND $Stiff_{Bot}$ = FALSE, k_b = 1.0			
If $Stiff_{Top}$ OR $Stiff_{Bot}$ = FALSE, k_b = 0.85			
Stiffened Gusset Factor, λ = 1.19 for Stiffened Gusset or 1.0 for Unstiffened Gusset	λ_{top}:	1.00	
	λ_{bot}:	1.00	
Global Elastic Buckling Capacity of BRB, Incl Effect of Gusset PL: $N^B_{cr} = \pi^2 \cdot EI_c / (k_b \cdot L_0)^2$	N^B_{cr}:	**1015.6 kip**	*(4518 kN)*
Effective Width in Compression: $b_{qa} = 2 \cdot L_{Br} \cdot \tan(\theta_{disp}) + (W_L - 2 \cdot e_{perp})$			
Lug Lap on Gusset: $L_{Br} = IF(n_i > n_o, (n_i - 1) \cdot s, (n_o - 0.5) \cdot s)$	L_{Br}:	3.50 in	*(89 mm)*
Dispersion Angle at Top Gusset	$\theta_{disp,top}$:	40.0°	
Dispersion Angle at Bottom Gusset	$\theta_{disp,bot}$:	30.0°	
Dispersion angle based on 30° for V or Chev, 40° otherwise per NLYL Methodology.			
Effective Compression Width, Top Gusset	$b_{qa,top}$:	9.50 in	*(241 mm)*
Effective Compression Width, Bottom Gusset	$b_{ga,bot}$:	7.67 in	*(195 mm)*
Average Gusset Buckling Length: L_{ave} = min[(a+min(b,c))/2, (a+b+c)/3]	$L_{ave,top}$:	3.85 in	*(98 mm)*
See Dowswell (2006) and Zaboli (2018)	$L_{ave,bot}$:	10.99 in	*(279 mm)*
Nominal Axial Capacity of Gusset Plate: $N^g_s = b_{qa} \cdot t_q \cdot F_{yq}$	$N^g_{s,top}$:	**296.8 kip**	*(1320 kN)*
	$N^g_{s,bot}$:	**239.6 kip**	*(1066 kN)*
Euler Buckling Capacity of Gusset Plate: $N_e = \pi^2 \cdot E \cdot (b_{qa} \cdot t_q^3 / 12) / L_{ave}^2$	$N_{e,top}$:	**3723.4 kip**	*(16562 kN)*
	$N_{e,bot}$:	**369.4 kip**	*(1643 kN)*
Plastic Moment Capacity of Gusset Plates			
Total Bendline Length: $b_{qf} = L_b + L_c$	$b_{qf,top}$:	15.95 in	*(405 mm)*
	$b_{qf,bot}$:	18.25 in	*(464 mm)*
Plastic Section Modulus: $Z_g = b_{gf} \cdot t_g^2/4 + Z_{stiff}$	$Z_{g,top}$:	1.56 in³	*(25524 mm³)*
	$Z_{q,bot}$:	1.78 in³	*(29205 mm³)*
Plastic Moment Capacity: $M^g_{zy} = Z_g \cdot F_{yg}$	$M^g_{zy,top}$:	**78 k-in**	*(8.8 kN-m)*
	$M^g_{zy,bot}$:	**89 k-in**	*(10.1 kN-m)*
Reduced Plastic Moment Capacity of Gusset Plate Including Axial Force Effect:	**$M^g_{p,top}$:**	**58 k-in**	*(6.6 kN-m)*
$M^g_p = \lambda \cdot \phi_{NLYL} \cdot M^g_{zy} [1 - (N^*cu / (\phi_{NLYL} \cdot N^g_s))^2] \geq 0$	**$M^g_{p,bot}$:**	**55 k-in**	*(6.2 kN-m)*

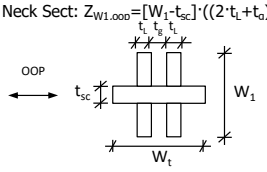
Axial Yield Strength of Neck at Web Zone: $N^n_{wy}=2\cdot(W_1-t_{sc})\cdot t_L\cdot F_{y,L}$ — N^n_{wy}: 155.3 kip *(691 kN)*

Axial Yield Strength of Neck: $N^n_y=W_t\cdot t_{sc}\cdot F_{ymax}+2\cdot(W_1-t_{sc})\cdot t_L\cdot F_{y,L}$ — N^n_y: 247.3 kip *(1100 kN)*

Axial Ultimate Strength of Neck: $N^n_v=W_t\cdot t_{sc}\cdot F_{u.sc}+2\cdot(W_1-t_{sc})\cdot t_L\cdot F_{u.L}$ — N^n_u: 333.9 kip *(1485 kN)*

OOP Plastic Section Modulus of Steel Core (W_t) at Neck Section: $Z_{Wt.oop}=t_{sc}\cdot W_t^2/4$ — $Z_{Wt,oop}$: 2.0 in³ *(32774 mm³)*

OOP Plastic Section Modulus of Lugs (W_1) at Neck Sect: $Z_{W1.oop}=[W_1-t_{sc}]\cdot((2\cdot t_L+t_q)^2-t_q^2)/$ — $Z_{W1,oop}$: 1.7 in³ *(28633 mm³)*



Section at Neck

Out-of-Plane Plastic Moment Capacity of Neck: $M^n_{zv}=Z_{WT.oop}\cdot F_{vmax}+Z_{W1.oop}\cdot F_{v.L}$ — M^n_{zv}: **179 k-in** *(20.3 kN-m)*

Reduced Restrainer Moment Transfer Capacity Determined by Neck + Core Plate, Including Axial Force Effect. — $M_D^{r-neck,top}$: 179.4 k-in *(20.3 kN-m)*; $M_D^{r-neck,bot}$: 179.4 k-in *(20.3 kN-m)*

$M_D^{r-neck}=\phi_{NLYL}\cdot M^n_{zv}\cdot[1-(MAX(N^*_{cu}-N^n_{wv},0)/(\phi_{NLYL}\cdot(N^n_u-N^n_{wv})))^n]$

Exponent, n = 2.0 Use N^n_y if Gst is Not Stiffened? FALSE

Per Takeuchi (2014), N^n_u is used in the denominator. Other methods use N^n_y in the denominator if the gusset is unstiffened.

Plastic Section Modulus of Restrainer, Z_{rp} — Z_{rp}: 17.1 in³ *(280116 mm³)*

Square / Rectangular Section: $Z_{rp}=H_c\cdot W_c^2/4-(H_c-2\cdot t_c)\cdot(W_c-2\cdot t_c)^2/4$

Round Casing Section: $Z_{rp}=W_c^3/6-(W_c-2\cdot t_c)^3/6$

Nominal Plastic Moment Capacity of Restrainer: $M^r_{zv}=Z_{rp}\cdot F_{yc}$ — M^r_{zy}: 786 k-in *(88.8 kN-m)*

Embed Length Calibration Factor: $\alpha^r_p=4.15-1.5\cdot(L_{in}/W_t)=4.15-1.5\cdot L_{in}/W_t\geq 1.5$ — α^r_p: 1.83

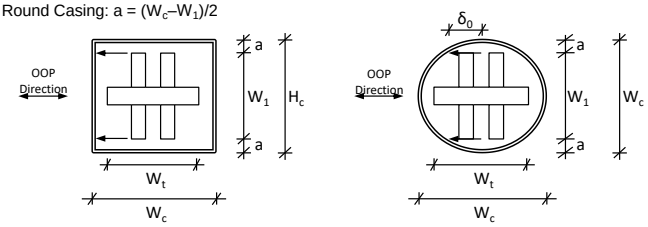
See Takeuchi (2014). While this increases as embedment ratio (L_{in}/W_t) decreases, the net effect of a decreasing embedment ratio decreases M_p^{r-rest}, and this factor only slows the decrease.

Distance between the shear force application point and the outer surface of the restraint tube, a

See Matsui (2010) for calculation of square and round restrainer properties.

Sq/Rect Casing: $a=(H_c-W_1)/2$ — a: 1.70 in *(43 mm)*

Round Casing: $a=(W_c-W_1)/2$



Square Restrainer Round Restrainer

Distance between the Core Plate Surface and the Shear Force Application Point when the Shear Force is not Present, δ_0. Not Applicable to Square/Rect Restrainers.

See Matsui (2010) and Takeuchi (2017). Eqn from Takeuchi (2017) Ch 4

$\delta_0=W_c/2\cdot\sin[\cos^{-1}((W_c-2\cdot a)/(W_c-2\cdot t_c))]$ — δ_0: 2.91 in *(74 mm)*

The Lateral Deflection of the Restraint Tube at the In-Plane Stress Yielding. Not Applicable to Square/Rect Restrainers.

See Matsui (2010) and Takeuchi (2017). Eqn from Takeuchi (2017) Ch 4

$\delta_y=\sqrt{[(\pi\cdot W_c\cdot F_{yc}/(4\cdot E_c)+W_c/2\cdot\cos^{-1}((W_c-2a)/(W_c-2t_c)))^2-a^2]}$ — δ_y: 3.00 in *(76 mm)*

Elastic Rotational Stiffness of Restrainer about Rib End:

Round Casing: $K_{Rr1.Round}=2\cdot F_{vc}\cdot t_c\cdot L_{in}^3/(3\cdot\sqrt{[a^2+\delta_v^2]})\cdot\delta_v/(\delta_v-\delta_0)\geq 0$ — $K_{Rr1,Round}$: 27006 k-in/rad (3.05E+03 kN-m/rad)

Square/Rect Casing: $K_{Rr1.Rect}=E_c\cdot H_c\cdot t_c^3\cdot L_{in}^3/(3\cdot(2\cdot H_c\cdot a^3-3\cdot a^4))\geq 0$ — $K_{Rr1,Rect}$: 8814 k-in/rad (9.96E+02 kN-m/rad)

Post-Yielding Rotational Stiffness of Restrainer about Rib End:

Round Casing: $K_{Rr2,Round}=0$

Square/Rect Casing: $K_{Rr2.Rect}=0.11\cdot F_{vc}\cdot H_c^3\cdot(L_{in}/W_t)^3\geq 0$ — $K_{Rr2,Rect}$: 9841 k-in/rad (1.11E+03 kN-m/rad)

Yield Angle of Circular Casing: $\theta_{y,Round}=(\delta_y-\delta_0)/L_{in}$ — $\theta_{y,Round}$: 0.012573 rad

Pseudo Initial Yield Angle of the Rect Casing: $\theta'_{y1}=0.00164\cdot(F_{yc}/E_{casinq})\cdot(H_c/t_c)\cdot(W_t/L_{in})$ — θ'_{y1}: 0.000041 rad

Angle at Which Plastic Hinge Occurs: $\theta_{y2}=H_c/L_{in}\cdot\sqrt{[(F_{vc}/(2\cdot E_{casinq}))^2+(a\cdot F_{vc}/(H_c\cdot E_{casinq}))]}$ — θ_{y2}: 0.019260 rad

See Matsui (2010) and Takeuchi (2017) ch 4

Reduced Restrainer Moment Transfer Capacity Determined by Restrainer Section at Rib:

Round Casing: $M_p^{r-rest} = MIN[M^r_{zv}, \alpha^r_p \cdot K_{Rr1.Round} \cdot \theta_{v.Round}]$ — M_p^{r-rest}: 346 k-in *(39.1 kN-m)*

Square/Rect Casing: $M_p^{r-rest} = MIN[M^r_{zv}, \alpha^r_p \cdot (K_{Rr1.Rect} \cdot \theta'_{v1} + K_{Rr2.Rect} \cdot (\theta_{v2} - \theta'_{v1}))]$

Controlling Restrainer Moment Transfer Capacity: $M^r_p = Min\{M_p^{r\text{-}neck,t/b}, M_p^{r\text{-}rest}\}$

Top End of Brace Controlled By: **Neck Capacity**	**$M^r_{p.top}$:**	**179.4 k-in**	*(20.3 kN-m)*
Bottom End of Brace Controlled By: **Neck Capacity**	**$M^r_{p.bot}$:**	**179.4 k-in**	*(20.3 kN-m)*

2.2.3 Over the Yield Line (OYL) Global Buckling Capacity

Total Initial Imperfection with Plastic Hinge at End of Casing: $\theta_{i,OYL}$ — $\theta_{i,OYL}$: 0.0190 rad

$\theta_{i,OYL} = \delta_m/L_0 + \delta_q/L_q + \theta_0$

Moment Amplification Factor to Account for 2nd Order Effects: $\delta_{s,OYL}$ — $\delta_{s,OYL}$: 1.1713

$\delta_{s.OYL} = 1/(1 - N^*_{cu}/N^B_{cr}) \geq 1.0$

Reports as "Error" if result is is less than 1.0, which occurs when applied load (N^*_{cu}) exceeds BRB elastic buckling capacity (N^B_{cr}).

Notional Load Applied at Brace End: $N_{OYL} = N^*_{cu} \cdot \theta_{i.OYL} + F_{Add'l\text{-}OOP}/2$ — N_{OYL}: 2.8 kip *(13 kN)*

$$N\xi L_0\delta_s \leq (1-2\xi)M_p^g + M_p^r \qquad \text{Iterative Solution}$$

$$\frac{N\xi L_0\delta_s}{(1-2\xi)M_p^g + M_p^r} \leq 1.0 \qquad \text{DCR}$$

Demand: $D = N_{OYL}\xi L_0\delta_{s,OYL}$	**D:**	**42.6 k-in**	*(4.8 kN-m)*
Capacity: $C_{top} = (1\text{-}2\xi)M^g_{p,top} + M^r_{p,top}$	**C_{top}:**	**224.6 k-in**	*(25.4 kN-m)*
$C_{bot} = (1\text{-}2\xi)M^g_{p,bot} + M^r_{p,bot}$	**C_{bot}:**	**221.9 k-in**	*(25.1 kN-m)*
DCR: $D/C_{OYL} = D/[\min\{C_{top}, C_{bot}\}]$	**D/C_{OYL}:**	**0.19**	**OK**

2.2.4 Under the Yield Line (UYL) Global Buckling Capacity

Total Initial Imperfection with Plastic Hinge at End of Casing: $\theta_{i,UYL}$ — $\theta_{i,UYL}$: 0.0290 rad

$\theta_{i,UYL} = \delta_m/L_0 + 2\cdot\delta_q/L_q + \theta_0$

Moment Amplification Factor to Account for 2nd Order Effects: $\delta_{s,OYL}$

$\delta_{s.UYL.top} = 1/(1 - N^*_{cu}/N_{e.top}) \geq 1.0$	$\delta_{s,UYL,top}$:	1.042
$\delta_{s.UYL.bot} = 1/(1 - N^*_{cu}/N_{e.bot}) \geq 1.0$	$\delta_{s,UYL,bot}$:	1.673

Reports as "Error" if result is is less than 1.0, which occurs when applied load (N^*_{cu}) exceeds gusset elastic buckling capacity (N_e).

Notional Load Applied at Brace End: $N_{UYL} = N^*_{cu} \cdot \theta_{i.UYL} + F_{Add'l\text{-}OOP}/2$ — N_{UYL}: 4.3 kip *(19 kN)*

Total Length, $L_T = L_{ave,bot} + L_0 + L_{ave,Top}$ — L_T: 129.32 in *(3285 mm)*

Length Factor, $\eta = (1 - L_0/L_T)/2$ — η: 0.057

$$NL_{ave}\delta_s\theta = (2-2\eta)M_p^g \Rightarrow M_p^g \geq \frac{NL_{ave}\delta_s}{(2-2\eta)} = M_y^* \qquad \text{Iterative Solution}$$

$$\frac{M_y^*}{M_p^g} \leq 1.0 \qquad \text{DCR}$$

$M^*_{y,top} = N_{UYL} \cdot L_{ave,top} \cdot \delta_{s,UYL,top}/(2\text{-}2\eta)$	**$M^*_{y.top}$:**	**9.2 k-in**	*(1.0 kN-m)*
$M^*_{y,bot} = N_{UYL} \cdot L_{ave,bot} \cdot \delta_{s,UYL,bot}/(2\text{-}2\eta)$	**$M^*_{y.bot}$:**	**42.0 k-in**	*(4.7 kN-m)*
$DCR = \max\{M^*_{y,top}/M^g_{p,top}, M^*_{y,top}/M^g_{p,top}\}$	**DCR_{top}:**	**0.16**	**OK**
	DCR_{bot}:	**0.77**	**OK**
	DCR_{UYL}:	**0.77**	**OK**

Interaction Equation Form of General Solution:

$$\left(\frac{N^*_{cu}}{\phi N^g_s}\right)^2 + \frac{M^*_y}{\lambda\phi M^g_{zy}} \leq 1 \qquad \text{Interaction Equation}$$

*Interaction equation will produce results that equal 1.0 at for same value of N*cu as the UYL DCR equation but it is less senstive (less volatile) to small changes in N*cu. Neither the DCR nor the Int Eqn produces results that are linear with respect to N*cu (i.e. a Int Eqn value = 0.5 is not capableof handling 2x N*cu). An interaction eqn solution is not possible for the OYL method.*

Int_{top}:	**0.37**	**OK**
Int_{bot}:	**0.86**	**OK**
Int_{UYL}:	**0.86**	**OK**

2.2.5 NLYL Summary

Global stability in the Asymmetrical Mode is controlled by the lesser of the capacities determined by the OYL and UYL methods.

OYL:	**DCR_{OYL}:**	**0.19**	**OK**
UYL:	**DCR_{UYL}:**	**0.77**	**OK**
UYL_{INT}:	**Int_{UYL}:**	**0.86**	**OK**
	Summary:	**OK**	

2.2.6 References

Dowswell, B. (2006), Effective length factors for gusset plate buckling, AISC Engineering Journal, Second Quarter, 91-101.

Dowswell, B. (2016), Advances in steel constructino analysis. 2016 NASCC (the Steel Conference) Proceedsings.

Matsui, R. Takeuchi, T. Nishimoto, K. Takahashi, S. & Ohyama, T. (2010), Effective buckling length of buckling restrained braces considering rotational stiffness at restrainer ends, 7th International Conference on Urban Earthquake Engineering & 5th International Conference on Earthquake Engineering, Proceedings 1049-1058

Takeuchi, T. Ozaki, H. Matsui, R. & Sutcu, F. (2014), Out-of-plane stability of buckling-restrained braces including moment transfer capacity, Earthquake Engineering & Structural Dynamics, 43(6), 851-869

Takeuchi, T. & Wada, A (2017), Buckling-restrained braces and applications, Tokyo: The Japan Society of Seismic Isolation (JSSI), Chapter 4

Zaboli, B. Clifton, G.C. & Cowie K. (2018), BRBF and CBF gusset plates: Out-of-plane stability design using a simplified notional load yield line (NLYL) method. Journal of the Structural Engineering Society of NZ, 31(1), 64-76

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

HSS Casing Buckling Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

					Casing Buckling													GLOBAL STABILITY CALCULATIONS Input Parameters															
EOR-ID	Line	Grids	Lvls	Mark	Qty	L_g	$F_{ysc,max}$	$P_{ysc,max}$	β	ω	$P_{u,max}$	FS	I_g	Type	H_c	W_c	t_c	Casing	I_c	I_{gc}*	Is V Bot	Is Chev Too	P_{UC}	L_b	t_{cc}	W_t	OOP Embed	t_g	F_{ye}	Casing is Sq/Rect?	H_c	W_c	t_c	I_c	E_{casing}	F_{yc}
#		#	#	#	#	in	ksi	kips			kips	Buckling	in^4		in	in	in	Size	in^4	I_c	T/F	T/F	kip	in	in	in	Ratio	in	ksi		in	in	in	in^4	ksi	ksi
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	109.62	46.0	92	1.17	1.38	149	1.27	8	t	7	7	0.2500	t7x1/4	46.5	0.17	TRUE	FALSE	148.5	114.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	109.62	46.0	92	1.17	1.38	149	1.27	8	t	7	7	0.2500	t7x1/4	46.5	0.17	TRUE	FALSE	148.5	114.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	217.62	46.0	92	1.11	1.33	136	1.27	28	t	7	7	0.2500	t7x1/4	46.5	0.61	FALSE	TRUE	135.8	222.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	217.62	46.0	92	1.11	1.33	136	1.27	28	t	7	7	0.2500	t7x1/4	46.5	0.61	FALSE	TRUE	135.8	222.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	5	E to D.5	1	**1903**	1	265.73	46.0	92	1.11	1.31	134	1.27	42	t	7	7	0.2500	t7x1/4	46.5	0.90	FALSE	FALSE	133.8	270.6	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	107.24	46.0	92	1.16	1.37	146	1.27	7	t	7	7	0.2500	t7x1/4	46.5	0.16	TRUE	FALSE	146.2	112.1	0.500	4.0	1.8	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	107.24	46.0	92	1.16	1.37	146	1.27	7	t	7	7	0.2500	t7x1/4	46.5	0.16	TRUE	FALSE	146.2	112.1	0.500	4.0	1.8	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	235.63	46.0	92	1.11	1.33	136	1.27	33	t	7	7	0.2500	t7x1/4	46.5	0.72	FALSE	TRUE	135.8	240.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	235.63	46.0	92	1.11	1.33	136	1.27	33	t	7	7	0.2500	t7x1/4	46.5	0.72	FALSE	TRUE	135.8	240.5	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	145.52	46.0	92	1.11	1.31	134	1.27	13	t	7	7	0.2500	t7x1/4	46.5	0.27	TRUE	FALSE	133.8	150.4	0.500	4.0	1.8	0.9	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	154.09	46.0	92	1.11	1.31	134	1.27	14	t	7	7	0.2500	t7x1/4	46.5	0.30	TRUE	FALSE	133.8	158.9	0.500	4.0	1.8	0.9	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	277.52	46.0	92	1.11	1.32	135	1.27	46	t	7	7	0.2500	t7x1/4	46.5	0.99	FALSE	TRUE	134.8	282.4	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	277.52	46.0	92	1.11	1.32	135	1.27	46	t	7	7	0.2500	t7x1/4	46.5	0.99	FALSE	TRUE	134.8	282.4	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	E	4.7 to 5	1	**1909**	1	278.18	46.0	92	1.11	1.31	134	1.27	46	t	7	7	0.2500	t7x1/4	46.5	0.99	FALSE	FALSE	133.8	283.0	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	130.53	46.0	92	1.12	1.34	138	1.27	10	t	7	7	0.2500	t7x1/4	46.5	0.22	FALSE	FALSE	138.1	135.4	0.500	4.0	1.8	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	225.02	46.0	138	1.17	1.23	199	1.27	45	t	7	7	0.2500	t7x1/4	46.5	0.96	FALSE	FALSE	198.6	233.4	0.750	4.0	2.0	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	4	A.8 to A.99	1	**1912**	1	211.47	46.0	92	1.11	1.32	135	1.27	27	t	7	7	0.2500	t7x1/4	46.5	0.57	FALSE	FALSE	134.8	216.3	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	B	5 to 4.7	1	**1913**	1	258.06	46.0	92	1.11	1.32	135	1.27	40	t	7	7	0.2500	t7x1/4	46.5	0.85	FALSE	TRUE	134.8	262.9	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	258.79	46.0	92	1.11	1.32	135	1.27	40	t	7	7	0.2500	t7x1/4	46.5	0.86	FALSE	TRUE	134.8	263.6	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	165.25	46.0	92	1.11	1.31	134	1.27	16	t	7	7	0.2500	t7x1/4	46.5	0.35	FALSE	FALSE	133.8	170.1	0.500	4.0	1.8	1.0	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-3.00	2	D to C.6	1	**1916**	1	273.02	46.0	138	1.17	1.22	197	1.27	65	t	8	8	0.2500	t8x1/4	70.7	0.92	FALSE	FALSE	197.0	281.4	0.750	4.0	2.0	1.0	50	TRUE	8.0	8.0	0.25	70.7	29000	46.0
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	127.21	46.0	92	1.11	1.31	134	1.27	10	t	7	7	0.2500	t7x1/4	46.5	0.21	TRUE	FALSE	133.8	132.1	0.500	4.0	1.8	1.0	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	127.21	46.0	92	1.11	1.31	134	1.27	10	t	7	7	0.2500	t7x1/4	46.5	0.21	TRUE	FALSE	133.8	132.1	0.500	4.0	1.8	1.0	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	3.2	D to C.6	1	**1918**	1	278.02	46.0	92	1.11	1.32	135	1.27	46	t	7	7	0.2500	t7x1/4	46.5	0.99	FALSE	TRUE	134.8	282.9	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	278.98	46.0	92	1.11	1.32	135	1.27	46	t	7	7	0.2500	t7x1/4	46.5	1.00	FALSE	TRUE	134.8	283.8	0.500	4.0	1.8	0.6	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	204.03	46.0	92	1.11	1.31	134	1.27	25	t	7	7	0.2500	t7x1/4	46.5	0.53	FALSE	FALSE	133.8	208.9	0.500	4.0	1.8	0.8	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.50	2	A.2 to A	1	**1921**	1	336.90	46.0	115	1.11	1.31	167	1.27	84	t	8	8	0.3125	t8x5/16	85.6	0.98	FALSE	FALSE	167.2	345.3	0.625	4.0	1.8	0.6	50	TRUE	8.0	8.0	0.31	85.6	29000	46.0
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	161.54	46.0	115	1.11	1.31	167	1.27	19	t	7	7	0.2500	t7x1/4	46.5	0.42	FALSE	FALSE	167.2	169.9	0.625	4.0	1.8	1.0	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-3.50	A	3 to 2.7	1	**1923**	1	263.02	46.0	161	1.17	1.23	232	1.27	71	t	8	8	0.3125	t8x5/16	85.6	0.83	FALSE	FALSE	231.7	271.4	0.750	4.7	1.8	1.0	50	TRUE	8.0	8.0	0.31	85.6	29000	46.0
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	149.45	46.0	92	1.11	1.33	136	1.27	13	t	7	7	0.2500	t7x1/4	46.5	0.29	FALSE	FALSE	135.8	154.3	0.500	4.0	2.0	1.3	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0
BRB-2.00	3	A.2 to A	1	**1925**	1	270.52	46.0	92	1.11	1.32	135	1.27	44	t	7	7	0.2500	t7x1/4	46.5	0.94	FALSE	FALSE	134.8	275.4	0.500	4.0	1.8	1.3	50	TRUE	7.0	7.0	0.25	46.5	29000	46.0

Table Symbols & Definitions

L_g = Length between tips of gussets
F_{ysc} = Specified yield force of core
P_{ysc} = Yield force of yielding core
β = Maximum compressive force to Tension force ratio
ω = Maximum Tension force to yield force ratio
$P_{u,max}$ = Buckling load, $P_{ysc,max}$ * β * ω
I_g = Inertia of casing to resist buckling from Euler Equation (F.S.*(P_uxL_b^2)/(π^2xE))

Type = Casing tpye, t = tube (rectangular) and p =pipe (round)
w = Width of casing
h = Height of casing
t = thickness of casing
L_{HSS} = Length of casing w/o extensions
FS Buckling = Buckling Factor of Safety. Typically Incl 1/(0.9*0.877).

HSS Casing Buckling Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

					--	GLOBAL STABILITY CALCULATIONS																								
					Calculation Parameters																	Gusset Capacity							
EOR-ID	Line	Grids	Lvls	Mark	Qty	S_r	L_{sh}	EI_0	θ_0	δ_m/L_0	δ_g/L_g	L_θ	ξL_0	ξ	Stiffened Gusset T/F	Stiffened Gusset T/F	k_b	N^e_{cr}	$Z_{g,bot}$	$Z_{g,top}$	N^*_{cu}	ϕ	$N^E_{t,bot}$	$N^E_{t,top}$	$N_{e,bot}$	$N_{e,top}$	$M^E_{zy,bot}$	$M^E_{zy,top}$	$M^E_{p,bot}$	$M^E_{p,top}$
#		#	#	#	#	in	in	kip-in^2	rad	rad	rad	in	in		T/F	T/F		kip	in^3	in^3	kip		kip	kip	kip	kip	kip-in	kip-in	kip-in	kip-in
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	0.0	7.1	1348500	0.007	0.002	0.010	114.5	12.88	0.11	FALSE	FALSE	1.0	1016	1.8	1.6	149	1.0	240	297	369	3723	89	78	55	58
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	0.0	7.1	1348500	0.007	0.002	0.010	114.5	12.88	0.11	FALSE	FALSE	1.0	1016	1.8	1.6	149	1.0	240	297	369	3723	89	78	55	58
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	0.0	7.1	1348500	0.007	0.002	0.010	222.5	12.88	0.06	FALSE	FALSE	1.0	269	1.7	1.8	136	1.0	297	240	4834	8077	87	92	69	62
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	0.0	7.1	1348500	0.007	0.002	0.010	222.5	12.88	0.06	FALSE	FALSE	1.0	269	1.7	1.8	136	1.0	297	240	4834	8077	87	92	69	62
BRB-2.00	5	E to D.5	1	**1903**	1	0.0	7.1	1348500	0.007	0.002	0.010	270.6	12.88	0.05	FALSE	FALSE	1.0	182	1.6	1.7	134	1.0	297	297	8663	5663	80	84	64	67
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	0.0	7.1	1348500	0.007	0.002	0.010	112.1	12.88	0.11	FALSE	FALSE	1.0	1059	2.7	2.1	146	1.0	287	356	396	3681	135	107	100	89
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	0.0	7.1	1348500	0.007	0.002	0.010	112.1	12.88	0.11	FALSE	FALSE	1.0	1059	2.7	2.3	146	1.0	287	356	396	3681	133	114	99	95
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	0.0	7.1	1348500	0.007	0.002	0.010	240.5	12.88	0.05	FALSE	FALSE	1.0	230	1.7	1.9	136	1.0	297	240	6558	7370	87	96	69	65
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	0.0	7.1	1348500	0.007	0.002	0.010	240.5	12.88	0.05	FALSE	FALSE	1.0	230	1.7	1.9	136	1.0	297	240	6558	7370	87	96	69	65
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	0.0	7.1	1348500	0.007	0.002	0.010	150.4	12.88	0.09	FALSE	FALSE	1.0	589	3.7	3.7	134	1.0	335	416	895	3057	184	187	155	168
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	0.0	7.1	1348500	0.007	0.002	0.010	158.9	12.88	0.08	FALSE	FALSE	1.0	527	3.7	3.7	134	1.0	335	416	1144	2930	187	183	157	164
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	0.0	7.1	1348500	0.007	0.002	0.010	282.4	12.88	0.05	FALSE	FALSE	1.0	167	1.8	1.8	135	1.0	297	240	3227	2433	88	90	69	62
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	0.0	7.1	1348500	0.007	0.002	0.010	282.4	12.88	0.05	FALSE	FALSE	1.0	167	1.8	1.8	135	1.0	297	240	3227	3306	88	90	69	62
BRB-2.00	E	4.7 to 5	1	**1909**	1	0.0	7.1	1348500	0.007	0.002	0.010	283.0	12.88	0.05	FALSE	FALSE	1.0	166	1.6	1.7	134	1.0	297	297	10455	6025	80	86	64	69
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	0.0	7.1	1348500	0.007	0.002	0.010	135.4	12.88	0.10	FALSE	FALSE	1.0	726	1.7	2.2	138	1.0	356	356	2199	5655	84	109	71	92
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	0.0	7.8	1348500	0.006	0.002	0.010	233.4	16.38	0.07	FALSE	FALSE	1.0	244	3.3	4.0	199	1.0	576	576	17409	14652	163	199	144	176
BRB-2.00	4	A.8 to A.99	1	**1912**	1	0.0	7.1	1348500	0.007	0.002	0.010	216.3	12.88	0.06	FALSE	FALSE	1.0	284	1.7	1.6	135	1.0	297	297	4959	9842	85	79	68	63
BRB-2.00	B	5 to 4.7	1	**1913**	1	0.0	7.1	1348500	0.007	0.002	0.010	262.9	12.88	0.05	FALSE	FALSE	1.0	193	1.7	1.8	135	1.0	297	240	7605	5447	83	89	66	61
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	0.0	7.1	1348500	0.007	0.002	0.010	263.6	12.88	0.05	FALSE	FALSE	1.0	191	1.7	1.9	135	1.0	297	240	7605	6067	83	97	66	66
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	0.0	7.1	1348500	0.007	0.002	0.010	170.1	12.88	0.08	FALSE	FALSE	1.0	460	4.7	3.8	134	1.0	475	475	1216	4422	234	192	216	176
BRB-3.00	2	D to C.6	1	**1916**	1	0.0	7.8	2050300	0.006	0.002	0.010	281.4	16.38	0.06	FALSE	FALSE	1.0	256	5.4	6.9	197	1.0	769	769	28236	1816	271	347	253	324
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	0.0	7.1	1348500	0.007	0.002	0.010	132.1	12.88	0.10	FALSE	FALSE	1.0	763	5.0	4.5	134	1.0	383	475	1098	3676	250	226	220	208
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	0.0	7.1	1348500	0.007	0.002	0.010	132.1	12.88	0.10	FALSE	FALSE	1.0	763	5.0	4.5	134	1.0	383	475	1098	3676	250	226	220	208
BRB-2.00	3.2	D to C.6	1	**1918**	1	0.0	7.1	1348500	0.007	0.002	0.010	282.9	12.88	0.05	FALSE	FALSE	1.0	166	1.7	1.8	135	1.0	297	240	3908	1954	86	91	68	62
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	0.0	7.1	1348500	0.007	0.002	0.010	283.8	12.88	0.05	FALSE	FALSE	1.0	165	1.7	2.0	135	1.0	297	240	3908	2143	86	98	68	67
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	0.0	7.1	1348500	0.007	0.002	0.010	208.9	12.88	0.06	FALSE	FALSE	1.0	305	2.8	2.1	134	1.0	356	356	1002	3503	140	103	120	89
BRB-2.50	2	A.2 to A	1	**1921**	1	0.0	7.2	2482400	0.007	0.002	0.010	345.3	16.38	0.05	FALSE	FALSE	1.0	206	2.3	2.1	167	1.0	480	480	3984	6285	116	107	102	94
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	0.0	7.1	1348500	0.007	0.002	0.010	169.9	16.38	0.10	FALSE	FALSE	1.0	461	5.6	4.7	167	1.0	769	769	2717	8236	282	234	268	223
BRB-3.50	A	3 to 2.7	1	**1923**	1	0.1	8.6	2482400	0.012	0.002	0.010	271.4	16.38	0.06	FALSE	FALSE	1.0	333	5.3	7.1	232	1.0	769	769	50975	1583	266	353	242	321
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	0.0	7.9	1348500	0.006	0.002	0.010	154.3	12.88	0.08	FALSE	FALSE	1.0	559	9.5	5.6	136	1.0	594	594	1269	13780	473	281	448	267
BRB-2.00	3	A.2 to A	1	**1925**	1	0.0	7.1	1348500	0.007	0.002	0.010	275.4	12.88	0.05	FALSE	FALSE	1.0	176	6.5	7.3	135	1.0	594	594	69117	12825	325	366	308	348

HSS Casing Buckling Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Restrainer Capacity											NLYL Global Stability									
						Based on Moment Capacity of Neck						Based on Mom Txfr Cap of Rest			Controlling Rest Cap		Over the Yield Line Buckling (Asymm Mode)				Under the Yield Line Buckling (Asymm Mode)					
EOR-ID	Line	Grids	Lvls	Mark	Qty	N^n_u	Z_{WT}	Z_{W1}	M^n_{zy}	$M_p^{r\text{-}neck,bot}$	$M_p^{r\text{-}neck,top}$	Z_{rp}	$Z_{rp}\sigma_{ry}$	$M_p^{r\text{-}rest}$	$M^r_{p,bot}$	$M^r_{p,top}$	θ_{LOYL}	$\delta_{L\,OYL}$	N_{OYL}	Stability Index Max	θ_{LUYL}	$\delta_{LUYL,bot}$	$\delta_{LUYL,top}$	N_{UYL}	Stability Index Max
#		#	#	#	#	kip	in^3	in^3	kip-in	kip-in	kip-in	in^3	kip-in	kip-in	kip-in	kip-in	rad	*M Mag factor*	kip	OYL	rad	*M Mag factor*	*M Mag factor*	kip	UYL
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	1.17	2.8	**0.19**	0.03	1.67	1.04	4.3	**0.77**
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	1.17	2.8	**0.19**	0.03	1.67	1.04	4.3	**0.77**
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	2.02	2.6	**0.29**	0.03	1.03	1.02	3.9	**0.10**
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	2.02	2.6	**0.29**	0.03	1.03	1.02	3.9	**0.10**
BRB-2.00	5	E to D.5	1	**1903**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	3.79	2.5	**0.52**	0.03	1.02	1.02	3.9	**0.09**
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	370	2.00	2.75	230	230	230	17.1	786	376	230	230	0.019	1.16	2.8	**0.14**	0.03	1.59	1.04	4.3	**0.51**
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	370	2.00	2.75	230	230	230	17.1	786	376	230	230	0.019	1.16	2.8	**0.14**	0.03	1.59	1.04	4.3	**0.51**
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	2.44	2.6	**0.34**	0.03	1.02	1.02	3.9	**0.09**
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	2.44	2.6	**0.34**	0.03	1.02	1.02	3.9	**0.09**
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	370	2.00	2.98	241	241	241	17.1	786	376	241	241	0.019	1.29	2.6	**0.12**	0.03	1.18	1.05	3.9	**0.18**
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	370	2.00	2.98	241	241	241	17.1	786	376	241	241	0.019	1.34	2.6	**0.12**	0.03	1.13	1.05	3.9	**0.15**
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.20	2.6	**0.73**	0.03	1.04	1.06	3.9	**0.15**
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.20	2.6	**0.73**	0.03	1.04	1.04	3.9	**0.12**
BRB-2.00	E	4.7 to 5	1	**1909**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.13	2.5	**0.71**	0.03	1.01	1.02	3.9	**0.09**
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	334	2.00	1.94	189	189	189	17.1	786	346	189	189	0.019	1.23	2.6	**0.17**	0.03	1.07	1.03	4.0	**0.21**
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	436	3.00	2.29	253	252	252	17.1	786	312	252	252	0.018	5.34	3.7	**0.85**	0.03	1.01	1.01	5.6	**0.06**
BRB-2.00	4	A.8 to A.99	1	**1912**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	1.90	2.6	**0.27**	0.03	1.03	1.01	3.9	**0.10**
BRB-2.00	B	5 to 4.7	1	**1913**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	3.33	2.6	**0.47**	0.03	1.02	1.03	3.9	**0.10**
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	3.38	2.6	**0.47**	0.03	1.02	1.02	3.9	**0.08**
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	370	2.00	3.21	252	252	252	17.1	786	376	252	252	0.019	1.41	2.6	**0.12**	0.03	1.12	1.03	3.9	**0.15**
BRB-3.00	2	D to C.6	1	**1916**	1	436	3.00	2.75	276	275	275	22.5	1036	585	275	275	0.018	4.36	3.6	**0.52**	0.03	1.01	1.12	5.6	**0.14**
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	370	2.00	3.21	252	252	252	17.1	786	376	252	252	0.019	1.21	2.6	**0.09**	0.03	1.14	1.04	3.9	**0.14**
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	370	2.00	3.21	252	252	252	17.1	786	376	252	252	0.019	1.21	2.6	**0.09**	0.03	1.14	1.04	3.9	**0.14**
BRB-2.00	3.2	D to C.6	1	**1918**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.28	2.6	**0.74**	0.03	1.04	1.07	3.9	**0.16**
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	334	2.00	1.75	179	179	179	17.1	786	346	179	179	0.019	5.43	2.6	**0.75**	0.03	1.04	1.07	3.9	**0.14**
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	334	2.00	1.94	189	189	189	17.1	786	346	189	189	0.019	1.78	2.5	**0.22**	0.03	1.15	1.04	3.9	**0.19**
BRB-2.50	2	A.2 to A	1	**1921**	1	373	2.50	1.80	205	205	205	27.7	1275	617	205	205	0.019	5.36	3.2	**0.96**	0.03	1.04	1.03	4.8	**0.12**
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	409	2.50	3.28	279	279	279	17.1	786	369	279	279	0.019	1.57	3.2	**0.18**	0.03	1.07	1.02	4.9	**0.12**
BRB-3.50	A	3 to 2.7	1	**1923**	1	508	4.08	3.19	348	346	346	27.7	1275	452	346	346	0.024	3.29	5.5	**0.53**	0.03	1.00	1.17	7.8	**0.22**
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	334	2.00	2.72	228	228	228	17.1	786	357	228	228	0.018	1.32	2.5	**0.09**	0.03	1.12	1.01	3.8	**0.10**
BRB-2.00	3	A.2 to A	1	**1925**	1	334	2.00	2.72	228	228	228	17.1	786	346	228	228	0.019	4.31	2.6	**0.28**	0.03	1.00	1.01	3.9	**0.03**

PSE Operational Training Center

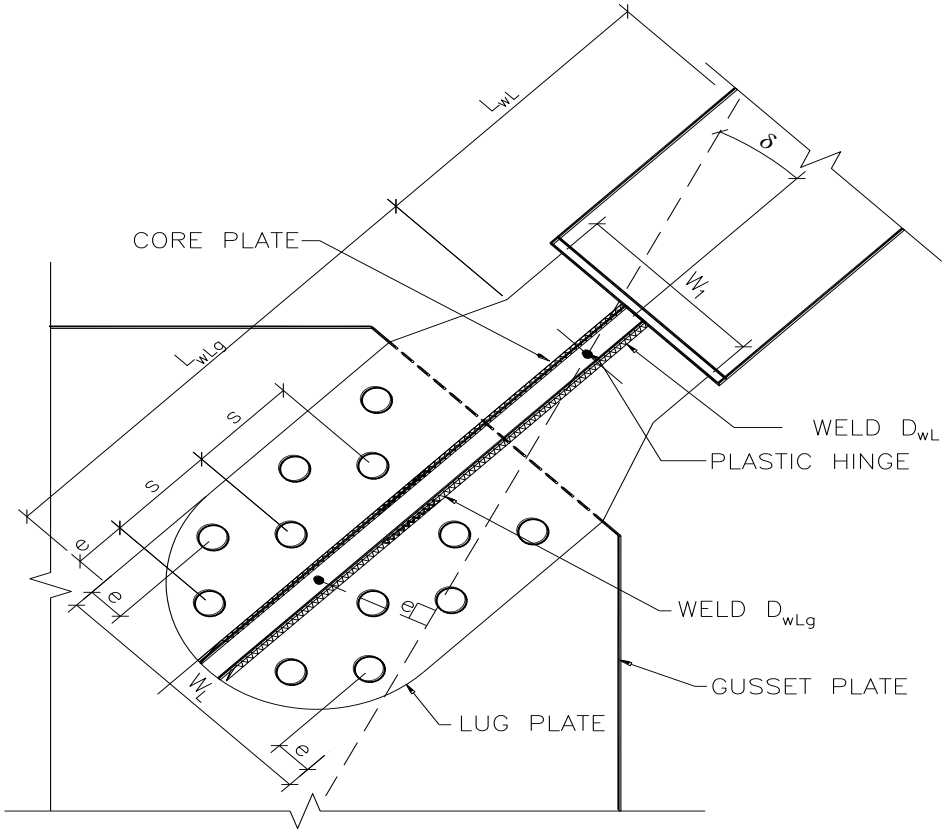
Calculation Submittal Package

Description

Section 3. **Brace End Connection Sample Calculation**
End Connection Summary Table

Brace Connection

Example Mark #: 1901
Line 4.1, Grid D.3 to D(+), Level Low Roof



WELD CONFIGURATION

3.0 DESIGN CRITERIA Example Mark #: 1901

Compresssion Strength Adjustment Factor	β:	1.17	
Strain Hardening Adjustment Factor	ω:	1.38	
Area of (Yielding) Steel Core (as Spec'd on Drawings)	A_{sc}:	2.00 in²	*(1290 mm²)*
Core Plate Ultimate Tensile Strength *Based on Coupon Test History*	F_{usc}:	66 ksi	*(455 MPa)*
Upper Bound Compressive Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Lower Bound Compressive Yield Stress of Core Material *Note:* *Ry factor not applicable since Fy of core material will be established based on results of coupon tests.*	$F_{y\text{-}min}$:	38 ksi	*(262 MPa)*

Axial Design Load:

Connection Strain Hardening Factor	CF:	1.00	
$P_{uC\text{-}max} = CF \cdot A_{sc} \cdot F_{y\text{-}max} \cdot \beta \cdot \omega$	$P_{uC\text{-}max}$:	148.5 kip	*(661 kN)*
$P_{uT\text{-}max} = CF \cdot A_{sc} \cdot F_{y\text{-}max} \cdot \omega$	$P_{uT\text{-}max}$:	127.0 kip	*(565 kN)*
$P_{ysc\text{-}max} = A_{sc} \cdot F_{y\text{-}max}$	$P_{ysc\text{-}max}$:	92.0 kip	*(409 kN)*
Core Dimensions: At Lug Connection	W_t:	4.00 in	*(102 mm)*
Lug Dimensions: Width of Lug Plate	W_L:	6.00 in	*(152 mm)*
At Extension Exit from Casing (Transv. Stiffener)	W_1:	3.61 in	*(92 mm)*
Plate Edge to CL of Bolt	e:	1.19 in	*(30 mm)*
Bolt Specifications: Number of Bolts in Inside Row	n_i:	2	
Number of Bolts in Outside Row	n_o:	0	
Total Number of Bolts at Each End $2(n_i + n_o)$	n_b:	4	
Bolt Spacing	s:	3.50 in	*(89 mm)*
Bolt Gage	g:	0.00 in	*(0 mm)*
Bolt Diameter	d_b:	0.875 in	*(22 mm)*
Standard Bolt Hole $d_s = d_b + x_{std}$ x_{std} = 1/16" (1.6mm)	d_s:	0.938 in	*(24 mm)*
Slip Plane (Single Shear = 1, Double Shear = 2)	n_s:	2	

3.1.0 Bolt Shear - LRFD J3.6

LRFD Resistance Factor	ϕ_v:	0.75	
Bolt Shear Strength $F_{nv} = F_{ub}*0.625*0.9*TCF*CLF$ *0.625 = V//T Ratio, 0.9 = Base Connection Length Factor for Non-Uniformity of Loading*	F_{nv}:	64.8 ksi	*(447 MPa)*
Bolt Grade and Ultimate Tensile Strength for Shear **Gr A490/F3148**	F_{ub}:	144 ksi	*(993 MPa)*
Thread Condition Factor TCF: IF BTC = "X" then 1.0, IF BTC = "N" then 0.8	TCF:	0.80	
Bolt Thread Condition (N = Include, X = Exclude)	BTC:	N	
Connection Length Factor Table J3.2 Note b *(For L'_{Lg} > 38")*	CLF:	1.00	
Connection Length	L'_{Lg}:	3.50 in	*(89 mm)*
Bolt Shear Capacity $\phi r_v = \phi_v F_{nv} n_s A_b$	ϕr_v:	58.4 kip	*(260 kN)*
Bolt Area $A_b = \pi d_b^2/4$	A_b:	0.601 in²	*(388 mm²)*
Bolt Group Shear Strength $\phi R_v = (n_i + n_o) \cdot 2 \cdot \phi r_v$	ϕR_v:	233.8 kip	*(1040 kN)*
Demand-Capacity Ratio $DCR_{Shear} = P_{uc\text{-}max}/R_v$	DCR_{Shear}:	0.64	

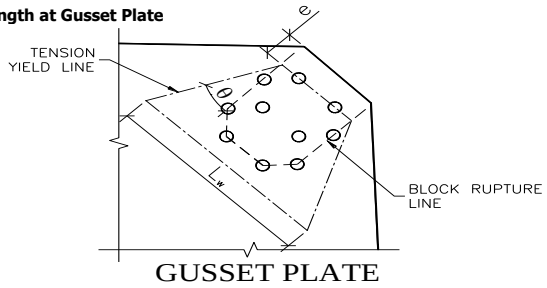
3.2.0 Bolt Friction - LRFD J3.8

LRFD Resistance Factor	ϕ_s:	0.85	
Min Bolt Tensile Area $A_{Tb_min} = \pi/4 \cdot (d-0.9743/n)^2$, where n = threads/in	A_{Tb_min}:	0.462 in²	*(298 mm²)*
Factor for fillers	h_f:	1.00	
Mean Slip Coefficient	μ:	0.30	
Bolt Pretension Adjustment Factor, f_T **Gr A490/F3148**	f_T:	1.04	
Accounts for fact that some bolt grades, such as F3148, have a specified Tb greater than that associated with Fub alone. If the combined grade A490/F3148 is specified and A490's are used, then Tb would be equal to that for the grade and FnV would be conservatively low by $1/f_T$.			
Fastener Tension $T_b = 0.7 \cdot f_T \cdot F_{ub} \cdot A_{Tb_min}$	T_b:	48 kip	*(216 kN)*
Bolt Tension Factor	D_u:	1.13	
Bolt Slip Capacity $\phi r_s = \phi_s m D_u h_f T_b n_s$	ϕr_s:	27.9 kip	*(124 kN)*
Bolt Group Slip Capacity $\phi R_s = (n_i + n_o) \cdot 2 \cdot \phi r_s$	ϕR_s:	111.8 kip	*(497 kN)*
Demand-Capacity Ratio $DCR_{Slip} = P_{ysc\text{-}max}/\phi R_s$	DCR_{Slip}:	0.82	

3.3.0 Bearing Strength at Bolt Holes - LRFD J3.10

LRFD Resistance Factor for Bearing or Tearout	$\phi_{brg\text{-}v}$:	0.75	

3.3.1 Bearing Strength at Gusset Plate



GUSSET PLATE

Additional Diameter of Hole in Gusset Plate	ovs_g:	0.13 in	*(3 mm)*
Thickness of Gusset Plate:	t_q:	0.63 in	*(16 mm)*
Thickness of Repad Plate for Design:	t_r:	0.00 in	*(0 mm)*
Gusset Plate Tensile Strength	F_{uq}:	65 ksi	*(448 MPa)*
Clear Distance Between Edge of Bolt Holes $L_{csg} = s - (d_s + ovs_g)$	L_{csg}:	2.438 in	*(62 mm)*
Number of Occurances of L_{cs} If $n_o = 0$ Then $n_{cs} = n_i - 1$, Otherwise $n_{cs} = n_i - ½ + n_o - 1$	n_{cs}:	1.0	
Clear Distance Between Plate Edge and Bolt Hole $L_{ceg} = e - (d_s + ovs_g)/2$	L_{ceg}:	0.656 in	*(17 mm)*
Number of Occurances of L_{ce} If $n_o = 0$ Then $n_{ce} = 1$, Otherwise $n_{ce} = 2$	n_{ce}:	1	
Clear Distance of Bolt Group $L_{cq} = 2 \cdot (n_{ce} \cdot L_{ceq} + n_{cs} \cdot L_{csq})$	L_{cq}:	6.19 in	*(157 mm)*

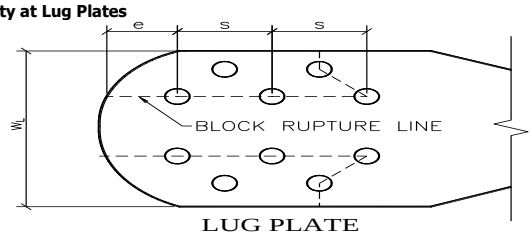
Gusset Plate Bearing Strength at Bolt Holes

$\phi R_{n\text{-}brq}$ = min of:			$\phi R_{n\text{-}brq}$:	226.2 kip	*(1006 kN)*
$\phi_{brq} 1.2 \cdot L_{cq} \cdot (t_q + 2t_r) \cdot F_{uq}$ =	226.2 kip	(Clear Dist/Tear-Out Controlled)			
$\phi_{brg} 2.4 \cdot d_b \cdot n_b \cdot (t_g + 2t_r) \cdot F_{ug}$ =	255.9 kip	(Bearing/Ovalization Controlled)			

Bearing Strength Stress Ratio $DCR_{brg\text{-}g} = P_{uc\text{-}max}/\phi_{brg} R_{n\text{-}brg}$	$DCR_{brg\text{-}g}$:	0.66	

Slip checked at serviceability limit state.

3.3.2 Bearing Capacity at Lug Plates



Additional Diameter of Holes in Lug Beyond Standard Hole Diam	ovs_L:	0.00 in	*(0 mm)*
Lug Plate Thickness	t_L:	0.50 in	*(13 mm)*
Lug Plate Tensile Strength	F_{uL}:	65 ksi	*(448 MPa)*
Clear Distance Between Edge of Bolt Holes $L_{csL} = s - (d_s + ovs_L)$	L_{csL}:	2.563 in	*(65 mm)*
Clear Distance Between Plate Edge and Bolt Hole $L_{ceL} = e - (d_s + ovs_q)/2$	L_{ceL}:	0.719 in	*(18 mm)*
Clear Distance of Bolt Group $L_{cL} = 2\cdot(n_{ce}\cdot L_{ceL} + n_{cs}\cdot L_{csL})$	L_{cL}:	6.56 in	*(167 mm)*

Lug Plate Bearing Strength at Bolt Holes

$\phi R_{n\text{-}brg}$ = min of: — $\phi R_{n\text{-}brg}$: 383.9 kip *(1708 kN)*

$\phi_{brq}1.2\cdot L_{cL}\cdot t_L\cdot F_{uL}\cdot n_s$ =	383.9 kip	*(1708 kN)*	(Clear Dist/Tear-Out Controlled)
$\phi_{brg}2.4\cdot d_b\cdot n_b\cdot t_L\cdot F_{uL}\cdot n_s$ =	409.5 kip	*(1822 kN)*	(Bearing/Ovalization Controlled)

Bearing Strength Stress Ratio
$DCR_{brg\text{-}L} = P_{uc\text{-}max}/\phi_{brg}R_{n\text{-}brg}$ — $DCR_{brg\text{-}L}$: 0.39

3.3.3 Combined Bolt Bearing/Tear-out/Bolt Shear at Lug and Gusset (Bolt by Bolt Method)

Extreme (Edge) Bolts - "Edge Bolts" Use Lceg, "Field Bolts" use Lcsg

Brace in Tension (T):
Free Edge Bolt when: Lug Field Bolt (LFB) or Gusset Edge Bolt (GEB)
Other Edge Bolt when: Lug Edge Bolt (LEB) or Gusset Edge Bolt (GFB)

Brace in Compression (C):
Free Edge Bolt when: Lug Field Bolt (LFG) or Gusset Edge Bolt (GFB)
Other Edge Bolt when: Lug Field Bolt (LFG) or Gusset Edge Bolt (GFB)

At all Conditions Check Min of Bearing, Edge Tear-out, and Bolt Shear

Gusset

G. Edge Bolts on n_i Row: $\phi_{brq\text{-}V}\cdot(t_q+2t_r)\cdot F_{uq}\cdot MIN[1.2\cdot L_{ceq}, 2.4\cdot d_b]$	GEB_{ni}:	24.0 kip	*(107 kN)*
G. Edge Bolts on n_o Row: $\phi_{brq\text{-}V}\cdot(t_q+2t_r)\cdot F_{uq}\cdot MIN[1.2\cdot(L_{ceq}+0.5s), 2.4\cdot d_b]$	GEB_{no}:	0.0 kip	*(0 kN)*
GEB Capacity = 0 Unless $n_o > 0$			
G. Field Bolts on n_i Row: $\phi_{brq\text{-}V}\cdot(t_g+2t_r)\cdot F_{ug}\cdot MIN[1.2\cdot L_{csg}, 2.4\cdot d_b]$	GFB_{ni}:	64.0 kip	*(285 kN)*
G. Field Bolts on n_o Row: $\phi_{brq\text{-}V}\cdot(t_q+2t_r)\cdot F_{uq}\cdot MIN[1.2\cdot(L_{csq}+0.5s), 2.4\cdot d_b]$	GFB_{no}:	0.0 kip	*(0 kN)*
GFB Capacity = 0 Unless $n_o > 0$			

Lug

L. Edge Bolts on n_i Row: $\phi_{brq\text{-}V}\cdot t_L\cdot F_{uL}\cdot MIN[1.2\cdot L_{ceL}, 2.4\cdot d_b]*2Lugs$	LEB_{ni}:	42.0 kip	*(187 kN)*
L. Edge Bolts on n_o Row: $\phi_{brq\text{-}V}\cdot t_L\cdot F_{uL}\cdot MIN[1.2\cdot(L_{ceL}+0.5s), 2.4\cdot d_b]*2Lugs$	LEB_{no}:	0.0 kip	*(0 kN)*
LEB Capacity = 0 Unless $n_o > 0$			
L. Field Bolts on n_i Row: $\phi_{brq\text{-}V}\cdot t_L\cdot F_{uL}\cdot MIN[1.2\cdot L_{csL}, 2.4\cdot d_b]*2Lugs$	LFB_{ni}:	102.4 kip	*(455 kN)*
L. Field Bolts on n_o Row: $\phi_{brq\text{-}V}\cdot t_L\cdot F_{uL}\cdot MIN[1.2\cdot(L_{csL}+0.5s), 2.4\cdot d_b]*2Lugs$	LFB_{no}:	0.0 kip	*(0 kN)*
LFB Capacity = 0 Unless $n_o > 0$			

Sum of Extreme Bolt Capacities (at each end of each line):

Tension: $2[MIN(LFB,\phi r_v$ or $GEB,\phi r_v) + MIN(LEB,\phi r_v$ or $GFB,\phi r_v)]$	$\phi R_{n\text{-}TE}$:	132.1 kip	*(588 kN)*
Compression: $2[2*MIN(LFB,\phi r_v$ or $GFB,\phi r_v)]$	$\phi R_{n\text{-}CE}$:	233.8 kip	*(1040 kN)*
Note Brace in Compression Results in "Field Bolt" Condition for all Extreme Bolts			

Sum of Remaining Field Bolt Capacities:

At Gusset: $2[MAX(n_i-2,0)*min(GFB_{ni},\phi r_v) + MAX(n_o-2,0)*min(GFB_{no},\phi r_v)]$:	$\phi R_{n\text{-}GF}$:	0.0 kip	*(0 kN)*
At Lug: $2[MAX(n_i-2,0)*min(LFB_{ni},\phi r_v) + MAX(n_o-2,0)*min(LFB_{no},\phi r_v)]$:	$\phi R_{n\text{-}LF}$:	0.0 kip	*(0 kN)*
Total Tension Capacity at Gusset:	$\phi R_{n\text{-}TG}$:	132.1 kip	*(588 kN)*
Total Compression Capacity at Gusset:	$\phi R_{n\text{-}CG}$:	233.8 kip	*(1040 kN)*
Total Tension Capacity at Lug:	$\phi R_{n\text{-}TL}$:	132.1 kip	*(588 kN)*
Total Compression Capacity at Lug:	$\phi R_{n\text{-}CL}$:	233.8 kip	*(1040 kN)*

Bearing/Tearout Strength Stress Ratio:

$DCR_{brg/Tear\text{-}G} = MAX(P_{uc\text{-}max}/\phi R_{n\text{-}CG}, P_{uT\text{-}max}/\phi R_{n\text{-}TG})$	$DCR_{brg/Tear\text{-}G}$:	0.96
$DCR_{brg/Tear\text{-}L} = MAX(P_{uc\text{-}max}/\phi R_{n\text{-}CL}, P_{uT\text{-}max}/\phi R_{n\text{-}TL})$	$DCR_{brg/Tear\text{-}L}$:	0.96

3.4.0 Tension Rupture Strength - LRFD D4

LRFD Resistance Factor	ϕ_{tr}:	0.75	
Compresssion Strength Adjustment Factor	β:	1.17	
Thickness of Yielding Core	t_{sc}:	0.50 in	*(13 mm)*
Shear Lag Factor (Table D3.1 Case 2)	U:	0.89	
Overslot for Gusset	OSL_g:	0.19 in	*(5 mm)*

Net Area Subject to Tension (Use AISC D3 for Staggered Bolt Net Area)

Stagger Adjustment Term If $n_o = 0$, then stg = 0, otherwise $stg = 2[(s/2)^2/(4g)]$	stg	0.00 in	*(0 mm)*
Number of Rows of Bolts If $n_o = 0$, then $n_r = 2$, otherwise $n_r = 4$	n_r:	2	
Net Area of Lug Transverse to Line of Force $A_{ntLb1} = 2t_L \cdot [W_L - n_r \cdot (d_s + ovs_L + 1/16) + stg]$	A_{ntLb1}:	4.00 in²	*(2581 mm²)*
$A_{ntLbx} = 2t_L \cdot [W_L - 2 \cdot (d_b + 1/8)]$	A_{ntLbx}:	4.00 in²	*(2581 mm²)*
$A_{ntLb} = \min(A_{ntLb1}, A_{ntLbx})$	A_{ntLb}:	4.00 in²	*(2581 mm²)*
Net Area of Lug Stiffener $A_{ntLc} = t_{sc} \cdot [W_t - (t_g + 2 \cdot t_L + OSL_g)]$	A_{ntLc}:	1.09 in²	*(706 mm²)*
Lug Plate Tension Rupture Strength $\phi R_{n\text{-}tr} = \phi_{tr} \cdot U \cdot (F_{uL} \cdot A_{ntLb} + F_{usc} \cdot A_{ntLc})$	$\phi R_{n\text{-}tr}$:	222.6 kip	*(990 kN)*
Tension Rupture Stress Ratio $DCR_{tr} = P_{ut\text{-}max}/\phi R_{n\text{-}tr}$	DCR_{tr}:	0.57	

3.5.0 Block Rupture Strength - LRFD J4.3

LRFD Resistance Factor	ϕ_{blk}:	0.75	
Block Shear Shear-Lag Factor	U_{bs}:	1.00	

3.5.1 Gusset Block Rupture Strength

Gusset Plate Yield Strength	F_{yg}:	50 ksi	*(345 MPa)*
Gusset Plate Edge Distance	e:	1.19 in	*(30 mm)*
Gross Area Subject to Shear	$L_{gv\text{-}g}$:	4.69 in	*(119 mm)*

If	Then
$n_o = 0$	$L_{gv\text{-}q} = (n_i - 1) \cdot s + e$
$n_o = n_i$	$L_{gv\text{-}g} = (n_o - 1) \cdot s + \sqrt{[(s/2)^2 + g^2]} + e$
Otherwise	$L_{gv\text{-}g} = (n_o - ½) \cdot s + \sqrt{[(s/2)^2 + g^2]} + e$

$A_{gv\text{-}q} = 2 \cdot L_{gv\text{-}q} \cdot (t_q + 2 \cdot t_r)$	$A_{gv\text{-}q}$:	5.86 in²	*(3780 mm²)*

Net Area Subject to Shear

If $n_o = 0$, Then $n_{na\text{-}g} = n_i - ½$, Otherwise $n_{na\text{-}g} = n_o + ½$ — $n_{na\text{-}g}$: 1.5

$L_{nv\text{-}q} = (d_s + ovs_q + 1/16)\cdot n_{na\text{-}q}$ — $L_{nv\text{-}q}$: 1.69 in *(43 mm)*

$A_{nv\text{-}g} = A_{gv\text{-}g} - 2\cdot L_{nv\text{-}g}\cdot(t_g + 2\cdot t_r)$ — $A_{nv\text{-}g}$: 3.75 in² *(2419 mm²)*

Gross Area Subject to Tension

$L_{gt\text{-}g} = W_L - 2\cdot(e + g)$ — $L_{gt\text{-}g}$: 3.63 in *(92 mm)*

Note: g = 0 if $n_o = 0$

$A_{qt\text{-}q} = L_{qt\text{-}q}\cdot(t_q + 2\cdot t_r)$ — $A_{qt\text{-}q}$: 2.27 in² *(1462 mm²)*

Net Area Subject to Tension

$L_{nt\text{-}g} = (d_s + ovs_g + 1/16)$ — $L_{nt\text{-}g}$: 1.13 in *(29 mm)*

$A_{nt\text{-}q} = A_{qt\text{-}q} - L_{nt\text{-}q}\cdot(t_q + 2\cdot t_r)$ — $A_{nt\text{-}q}$: 1.56 in² *(1008 mm²)*

Gusset Plate Block Rupture Strength

Shear Rupture Term $0.6\cdot F_{ug}\cdot A_{nv\text{-}q}$ — SRT: 146.3 kip *(651 kN)*

Shear Yield Term $0.6\cdot F_{yg}\cdot A_{gv\text{-}g}$ — SYT: 175.8 kip *(782 kN)*

Tension Rupture Term $U_{bs}\cdot F_{ug}\cdot A_{nt\text{-}g}$ — TRT: 101.6 kip *(452 kN)*

$\phi R_{n\text{-}blk\text{-}g} = \phi[\min(SRT, SYT) + TRT]$ — $\phi R_{n\text{-}blk\text{-}g}$: 185.9 kip *(827 kN)*

Block Shear Strength Stress Ratio at Gusset

$DCR_{blk\text{-}g} = P_{ut\text{-}max}/\phi R_{n\text{-}blk\text{-}g}$ — $DCR_{blk\text{-}g}$: 0.68

3.5.2 Lug Plates Block Rupture Strength

Lug Plate Yield Strength — F_{yL}: 50 ksi *(345 MPa)*

Gusset Plate Edge Distance — e: 1.19 in *(30 mm)*

Gross Area Subject to Shear

If — Then — $L_{gv\text{-}L}$: 4.69 in *(119 mm)*

$n_o = 0$ — $L_{gv\text{-}L} = (n_i - 1)\cdot s + e$

Otherwise — $L_{gv\text{-}L} = (n_i - 1)\cdot s + \sqrt{[(s/2)^2 + g^2]} + e$

$A_{gv\text{-}L} = 4\cdot L_{gv\text{-}L}\cdot t_L$ — $A_{gv\text{-}L}$: 9.38 in² *(6048 mm²)*

Net Area Subject to Shear

If $n_o = 0$, Then $n_{na\text{-}L} = n_i - ½$, Otherwise $n_{na\text{-}L} = n_i + ½$ — $n_{na\text{-}L}$: 1.5

$L_{nv\text{-}L} = (d_s + ovs_L + 1/16)\cdot n_{na\text{-}L}$ — $L_{nv\text{-}L}$: 1.50 in *(38 mm)*

$A_{nv\text{-}L} = A_{gv\text{-}L} - 4\cdot L_{nv\text{-}L}\cdot t_L$ — $A_{nv\text{-}L}$: 6.38 in² *(4113 mm²)*

Gross Area Subject to Tension

$A_{qt\text{-}L} = 4\cdot e\cdot t_L$ — $A_{qt\text{-}L}$: 2.38 in² *(1532 mm²)*

Net Area Subject to Tension

$L_{nt\text{-}L} = (d_s + ovs_L + 1/16)/2$ — $L_{nt\text{-}L}$: 0.50 in *(13 mm)*

$A_{nt\text{-}L} = A_{gt\text{-}L} - L_{nt\text{-}L}\cdot t_L\cdot 4$ — $A_{nt\text{-}L}$: 1.38 in² *(887 mm²)*

Lug Plate Block Rupture Strength

Shear Rupture Term $0.6\cdot F_{uL}\cdot A_{nv\text{-}L}$ — SRT: 248.6 kip *(1106 kN)*

Shear Yield Term $0.6\cdot F_{yL}\cdot A_{gv\text{-}L}$ — SYT: 281.3 kip *(1251 kN)*

Tension Rupture Term $U_{bs}\cdot F_{uL}\cdot A_{nt\text{-}L}$ — TRT: 89.4 kip *(398 kN)*

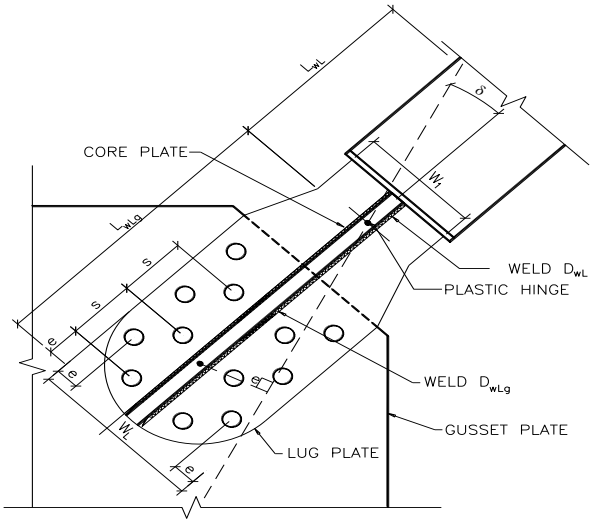
$\phi R_{n\text{-}blk\text{-}L} = \phi[\min(SRT, SYT) + TRT]$ — $\phi R_{n\text{-}blk\text{-}L}$: 253.5 kip *(1128 kN)*

Block Shear Strength Stress Ratio at Lug

$DCR_{blk\text{-}L} = P_{ut\text{-}max}/\phi R_{n\text{-}blk\text{-}L}$ — $DCR_{blk\text{-}L}$: 0.50

3.6.0 Weld Design

Assume plastic hinge forms in core just outside casing to accommodate story drift rotation δ



WELD CONFIGURATION

LRFD Resistance Factor	ϕ_{Weld}:	0.75	
Upper Bound Compressive Yield Stress of Core Material	$F_{ysc\text{-}max}$:	46 ksi	*(317 MPa)*
Weld Material Minimum Yield Strength for BRB Components	$F_{exx,BRB}$:	70 ksi	*(483 MPa)*
Length of Lug to Core Weld at Bolt Pattern	L_{wLg}:	9.88 in	*(251 mm)*
Length of Lug to Core Weld beyond Bolt Pattern	L_{wL}:	10.13 in	*(257 mm)*
Weld Both Sides of Lug Beyond Bolt Pattern?	WBS:	FALSE	
Width of Steel Yielding Core	W_{sc}:	4.00 in	*(102 mm)*
Width of Stiffener at Lug	W_s:	1.09 in	*(28 mm)*
Thickness of Stiffener at Lug	t_s:	0.50 in	*(13 mm)*

3.6.1 Weld Size Required at Bolt Pattern

Percent of Core Stub Capacity at Lug Allowed to be Transferred thru that Section (max 100%). — $\%A_{sc\text{-}stub}$: 100%

Max Force in Stiffener at Lug

$P_{wLg} = P_{uC\text{-}max} \cdot W_s/W_{sc} \cdot \min(\%A_{sc\text{-}Stub}, 1.0)$ — P_{wLg}: 40.6 kip *(181 kN)*

**Conservative for sizing weld*

Min Weld Size Based on Material Thickness

IF	Then
$\min(t_L, t_s) \le$ ½"	$D_{wLg\text{-}min} = 3^{16ths}$
$\min(t_L, t_s) \le$ ¾"	$D_{wLg\text{-}min} = 4^{16ths}$
Otherwise	$D_{wLg\text{-}min} = 5^{16ths}$

$D_{wLg\text{-}min}$: 3.00 (16ths) *(5 mm)*

Weld Size Based on Required Force

$D'_{wLg} = P_{wLg}/(\phi_{Weld} \cdot 0.6 \cdot F_{exx} \cdot 0.7071 \cdot 2 \cdot L_{wLg}) \cdot 16$ — D'_{wLg}: 1.48 (16ths) *(2 mm)*

Required Weld Size

D_{wLg}:	3.00	*(5 mm)*
D_{wLg}:	3.00 (16ths)	*(5 mm)*
D_{wLg}:	3/16"	*(5 mm)*

Base Metal Thickness Check

$t_{min}/t_{L,sc}$ = Max of:

$1 \cdot F_{EXX,BRB} \cdot 0.7071 \cdot (D_{wLg}/16)/(F_{uL} \cdot t_L)$ = 0.286

$2 \cdot F_{EXX,BRB} \cdot 0.7071 \cdot (D_{wLg}/16)/(F_{usc} \cdot t_s)$ = 0.562

$DCR_{Weld\text{-}Lg}$: 0.56

3.6.2 Weld Size Required Beyond Bolt Pattern

Yield Strength of Stub Section

$F_{Y\text{-}wLq} = W_s \cdot t_s \cdot F_{ysc\text{-}max} \cdot \min(\%A_{sc\text{-}Stub}, 1.0)$ — $F_{Y\text{-}wLq}$: 25.2 kip *(112 kN)*

**Conservative for determining force in section before stub*

Force in Weld Beyond Bolt Group

$P_{wL} = P_{uC\text{-}max} - 2 \cdot F_{Y\text{-}wLg}$ — P_{wL}: 98.2 kip *(437 kN)*

Weld Size Based on Required Force

$D'_{wL} = P_{wL}/(\phi_{Weld} \cdot 0.6 \cdot F_{exx} \cdot 0.7071 \cdot 4 \cdot L_{wL}) \cdot 16$ — D'_{wL}: 1.74 (16ths) *(3 mm)*

Required Weld Size — D_{wL}: 3.00 (16ths) *(5 mm)*

Note that minimum weld size here equal to minimum size req'd at bolt pattern ($D_{wLg\text{-}min}$) since lug and core thickness are the same as at that location. — D_{wL}: 3.00 (16ths) *(5 mm)*; D_{wL}: 3/16" *(5 mm)*

Base Metal Thickness Check

Factor for Weld Both Sides (WBS) Beyond Bolt Pattern:

IF WBS = TRUE Then WBSF = 2, Otherwise WBSF = 1 — WBSF: 1

$t_{min}/t_{L,sc}$ = Max of: — $DCR_{Weld\text{-}L}$: 0.56

$WBSF \cdot F_{EXX,BRB} \cdot 0.7071 \cdot (D_{wL}/16)/(F_{uL} \cdot t_L)$ = 0.286

$2 \cdot F_{EXX,BRB} \cdot 0.7071 \cdot (D_{wL}/16)/(F_{usc} \cdot t_{sc})$ = 0.562

3.6.3 Weld Around Lug in Lieu of Bolting

Weld Material Minimum Yield Strength for Lug to Gusset (Alt Weld) — $F_{exx,BRB}$: 70 ksi *(483 MPa)*

Length of Sides of Lug Only — L_{LS}: 13.56 in *(344 mm)*

$L_{LS} = (L_{Lg} - W_L/2 - Tol_{LLS}) \cdot 4$ Tol_{LLS} = 0.50 in *(13 mm)*

Length Around Lug (Including Sides) — L_{rs}: 32.41 in *(823 mm)*

$L_{Lrs} = L_{Ls} + \pi \cdot (W_L/2) \cdot 2$

Plastic Section Modulus of Core Extension (Section Just Outside Casing)

$Z_+ = (2t_L \cdot W_1^2 + (W_t - 2t_L) \cdot t_{sc}^2)/4$ — Z_+: 3.44 in³ *(56351 mm³)*

Force Couple to Resist Plastification of Core Extension $F_R = Z_+ * F_{yL}/W_L$ — F_R: 28.7 kip *(127 kN)*

Required Weld if Welded Around Lug — D_{rs}: 4.56 *(7 mm)*

$D_{rs} = (P_{uC\text{-}max} + 2 \cdot F_R)/(L_{rs} \cdot 0.7071 \cdot 0.6 \cdot \phi_{Weld} \cdot F_{exx,Gst}) * 16$ — D_{rs}: 5.00 (16ths) *(8 mm)*; D_{rs}: 5/16" *(8 mm)*

Required Weld if Welded Around Sides of Lug Only — D_s: 10.90 *(17 mm)*

$D_s = (P_{uC\text{-}max} + 2 \cdot F_R)/(L_{Ls} \cdot 0.7071 \cdot 0.6 \cdot \phi_{Weld} \cdot F_{exx,Gst}) * 16$ — D_s: 11.00 (16ths) *(17 mm)*; D_s: 11/16" *(17 mm)*

3.7.0 Summary

3.1.0 Bolt Shear	DCR_{Shear}:	0.64
3.2.0 Bolt Friction	DCR_{Slip}:	0.82
3.3.1 Bolt Bearing - Gusset Plate	$DCR_{brq\text{-}g}$:	0.66
3.3.2 Bolt Bearing - Lug Plates	$DCR_{brg\text{-}L}$:	0.39
3.3.3 Combined Bolt Bearing & Tearout - Gusset	$DCR_{brq/Tear\text{-}G}$:	0.96
3.3.3 Combined Bolt Bearing & Tearout - Lug	$DCR_{brg/Tear\text{-}L}$:	0.96
3.4.0 Tension Fracture - Lug Plates	DCR_{tr}:	0.57
3.5.1 Block Rupture - Gusset Plate	$DCR_{blk\text{-}g}$:	0.68
3.5.2 Block Rupture - Lug Plates	$DCR_{blk\text{-}L}$:	0.50
3.6.1 Weld Strength at Bolt Pattern	$DCR_{Weld\text{-}Lq}$:	0.56
3.6.2 Weld Strength Beyond Bolt Pattern	$DCR_{Weld\text{-}L}$:	0.56
	Max:	0.96

End Connection Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																												Bolt Shear						Bolt Friction							
EOR-ID	Line	Grids	Lvls	Mark	Qty	W_T	W_s	W_L	t_{sc}	t_L	d_b	e	d_s	os_L	os_g	A_{sc}	n_i	n_o	g	s	$F_{u,sc}$	F_{ug}	F_{uL}	F_{vsc} max	F_{yg}	F_{yL}	β	$P_{ysc-max}$	P_{uc-max}	F_{nv}	Shear Type	L'_{Lg}	CLF	R_v	$\frac{P_u}{R_v}$	μ	ϕ	D_u	A_{Tb_min}	$F_{u,bolt}$	T_b	R_{str}	$\frac{P_{vsc}}{R_{str}}$
#		#	#	#	#	in	in	in	in	in	in	in	in	in	in	in^2	qty	qty	in	in	ksi	ksi	ksi	ksi	ksi	ksi		kip	kip	ksi		in		kip	$\frac{P_u}{R_v}$				in^2	ksi	kip	kip	$\frac{P_{vsc}}{R_{str}}$
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.17	92	149	64.8	N	3.5	1.00	234	0.64	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.17	92	149	64.8	N	3.5	1.00	234	0.64	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	5	E to D.5	1	**1903**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	4.000	0.781	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.16	92	146	64.8	N	3.5	1.00	234	0.63	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	4.000	0.781	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.16	92	146	64.8	N	3.5	1.00	234	0.63	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	4.000	0.719	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	4.000	0.719	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	E	4.7 to 5	1	**1909**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	4.000	1.031	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.12	92	138	64.8	N	3.5	1.00	234	0.59	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	4.000	1.031	6.00	0.750	0.50	0.875	1.188	0.9375	0.000	0.13	3.00	3	0	0.000	3.500	66	65	65	46	50	50	1.17	138	199	64.8	N	7.0	1.00	351	0.57	0.30	0.85	1.13	0.46	144	48	168	0.82
BRB-2.00	4	A.8 to A.99	1	**1912**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	B	5 to 4.7	1	**1913**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	4.000	0.656	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-3.00	2	D to C.6	1	**1916**	1	4.000	0.906	6.00	0.750	0.50	0.875	1.188	0.9375	0.000	0.13	3.00	3	0	0.000	3.500	66	65	65	46	50	50	1.17	138	197	64.8	N	7.0	1.00	351	0.56	0.30	0.85	1.13	0.46	144	48	168	0.82
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	4.000	0.656	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	4.000	0.656	6.00	0.500	0.75	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	3.2	D to C.6	1	**1918**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	4.000	1.094	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	4.000	1.031	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	134	64.8	N	3.5	1.00	234	0.57	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.50	2	A.2 to A	1	**1921**	1	4.000	1.094	6.00	0.625	0.50	0.875	1.188	0.9375	0.000	0.13	2.50	3	0	0.000	3.500	66	65	65	46	50	50	1.11	115	167	64.8	N	7.0	1.00	351	0.48	0.30	0.85	1.13	0.46	144	48	168	0.69
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	4.000	0.656	6.00	0.625	0.75	0.875	1.188	0.9375	0.000	0.13	2.50	3	0	0.000	3.500	66	65	65	46	50	50	1.11	115	167	64.8	N	7.0	1.00	351	0.48	0.30	0.85	1.13	0.46	144	48	168	0.69
BRB-3.50	A	3 to 2.7	1	**1923**	1	4.667	1.240	6.00	0.750	0.50	0.875	1.188	0.9375	0.000	0.13	3.50	3	0	0.000	3.500	66	65	65	46	50	50	1.17	161	232	64.8	N	7.0	1.00	351	0.66	0.30	0.85	1.13	0.46	144	48	168	0.96
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	4.000	0.781	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	136	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82
BRB-2.00	3	A.2 to A	1	**1925**	1	4.000	0.781	6.00	0.500	0.50	0.875	1.188	0.9375	0.000	0.13	2.00	2	0	0.000	3.500	66	65	65	46	50	50	1.11	92	135	64.8	N	3.5	1.00	234	0.58	0.30	0.85	1.13	0.46	144	48	112	0.82

Table Symbols & Definitions

W_T = Width of CB at connection
W_L = Width of lug
t_{sc} = Thickness of main core
t_L = Thickness of lug
d_b = Bolt diameter (A490 SC)
e = Edge distance
d_s = Standard bolt size
os_L = Amount lug hole oversized beyond standard hole
os_g = Amount gusset hole oversize beyond standard hole

A_{sc} = Cross sectional area of yielding core
n = Number of bolts in a row
g_o = Outer Bolt gauge
g_i = Inner Bolt gauge
s = Bolt spacing
$F_{u,sc}$ = Minimum tensile strength of core, MTRs
$F_{u,L\&g}$ = Minimum tensile strength of lug & gusset, ASTM
$F_{ysc,max}$ = Maximum yield strength of core per specification
$F_{y,L\&g}$ = Minimum yield strength of lug & gusset, ASTM

β = Compression strength adjustment factor
P_{ysc} = Minimum yield force of yielding element of steel core
P_u = Ultimate CB demand
F_{nv} = Nominal shear stress of bolt
L'_{Lg} = Length of bolt group parallel to direction of load.
CLF = Connection Length Factor per AISC 360 Table J3.2
R_v = Design shear strength of bolts at connection (double shear)
ϕ = LRFD Resistance Factor for oversized and short-slotted holes parallel to the direction of the load per AISC 360-10 J3.8

End Connection Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Gusset Dims		Bearing: Gusset				Bearing: Lug				Combined Bolt Bearing, Tearout, & Shear: Gusset										Combined Bolt Bearing, Tearout, & Shear: Lug										Tension Rupture (Fracture): Lug					
EOR-ID	Line	Grids	Lvls	Mark	Qty	t_g	t_{r_Des}	L_{ce}	L_{cs}	$R_{b,g}$	$\underline{P_\mu}$	$L_{c,e}$	$L_{c,s}$	$R_{b,L}$	$\underline{P_\mu}$	GEB_{ni}	GEB_{no}	GFB_{ni}	GFB_{no}	ϕr_{nv}	$\phi R_{n\text{-}C,Edge}$	$\phi R_{n\text{-}T,Edge}$	$\phi R_{n\text{-}G,Field}$	$\phi R_{n\text{-}CG}$	$\phi R_{n\text{-}TG}$	$\underline{P_\mu}$	LEB_{ni}	LEB_{no}	LFB_{ni}	LFB_{no}	$\phi R_{n\text{-}L,Field}$	$\phi R_{n\text{-}CL}$	$\phi R_{n\text{-}TL}$	$\underline{P_\mu}$	$A_{e,L}$	A_{gt}	$A_{e,L\&t}$	U	$R_{n,L}$	$\underline{P_\mu}$
#		#	#	#	#	in	in	in	in	kip	R_{bg}	in	in	kip	$R_{b,L}$	kip	kip	kip	kip	kip	kip	kip	kip	kip	kip	$\phi R_{n\text{-}G}$	kip	kip	kip	kip	kip	kip	kip	$\phi R_{n\text{-}L}$	in^2	in^2	in^2		kip	$R_{n,L}$
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	0.63	0.000	0.66	2.44	226	0.66	0.72	2.56	384	0.39	24	0	64	0	58	234	132	0	234	132	0.96	42	0	102	0	0	234	132	0.96	4.00	1.09	5.09	0.89	223	0.57
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	0.63	0.000	0.66	2.44	226	0.66	0.72	2.56	384	0.39	24	0	64	0	58	234	132	0	234	132	0.96	42	0	102	0	0	234	132	0.96	4.00	1.09	5.09	0.89	223	0.57
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.93	42	0	102	0	0	234	132	0.93	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.93	42	0	102	0	0	234	132	0.93	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	5	E to D.5	1	**1903**	1	0.63	0.000	0.66	2.44	226	0.59	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.91	42	0	102	0	0	234	132	0.91	4.00	1.09	5.09	0.89	223	0.54
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	0.75	0.000	0.66	2.44	271	0.54	0.72	2.56	576	0.25	29	0	77	0	58	234	174	0	234	174	0.72	63	0	154	0	0	234	174	0.72	6.00	0.78	6.78	0.88	290	0.43
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	0.75	0.000	0.66	2.44	271	0.54	0.72	2.56	576	0.25	29	0	77	0	58	234	174	0	234	174	0.72	63	0	154	0	0	234	174	0.72	6.00	0.78	6.78	0.88	290	0.43
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.93	42	0	102	0	0	234	132	0.93	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.93	42	0	102	0	0	234	132	0.93	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	0.88	0.000	0.66	2.44	317	0.42	0.72	2.56	576	0.23	34	0	90	0	58	234	184	0	234	184	0.65	63	0	154	0	0	234	184	0.65	6.00	0.72	6.72	0.88	288	0.42
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	0.88	0.000	0.66	2.44	317	0.42	0.72	2.56	576	0.23	34	0	90	0	58	234	184	0	234	184	0.65	63	0	154	0	0	234	184	0.65	6.00	0.72	6.72	0.88	288	0.42
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	E	4.7 to 5	1	**1909**	1	0.63	0.000	0.66	2.44	226	0.59	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.91	42	0	102	0	0	234	132	0.91	4.00	1.09	5.09	0.89	223	0.54
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	0.75	0.000	0.66	2.44	271	0.51	0.72	2.56	384	0.36	29	0	77	0	58	234	142	0	234	142	0.87	42	0	102	0	0	234	142	0.87	4.00	1.03	5.03	0.90	221	0.56
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	0.75	0.000	0.66	2.44	461	0.43	0.72	2.56	614	0.32	29	0	77	0	58	234	142	117	351	259	0.66	42	0	102	0	117	351	259	0.66	4.00	1.55	5.55	0.94	256	0.66
BRB-2.00	4	A.8 to A.99	1	**1912**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	B	5 to 4.7	1	**1913**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	1.00	0.000	0.66	2.44	362	0.37	0.72	2.56	576	0.23	38	0	102	0	58	234	194	0	234	194	0.62	63	0	154	0	0	234	194	0.62	6.00	0.66	6.66	0.88	286	0.42
BRB-3.00	2	D to C.6	1	**1916**	1	1.00	0.000	0.66	2.44	614	0.32	0.72	2.56	614	0.32	38	0	102	0	58	234	161	117	351	278	0.61	42	0	102	0	117	351	278	0.61	4.00	1.36	5.36	0.95	248	0.68
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	1.00	0.000	0.66	2.44	362	0.37	0.72	2.56	576	0.23	38	0	102	0	58	234	194	0	234	194	0.62	63	0	154	0	0	234	194	0.62	6.00	0.66	6.66	0.88	286	0.42
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	1.00	0.000	0.66	2.44	362	0.37	0.72	2.56	576	0.23	38	0	102	0	58	234	194	0	234	194	0.62	63	0	154	0	0	234	194	0.62	6.00	0.66	6.66	0.88	286	0.42
BRB-2.00	3.2	D to C.6	1	**1918**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	0.63	0.000	0.66	2.44	226	0.60	0.72	2.56	384	0.35	24	0	64	0	58	234	132	0	234	132	0.92	42	0	102	0	0	234	132	0.92	4.00	1.09	5.09	0.89	223	0.55
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	0.75	0.000	0.66	2.44	271	0.49	0.72	2.56	384	0.35	29	0	77	0	58	234	142	0	234	142	0.85	42	0	102	0	0	234	142	0.85	4.00	1.03	5.03	0.90	221	0.55
BRB-2.50	2	A.2 to A	1	**1921**	1	0.63	0.000	0.66	2.44	384	0.44	0.72	2.56	614	0.27	24	0	64	0	58	234	132	117	351	249	0.61	42	0	102	0	117	351	249	0.61	4.00	1.37	5.37	0.94	248	0.61
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	1.00	0.000	0.66	2.44	614	0.27	0.72	2.56	921	0.18	38	0	102	0	58	234	194	117	351	311	0.49	63	0	154	0	117	351	311	0.49	6.00	0.82	6.82	0.94	312	0.48
BRB-3.50	A	3 to 2.7	1	**1923**	1	1.00	0.000	0.66	2.44	614	0.38	0.72	2.56	614	0.38	38	0	102	0	58	234	161	117	351	278	0.71	42	0	102	0	117	351	278	0.71	4.00	1.86	5.86	0.93	268	0.74
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	1.25	0.000	0.66	2.44	452	0.30	0.72	2.56	384	0.35	48	0	128	0	58	234	180	0	234	180	0.68	42	0	102	0	0	234	180	0.68	4.00	0.78	4.78	0.91	212	0.58
BRB-2.00	3	A.2 to A	1	**1925**	1	1.25	0.000	0.66	2.44	452	0.30	0.72	2.56	384	0.35	48	0	128	0	58	234	180	0	234	180	0.67	42	0	102	0	0	234	180	0.67	4.00	0.78	4.78	0.91	212	0.57

μ = Slip coefficient
D_u = Multiplier that reflects the ratio of the mean installed bolt pretension to the specified minimum bolt pretension.
A_{Tb_min} = Minimum tensile area of bolt
$F_{u,bolt}$ = Specified minimum tensile strength of bolt
T_b = Minimum fastener tension
R_{str} = Design friction strength of bolts at connection

t_g = Total thickness of gusset
t_{r_Des} = Thickness of the gusset repad that gets used for strength calculations.
$L_{c,e}$ = Distance between edge of plate and edge of bolt hole
$L_{c,s}$ = Distance between edge of bolt holes
$R_{b,g}$&$R_{b,L}$ = Bearing strength of bolts at gusset and lug
$A_{c,Wc1}$ = Area of core at end connection
$R_{n,sc}$&$R_{n,L}$ = Tension and or shear strength of core and splice plate at bolts.
$A_{e,L}$ = Net area of lugs at end connection

GEB = Gusset Capacity at Edge Bolt (min of Bearing and Tearout)
GFB = Gusset Capacity at Field Bolt (min of Bearing and Tearout)
LEB = Lug Capacity at Edge Bolt (min of Bearing and Tearout)
LFB = Lug Capacity at Field Bolt (min of Bearing and Tearout)
$\phi R_{n\text{-}C}$ = Group (or Subgroup) Capacity in Compression
$\phi R_{n\text{-}T}$ = Group (or Subgroup) Capacity in Tension
Note, T or C Edge Subgroup Capacities are the Same for Lug or Gusset
$\phi R_{n\text{-}G}$ = Group (or Subgroup) Capacity at Gusset
$\phi R_{n\text{-}L}$ = Group (or Subgroup) Capacity at Lug

End Connection Calculations

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Block Rupture												Weld Lengths																			
						Gusset							Lug					Lug to Core																Alt Lug Weld			
EOR-ID	Line	Grids	Lvls	Mark	Qty	$A_{nv,g}$	$A_{gt,g}$	$A_{gv,g}$	$A_{nt,g}$	U_{bs}	$R_{n,g}$	$\underline{P_u}$	$A_{gv,L}$	$A_{nv,L}$	$A_{gt,L}$	$A_{nt,L}$	$R_{n,L}$	$\underline{P_u}$	$F_{exx,BRB}$	$F_{exx,Gst}$	$\underline{W_s}$	Weld 2	L_{wL}	P_{wL}	$D_{wL\text{-}min}$	$D_{wL\text{-}req'd}$	$L_{wL\text{-}stub}$	$P_{wL\text{-}stub}$	$D_{wLg\text{-}req'd}$	D_{wLg}	$\underline{t_{min}}$	D_{wL}	$\underline{t_{min}}$	L_{Lr+s}	L_{Ls}	Alt	Alt
#		#	#	#	#	in^2	in^2	in^2	in^2		kip	$R_{n,g}$	in^2	in^2	in2	in2	kip	$R_{n,L}$	ksi	ksi	W_{sc}	Sides?	in	kip	#	#	in	kip	#	#	$t_{g,sc}$	#	$t_{g,sc}$	in	in	D_{Lr+s}	D_{Ls}
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	3.8	2.3	5.9	1.6	1.0	186	0.68	9.4	6.4	2.4	1.4	254	0.50	70	70	0.27	FALSE	10	98	3.0	1.7	9.9	41	1.5	3	0.56	3	0.56	32	14	5	11
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	3.8	2.3	5.9	1.6	1.0	186	0.68	9.4	6.4	2.4	1.4	254	0.50	70	70	0.27	FALSE	10	98	3.0	1.7	9.9	41	1.5	3	0.56	3	0.56	32	14	5	11
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	3.8	2.3	5.9	1.6	1.0	186	0.66	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	86	3.0	1.5	9.9	37	1.4	3	0.56	3	0.56	32	14	5	11
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	3.8	2.3	5.9	1.6	1.0	186	0.66	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	86	3.0	1.5	9.9	37	1.4	3	0.56	3	0.56	32	14	5	11
BRB-2.00	5	E to D.5	1	**1903**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	83	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	4.5	2.7	7.0	1.9	1.0	223	0.57	14.1	9.6	3.6	2.1	380	0.33	70	70	0.20	FALSE	10	110	3.0	2.0	9.9	29	1.0	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	4.5	2.7	7.0	1.9	1.0	223	0.57	14.1	9.6	3.6	2.1	380	0.33	70	70	0.20	FALSE	10	110	3.0	2.0	9.9	29	1.0	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	3.8	2.3	5.9	1.6	1.0	186	0.66	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	86	3.0	1.5	9.9	37	1.4	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	3.8	2.3	5.9	1.6	1.0	186	0.66	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	86	3.0	1.5	9.9	37	1.4	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	5.3	3.2	8.2	2.2	1.0	260	0.46	14.1	9.6	3.6	2.1	380	0.32	70	70	0.18	FALSE	10	101	3.0	1.8	9.9	24	0.9	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	5.3	3.2	8.2	2.2	1.0	260	0.46	14.1	9.6	3.6	2.1	380	0.32	70	70	0.18	FALSE	10	101	3.0	1.8	9.9	24	0.9	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	E	4.7 to 5	1	**1909**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	83	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	E	3.8 to 4.1	Low Roof	**1910**	1	4.5	2.7	7.0	1.9	1.0	223	0.55	9.4	6.4	2.4	1.4	254	0.49	70	70	0.26	FALSE	10	91	3.0	1.6	9.9	36	1.3	3	0.56	3	0.56	32	14	5	11
BRB-3.00	E	4.1 to 3.8	1	**1911**	1	8.1	2.7	12.3	1.9	1.0	327	0.52	16.4	11.4	2.4	1.4	400	0.42	70	70	0.26	FALSE	11	127	3.0	2.1	13.4	51	1.4	3	0.37	3	0.37	46	28	5	8
BRB-2.00	4	A.8 to A.99	1	**1912**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	B	5 to 4.7	1	**1913**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	2	D to C.6	Low Roof	**1915**	1	6.0	3.6	9.4	2.5	1.0	297	0.41	14.1	9.6	3.6	2.1	380	0.32	70	70	0.16	TRUE	20	104	3.0	0.9	9.9	22	0.8	3	0.56	3	0.56	32	14	5	11
BRB-3.00	2	D to C.6	1	**1916**	1	10.8	3.6	16.4	2.5	1.0	436	0.39	16.4	11.4	2.4	1.4	400	0.42	70	70	0.23	TRUE	22	134	3.0	1.1	13.4	45	1.2	3	0.37	3	0.57	46	28	5	8
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	6.0	3.6	9.4	2.5	1.0	297	0.41	14.1	9.6	3.6	2.1	380	0.32	70	70	0.16	TRUE	20	104	3.0	0.9	9.9	22	0.8	3	0.56	3	0.56	32	14	5	11
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	6.0	3.6	9.4	2.5	1.0	297	0.41	14.1	9.6	3.6	2.1	380	0.32	70	70	0.16	TRUE	20	104	3.0	0.9	9.9	22	0.8	3	0.56	3	0.56	32	14	5	11
BRB-2.00	3.2	D to C.6	1	**1918**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	3.8	2.3	5.9	1.6	1.0	186	0.65	9.4	6.4	2.4	1.4	254	0.48	70	70	0.27	FALSE	10	84	3.0	1.5	9.9	37	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.00	E	1.5 to 2	Low Roof	**1920**	1	4.5	2.7	7.0	1.9	1.0	223	0.54	9.4	6.4	2.4	1.4	254	0.48	70	70	0.26	FALSE	10	86	3.0	1.5	9.9	34	1.3	3	0.56	3	0.56	32	14	5	11
BRB-2.50	2	A.2 to A	1	**1921**	1	6.7	2.3	10.2	1.6	1.0	273	0.55	16.4	11.4	2.4	1.4	400	0.38	70	70	0.27	FALSE	10	104	3.0	1.8	13.4	46	1.2	3	0.45	3	0.45	46	28	5	7
BRB-2.50	A	3 to 2.7	Low Roof	**1922**	1	10.8	3.6	16.4	2.5	1.0	436	0.35	24.6	17.1	3.6	2.1	600	0.25	70	70	0.16	TRUE	20	129	4.0	1.1	13.4	27	0.7	4	0.60	4	0.60	46	28	5	7
BRB-3.50	A	3 to 2.7	1	**1923**	1	10.8	3.6	16.4	2.5	1.0	436	0.45	16.4	11.4	2.4	1.4	400	0.50	70	70	0.27	FALSE	12	146	3.0	2.3	13.4	62	1.7	3	0.37	3	0.37	46	28	6	9
BRB-2.00	3	A.2 to A	Low Roof	**1924**	1	7.5	4.5	11.7	3.1	1.0	372	0.33	9.4	6.4	2.4	1.4	254	0.48	70	70	0.20	TRUE	22	100	3.0	0.8	9.9	27	1.0	3	0.56	3	0.57	32	14	5	11
BRB-2.00	3	A.2 to A	1	**1925**	1	7.5	4.5	11.7	3.1	1.0	372	0.33	9.4	6.4	2.4	1.4	254	0.48	70	70	0.20	TRUE	20	99	3.0	0.9	9.9	26	1.0	3	0.56	3	0.57	32	14	5	11

A_{gt} = Area gross of stiffeners at lugs at end connection
$A_{e,L\&t}$ = Net area of lugs and stiffener at end connection
U = Shear lag factor (AISC 360, Table D3.1)
$A_{nv,g}\&A_{nv,L}$ = Net shear area of gusset & lug
$A_{gt,g}\&A_{gt,L}$ = Gross tensile area of gusset & lug
$A_{nt,g}\&A_{nt,L}$ = Net tensile area of gusset & lug
$A_{gv,g}\&A_{gv,L}$ = Gross shear area of gusset & lug
U_{bs} = Reduction coefficient for block rupture (1.0 for uniform loading, 0.5 otherwise)

F_{exx} = Filler metal classification strength
L_{wL} = Length of weld lug to main core PL
F_{wL} = Force that must be transferred to the lug in at the tapered down section.
$R_{n,g}\&R_{n,L}$ = Capacity of gusset & lug

PSE Operational Training Center

Calculation Submittal Package

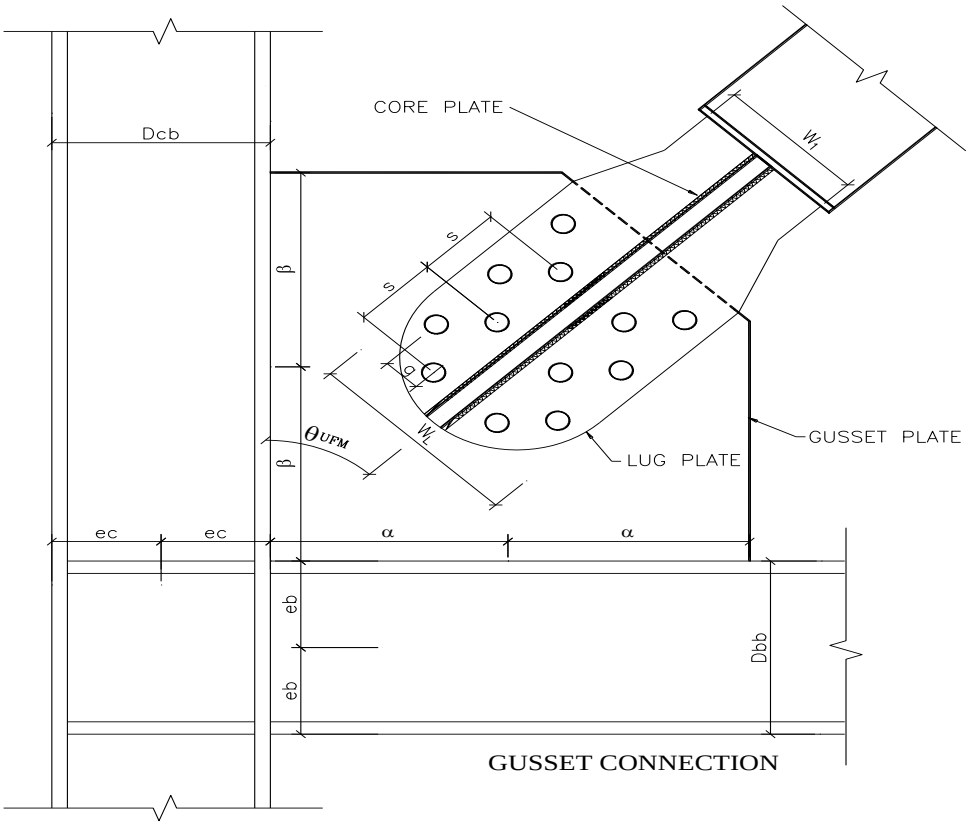
Description

Section 4. **Bottom Gusset Beam to Column Flange (Strong-Axis) Connection Sample Calculation**
Top and Bottom Connection Summary Tables

Bottom Gusset Connection

(Top Connection Similar)

Example Mark #: 1910
Line E, Grid 3.8 to 4.1, Level Low Roof



Uniform Force Method - AISC 360 - Bracing Section

4.0 DESIGN CRITERIA

Area of Yielding Steel Core	A_{sc}:	2.00 in²	*(1290 mm²)*
Maximum Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Compresssion Strength Adjustment Factor	β:	1.12	
Strain Hardening Adjustment Factor	ω:	1.34	
Connection Strain Hardening Factor	CF:	1.00	
Adjusted Brace Strength (Design Axial Load) in Compression ($CF \cdot \beta\omega F_{y\text{-}max}A_{sc}$)	P_{uc}:	138.1 kip	*(614 kN)*
Adjusted Brace Strength (Design Axial Load) in Tension ($CF \cdot \omega F_{y\text{-}max}A_{sc}$)	P_{ut}:	123.3 kip	*(548 kN)*
Thickness of Yielding Core	$t_{sc:}$	0.50 in	*(13 mm)*
Width of Lug	W_L:	6.00 in	*(152 mm)*
Column Depth	D_{cb}:	6.00 in	*(152 mm)*
Column Web Thickness	t_{wc}:	1.25 in	*(32 mm)*
Column Flange Thickness	t_{fc}:	0.63 in	*(16 mm)*
Column Flange Width	b_{fc}:	6.00 in	*(152 mm)*
Column Web Doubler Plate Thickness (one side)	t_{wcPL}:	0.00 in	*(0 mm)*
Beam Depth	D_{bb}:	11.90 in	*(302 mm)*
Nominal Depth of Beam	DN_{bb}:	11.90 in	*(302 mm)*
Beam Web Thickness	t_{wb}:	0.30 in	*(7 mm)*
Beam Flange Thickness	t_{fb}:	0.52 in	*(13 mm)*
Beam Flange Width	b_{fb}:	8.01 in	*(203 mm)*
Beam Distance from Outer Face of Flange to Toe of Fillet	k_{desb}:	1.02 in	*(26 mm)*
Column Distance from Outer Face of Flange to Toe of Fillet	k_{desc}:	1.00 in	*(25 mm)*
Beam Web Doubler Plate Thickness (one side)	t_{wbPL}:	0.00 in	*(0 mm)*
Angle Between the Beam and Brace CL	θ_{CB}:	0.434 rad	*24.9°*
Angle Between the Column and Brace CL	θ_{UFM}:	1.136 rad	*65.1°*
Min Clear Distance from Face of Beam to Edge of Lug	$b_{bot\text{-}Bm}$:	2.38 in	*(60 mm)*
Min Clear Distance from Face of Column to Edge of Lug	$b_{bot\text{-}Col}$:	1.00 in	*(25 mm)*
Distance from Last Bolt to Start of Radius on Lug	b_r:	0.80 in	*(20 mm)*
Bolt Edge Distance	e:	1.19 in	*(30 mm)*
Provided Stroke Distance at Each End of Brace	c:	3.00 in	*(76 mm)*
Distance Between End of Core and Gusset	a:	4.00 in	*(102 mm)*

4.1.0 GEOMETRY CALCULATIONS - UNIFORM FORCE METHOD

Length from WP to Bottom Tip of Brace			
Length from WP to Outside Edge of Col along WorkLine			
$L_{cb} = (D_{cb}/2)/COS(\theta_{CB})$	L_{cb}:	3.31 in	*(84 mm)*
Length from Edge of Column to Tip of CB along WL			
$L_{1cb} = [b_{bot\text{-}Col} + (W_L/2)]/COS(\theta_{CB}) - (e + b_r)$	L_{1cb}:	2.43 in	*(62 mm)*
Length from WP to Top Edge of Beam along WL			
$L_{bb} = (DN_{bb}/2)/SIN(\theta_{CB})$	L_{bb}:	14.14 in	*(359 mm)*
Length from Edge of Beam to Tip of CB along WL			
$L_{1bb} = [b_{bot\text{-}Bm} + (W_L/2)]/SIN(\theta_{CB}) - (e + b_r)$	L_{1bb}:	10.80 in	*(274 mm)*
Controling Length is $MAX(L_{cb}+L_{1cb}, L_{bb}+L_{1bb})$	L_{tb}:	24.94 in	*(634 mm)*
Length from Square Projection to Edge of Gusset (CB Lap on Gusset)	L_g:	5.88 in	*(149 mm)*
Horizontal Distance from Column to WP ($D_{cb}/2$)	e_c:	0.00 in	*(0 mm)*
For HSS columns, set e_c to 0" and slot the gusset through the column, welding on both sides. This allows the resultent of the weld group to be concentric with the work point and eliminates horizontal forces and moments from being applied to the relatively flexible face of the HSS column.			
Vertical Distance from Beam to WP ($DN_{bb}/2$)	e_b:	5.95 in	*(151 mm)*

Minimum Weld on Column from Geometry

$L_{wc_min} = (L_{tb} + L_g)*SIN(\theta_{CB}) + (W_L/2 + 1)*COS(\theta_{CB}) - DN_{bb}/2$ | L_{wc_min}: | 10.65 in | *(270 mm)*

Minimum Weld on Beam from Geometry

$L_{wb_min} = (L_{tb} + L_g)*COS(\theta_{CB}) + (W_L/2 + 1)*SIN(\theta_{CB}) - D_{cb}/2$ | L_{wb_min}: | 26.64 in | *(677 mm)*

Dist from Face of Col Fl to Centriod of Gusset-to-Beam Connection (UFM)

$\alpha_{min} = L_{wb_min}/2$ | α_{min} | 13.32 in | *(338 mm)*

α_{Hand} = Hand Input Value to Force | α_{Hand} | 10.51 in | *(267 mm)*

If Hand Input Value is Different from α_{min} use Hand Input Value | α_{min}: | 10.51 in | *(267 mm)*

Inside Weld Deducts: | $WD_{Bm,In}$: | 1.50 in | *(38 mm)*

Outside Weld Deducts: | $WD_{Bm,Out}$: | 0.50 in | *(13 mm)*

α Dist for Weld (1/2 of the actual weld length used for design) | α_g: | 9.51 in | *(242 mm)*

α Dist from face of column to mid point on beam welds

$\alpha_{bar} = WD_{Bm,In} + \alpha_g$ | α_{bar}: | 11.01 in | *(280 mm)*

Dist from Face of Beam Fl to Centriod of Gusset-to-Column Connection (UFM)

$\beta_{min} = L_{wc_min}/2$ | β_{min} | 5.32 in | *(135 mm)*

β_{Hand} = Hand Input Value to Force | β_{Hand} | 5.32 in | *(135 mm)*

If Hand Input Value is Different from β_{min} use Hand Input Value | β_{min}: | 5.32 in | *(135 mm)*

Inside Weld Deducts: | $WD_{Col,In}$: | 1.50 in | *(38 mm)*

Outside Weld Deducts: | $WD_{Col,Out}$: | 0.50 in | *(13 mm)*

β Dist for Weld (1/2 of the actual weld length used for design) | β_g: | 4.32 in | *(110 mm)*

β from face of beam to mid point on column welds

$\beta_{bar} = WD_{Col,In} + \beta_g$ | β_{bar}: | 5.82 in | *(148 mm)*

Final Gusset-Beam Weld Length *(note that welds sized on 2 α g only)*

$L_{wbu} = ROUNDUP(2\alpha_q)$ | L_{wbu}: | 20.00 in | *(508 mm)*

Final Gusset-Column Weld Length *(note that welds sized on 2βg only)*

$L_{wcu} = ROUNDUP(2\beta_g)$ | L_{wcu}: | 9.00 in | *(229 mm)*

Constants for Connections not in Equilibrium

$K = e_b TAN(\theta_{UFM}) - e_c$ | K: | 12.83 in | *(326 mm)*

$K' = \alpha_{bar}[TAN(\theta_{UFM}) + \alpha_{bar}/\beta_{bar}]$ | K': | 44.55 in | *(1132 mm)*

$D = (TAN(\theta_{UFM}))^2 + (\alpha_{bar}/\beta_{bar})^2$ | D: | 8.22

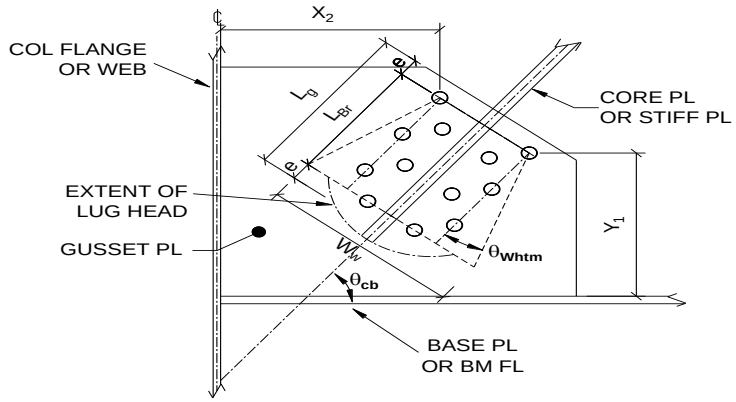
Final values of α and β

$\alpha_{nE} = [K'*TAN(\theta_{UFM}) + K(\alpha_{bar}/\beta_{bar})^2]/D$ | α_{nE}: | 17.26 in | *(438 mm)*

$\beta_{nE} = [K' - K*TAN(\theta_{UFM})]/D$ | β_{nE}: | 2.05 in | *(52 mm)*

$r = \sqrt{((\alpha_{nE} + e_c)^2 + (\beta_{nE} + e_b)^2)}$ | r: | 19.02 in | *(483 mm)*

4.2.0 GUSSET STRESS CALCULATIONS - AISC 360



4.2.1 WHITMORE SECTION STRESS CHECK

LRFD Resistance Factor	ϕ_W:	0.90	
Number of Bolts in Inside Row	n_i:	2	
Number of Bolts in Outside Row	n_o:	0	
Total Number of Bolts at Each End $2(n_i + n_o)$	n_b:	4	
Bolt Spacing	s:	3.50 in	*(89 mm)*
Lug Width	W_L:	6.00 in	*(152 mm)*
Minimum Yield Strength of Gusset	F_{yg}:	50 ksi	*(345 MPa)*
Minimum Tensile Strength of Gusset	F_{ug}:	65 ksi	*(448 MPa)*
Thickness of Gusset Plate	$t_{q:}$	0.75 in	*(19 mm)*
Thickness of Repad Plate for Design:	$t_{r:}$	0.00 in	*(0 mm)*
Whitmore Angle	θ_{Whtm}:	28.0°	*0.489 rad*
Total Length Between Outer Bolt Holes $L_{Br} = L_q - 2e$	L_{Br}:	3.50 in	*(89 mm)*
Vertical Distance to Top Bolt on Beam Side of CL $Y_1 = L_{wc\text{-}min} - (W_L + 1 - e)\cdot COS(\theta_{CB}) - e\cdot SIN(\theta_{CB})$	Y_1:	4.87 in	*(124 mm)*
Horizontal Distance to Top Bolt on Column Side of CL $X_2 = L_{wb\text{-}min} - (W_L + 1 - e)\cdot SIN(\theta_{CB}) - e\cdot COS(\theta_{CB})$	X_2:	23.12 in	*(587 mm)*
Whitmore Length if Not Limited by Beam or Column $h_{Br} = L_{Br}/COS(\theta_{Whtm})$	h_{Br}:	3.96 in	*(101 mm)*
Gusset Condition: FHG - Full Height Gusset NFG - Non Full Height Gusset	FHG:	TRUE	
Whitmore Length if Limited by Beam IF — Then FHG = TRUE — $h_{Bm} = h_{Br}$ FHG = FALSE — $h_{Bm} = Y_1/SIN(\theta_{CB} + \theta_{Whtm})$	h_{Bm}:	3.96 in	*(101 mm)*
Whitmore Length if Limited by Column $h_{Col} = X_2/COS(\theta_{CB} - \theta_{Whtm})$	h_{Col}:	23.15 in	*(588 mm)*
Constrain Whitmore Section within Gusset Plate?	WSG:	FALSE	
Whitmore Area IF — Then WSG = TRUE — $A_w = [2\cdot\min(h_{Br},h_{Bm},h_{Col})\cdot SIN(\theta_{Whtm})]\cdot t_g + (W_L - 2e)\cdot(t_g + 2t_r)$ WSG = FALSE — $A_w = [2\cdot L_{BR}\cdot TAN(\theta_{Whtm})]\cdot t_q + (W_L - 2e)\cdot(t_q + 2t_r)$	A_W =	5.51 in²	*(3555 mm²)*

Whitmore Capacity $\phi R_{n\text{-}W} = \phi_W \cdot A_W \cdot F_{yg}$	$\phi R_{n\text{-}W}$:	248.0 kip	*(1103 kN)*
Whitmore Stress Ratio			
$DCR_W = P_{ut}/\phi R_{n\text{-}W}$	DCR_W:	0.50	

4.2.2 Gusset Plate Buckling

LRFD Resistance Factor	ϕ_{gb}:	0.85	
Modulus of Elasticity	E:	29000 ksi	*(199955 MPa)*
Effective Length Factor for Gusset Buckling	K_{gb}:	1.00	
Average Buckling Length *Average of L_1, L_2, & L_3. If average is less than zero, zero is used (Gusset is Elastic).*	L':	12.39 in	*(315 mm)*
Radius of Gyration of Gusset $r_g = \sqrt{(t_g^2/12)}$	r_g:	0.22 in	*(5 mm)*
Gusset Slenderness Parameter $\lambda = K_{gb} \cdot L'/(r_g \cdot \pi) \cdot \sqrt{(F_{yg}/E)}$	λ:	0.76	
Gusset Buckling Capacity $\phi R_{n\text{-}gb} = \phi_{gb} \cdot 0.658^{\wedge}(\lambda_c^2) \cdot F_{yg} \cdot A_w$	$\phi R_{n\text{-}gb}$:	184.3 kip	*(820 kN)*
Gusset Buckling Capacity Ratio			
$DCR_{gb} = P_{uc}/\phi R_{n\text{-}gb}$	DCR_{gb}:	0.75	

4.2.3 Gusset Plate Buckling (Out-of-Plane)

A. Consider Self Weight of Brace Out-of-Plane Acting on Gusset

Assumed Spectral Acceleration	S_A:	1.02 g	
Factor on S_A	F_{SA}	0.40	
Importance Factor	I_p:	1.00	
Brace Weight	Wt_{br}:	0.72 kip	*(3.2 kN)*
Additional Out-of-Plane Force on Gusset *(when present)*.	$F_{Add'l\text{-}OOP/End}$:	0.00 kip	*(0.0 kN)*
Out of Plane Force at Each End of Brace due to BRB Self Weight SW $F_{OOP} = F_{SA} \cdot S_A \cdot I_p \cdot Wt_{br}/2 + F_{Add'l\text{-}OOP/End}$	F_{OOP}:	0.147 kip	*(1 kN)*
Moment Arm $M_{Arm_OOP} = L_g + a + 2 \cdot C$	M_{Arm_OOP}:	15.88 in	*(403 mm)*
Resulting Self Weight Out-of-Plane Moment SW $M_{OOP} = F_{OOP} \cdot M_{Arm_OOP}$	M_{OOP}:	2.3 kip-in	*(263 kN-mm)*

B. Consider Adjusted Brace Strength at Out Of Plane Frame Deformation

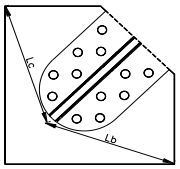
Story Drift Factor *(Usually 2x, But if considering 100% of ABS, Use only 1/3 of this)*	F_{SD}:	0.67	
Story Drift (See Stiffness Section for Calculation)	SD:	1.00%	
Drift Angle $\theta_{SD} = ATAN(SD \cdot F_{SD})$	θ_{SD}:	0.0067	(0.38°)
Percentage of Adjusted Brace Strength to Consider *Use either 100% ABS and 1/3 of 2xSD, or 30% ABS and 2xSD*	F_{ABS}:	100%	
Out of Plane component of F_{ABS}xAdjusted Brace Strength $P_H = F_{ABS} \cdot P_{uc} \cdot SIN(\theta_{SD})$	P_H:	0.92 kip	*(4.1 kN)*
Moment Arm (consider PH applied at centroid of BRB-gusset connection) $M_{Arm_PH} = L_{Lg}/2$	M_{Arm_PH}:	2.94 in	*(75 mm)*
Resulting Horizontal Moment $M_{PH} = P_H \cdot M_{Arm_PH}$	M_{PH}:	2.70 k-in	*(306 kN-mm)*

C. Consider Total Moment from Part A and B

Total Out of Plane Moment

$M_u = M_{OOP} + M_{PH}$ — M_u: 5 k-in *(569 kN-mm)*

Length of potential yielding line (disregarding concrete where occurs)



To Intersection with Column — L_c: 7.2 in *(183 mm)*

To Intersection with Beam/BP — L_b: 4.7 in *(120 mm)*

Total Length — L_t: 11.9 in *(303 mm)*

Plastic Modulus

$Z_q = L_t \cdot t_q^2/4$ — Z_q: 1.68 in³ *(27469 mm³)*

Design Flexural Strength

$\phi M_n = 0.9 \cdot Z_R \cdot F_{yR}$ — ϕM_n: 75 k-in *(8524 kN-mm)*

Gusset Flexure Capacity Ratio

$DCR_{gf} = M_u/\phi M_n$ — DCR_{gf}: 0.07

Combined Gusset Buckling & Flexure DCR

IF $DCR_{gb} \geq 0.2$, $DCR_{gb+f} = DCR_{gb} + (8/9)DCR_{gf}$ — DCR_{gb+f}: 0.81

IF $DCR_{gb} < 0.2$, $DCR_{gb+f} = (1/2)DCR_{gb} + DCR_{gf}$ — DCR_{gb+f}: -

4.3.0 FORCE CALCULATIONS - AISC 360 BRACING SECTION

Force at the Column Face

Vertical Force $V_{uc} = P_{uc} * \beta_{nE}/r$ — V_{uc}: 14.9 kip *(66 kN)*

See Section 4.4.2 for definitions of R_{ub} and $\phi_{OGC,Below}$

Eccentricity of Beam Reaction (at Full Height Gusset Only)

ecc_{Rub}=ROUNDUP(2·α min,0)+D_{cb}/2 — ecc_{Rub}: 25.0 in *(635 mm)*

Vertical force Couple from Moment Caused by Eccentric Reaction from Beam at FHG

FHG FC=$(R_{ub}/\phi_{OGC,Below}) \cdot ecc_{Rub}/D_{cb}$ — FHG FC: 66.04 kip *(293.7 kN)*

Portion of the FHG Force Couple Resisted Along the Gusset Height, Outside Beam Depth

FC_c=(FHG FC)·$(2 \cdot \beta_g)/(2 \cdot \beta_g + D_{bb}/\phi_{OGC,Below})$ — FC_c: 38.24 kip *(170.1 kN)*

Portion of the FHG Force Couple Resisted Through the Beam Depth

$FC_{c,g}$=(FHG FC)·$(D_{bb}/\phi_{OGC,Below})/(2 \cdot \beta_g + D_{bb}/\phi_{OGC,Below})$ — $FC_{c,g}$: 27.80 kip *(123.7 kN)*

Adjusted Vertical Force in Gusset Outside Beam Depth

$V_{uc}' = V_{uc} + FC_c$ — V_{uc}': 53.2 kip *(236 kN)*

Horizontal Force $H_{uc} = P_{uc} * e_c/r$ — H_{uc}: 0.0 kip *(0 kN)*

Moment at Column $M_{uc} = H_{uc} * |\beta_{nE} - \beta_{bar}|$ — M_{uc}: 0.0 kip-in *(0 kN-mm)*

Force at Beam Face

Vertical Force $V_{ub} = P_{uc} * e_b/r$ — V_{ub}: 43.2 kip *(192 kN)*

Horizontal Force $H_{ub} = P_{uc} * \alpha_{nE}/r$ — H_{ub}: 125.3 kip *(557 kN)*

Moment at Beam $M_{ub} = V_{ub} * |\alpha_{nE} - \alpha_{bar}|$ — M_{ub}: 269.8 kip-in *(30489 kN-mm)*

Equivalent Stress for Mu

$H_{uc_eq} = 6 \cdot M_{uc}/(2 \cdot \beta_g) + H_{uc}$ — H_{uc_eq}: 0.0 kip *(0 kN)*

$V_{ub_eq} = 6 \cdot M_{ub}/(2 \cdot \alpha_q) + V_{ub}$ — V_{ub_eq}: 128.3 kip *(571 kN)*

Where $2\beta_g = L_{wc}$, $2\alpha_g = L_{wb}$

Stresses at the interface between Gusset Plate and Column:

$f_{vc} = V_{uc}/2\beta_q$ — f_{vc}: 1.72 k/in *(0.3 kN/mm)*

$f_{Hc} = H_{uc}/2\beta_q$ — f_{Hc}: 0.00 k/in *(0.0 kN/mm)*

$f_{bc} = 6M_{uc}/(2\beta_q)^2$ — f_{bc}: 0.00 k/in *(0.0 kN/mm)*

Stresses at the interface between Gusset Plate and Beam:

$f_{vb} = V_{ub}/2\alpha_g$ — f_{vb}: 2.27 k/in *(0.4 kN/mm)*

$f_{Hb} = H_{ub}/2\alpha_q$ — f_{Hb}: 6.59 k/in *(1.2 kN/mm)*

$f_{bb} = 6M_{ub}/(2\alpha_q)^2$ — f_{bb}: 4.48 k/in *(0.8 kN/mm)*

4.4.0 WELD DESIGN & STRESS CHECKS - AISC 360

Weld Material Minimum Yield Strength	F_{exx}:	70 ksi	*(483 MPa)*
Minimum Yield Strength of Beam ASTM	F_{yBm}:	50 ksi	*(345 MPa)*
Minimum Tensile Strength of Beam ASTM	F_{uBm}:	65 ksi	*(448 MPa)*
Minimum Yield Strength of Col ASTM	F_{yCol}:	46 ksi	*(317 MPa)*
Minimum Tensile Strength of Col ASTM	F_{uCol}:	58 ksi	*(400 MPa)*
Weld Ductility Factor	μ_F:	1.25	

4.4.1 INITIAL FILLET WELD CALCULATIONS

Angle of Resultant Demand on Column $\theta_{wc} = \tan^{-1}(H_{uc_eq}/V_{uc})$	θ_{wc}:	0.00 rad	*0.0°*
Weld Capacity Increase Factor for Rotation at Column			
$C_c = 1+0.5(\sin(\theta wc))^{1.5}$	C_c:	1.00	
Angle of Resultant Demand on Beam $\theta_{wb} = \tan^{-1}(V_{ub_eq}/H_{ub})$	θ_{wb}:	0.80 rad	*45.7°*
Weld Capacity Increase Factor for Rotation at Beam			
$C_b = 1+0.5(\sin(\theta wb))^{1.5}$	C_b:	1.30	
Initial Weld Required at Beam and Column (16^{ths})			
Peak Stresses at the interface between Gusset Plate and Column:			
$f_{peak_c} = \sqrt{(f_{bc}+f_{Hc})^2+f_{vc}^2}$	f_{peak_c}:	1.72 k/in	*(0.3 kN/mm)*
Average Stresses at the interface between Gusset Plate and Column:			
$f_{avg_c} = (\sqrt{(f_{bc}-f_{Hc})^2+f_{vc}^2} + f_{peak_c})/2$	f_{avg_c}:	1.72 k/in	*(0.3 kN/mm)*
Control Stresses at the interface between Gusset Plate and Column:			
$f_{cont_c} = \text{Max}(\mu_F f_{avg_c}, f_{peak_c})$	f_{cont_c}:	2.16 k/in	*(0.4 kN/mm)*
Peak Stresses at the interface between Gusset Plate and Beam:			
$f_{peak_b} = \sqrt{(f_{bb}+f_{vb})^2+f_{Hb}^2}$	f_{peak_b}:	9.43 k/in	*(1.7 kN/mm)*
Average Stresses at the interface between Gusset Plate and Beam:			
$f_{avg_b} = (\sqrt{(f_{bb}-f_{vb})^2+f_{Hb}^2})+f_{peak_b})/2$	f_{avg_b}:	8.19 k/in	*(1.4 kN/mm)*
Control Stresses at the interface between Gusset Plate and Beam:			
$f_{cont_b} = \text{Max}(\mu_F f_{avg_b}, + f_{peak_b})$	f_{cont_b}:	10.23 k/in	*(1.8 kN/mm)*
Initial Weld Required at Beam and Column (16^{ths})			
$D_{wc1} = \dfrac{f_{cont_c}}{0.75\frac{(1in)0.7071}{16}0.6F_{eex}(2Lines)C_c}$	D_{wc1}:	0.77 (16ths)	*(1 mm)*
$D_{wb1} = \dfrac{f_{cont_b}}{0.75\frac{(1in)0.7071}{16}0.6F_{eex}(2Lines)C_b}$	D_{wb1}:	2.82 (16ths)	*(4 mm)*

4.4.2. BEAM/COLUMN STRESS CHECKS

Gusset and Opposing Brace Conditions			
Opposing Gusset Case - BELOW (for Beam):	OGC_{Below}:	Yes	
"Yes" - There is a gusset plate directly below this plate.			
"No" - There is not a gusset plate directly below this plate.			
$V_{ub,OGC}$: *(For equal capacity oposing brace = V_{ub}/β)*	$V_{ub,OGC}$:	38.6 kip	*(172 kN)*
Apportionment Factor: $\phi_{OGC,Below} = V_{ub,OGC}/V_{ub} + 1$	$\phi_{OGC,Below}$:	1.9	
Opposing Gusset Case - ACROSS (for Column):	OGC_{Across}:	No	
"Yes" - There is a gusset plate directly across from this plate.			
"No" - There is not a gusset plate directly across from this plate.			
$\phi_{OGC,Across}$: = 1 if OGC = YES	$\phi_{OGC,Across}$:	0	
= 0 otherwise			
Gusset Condition:	FHG:	TRUE	
FHG - Full Height Gusset			
NFG - Non Full Height Gusset			
Assumed Beam Reaction (EOR to Verify)	R_{ub}:	30.0 kip	*(133 kN)*
Beam Reaction Adjusted for OCG $R'_{ub} = R_{ub}/\phi_{OGC,Below}$	R'_{ub}:	15.8 kip	*(70 kN)*
Consider half of reaction if OCG = YES because only half of beam shear capacity is considered.			
Other half is considered in the design of the opposing gusset.			
Beam/Column Web Capacity			
t_{wbb}: = t_g if FHG	t_{wbb}:	0.75 in	*(19 mm)*
= t_{wb} if NFG			

Pseudo Thickness of Beam Web (Amount to use to calc weld to column for FHG) — t'_{wbb}: 0.75 in *(19 mm)*

t_{wbb1}: $= t'_{wbb}$ if $t'_{wbb} \neq 0$ AND FHG = TRUE; $= t_{wbb}$ Otherwise — t_{wbb1}: 0.75 in *(19 mm)*

Beam and Column Shear Capacities

$\phi V_{nb} = 0.6 \cdot F_{yBm} \cdot (\phi_{Vb} \cdot t_{wbb1} + 0.9 \cdot t_{wbPL}) \cdot D_{bb} / \phi_{OGC,Below}$ — ϕV_{nb}: 141.5 kip *(629 kN)*

$\phi_{Vb} =$ 1.00

ϕV_{nbc} = Shear Capacity of Beam at Col Connection — ϕV_{nbc}: 127.3 kip *(566 kN)*

$\phi V_{nc} = \phi_{Vc} \cdot \phi_{Vc,BP} \cdot 0.6 \cdot F_{yCol} \cdot (t_{wc} + t_{wbPL}) \cdot D_{cb}$ — ϕV_{nc}: 186.3 kip *(829 kN)*

$\phi_{Vc} =$ 0.90

$\phi_{Vc,BP} =$ 1.00 *Accounts for shear cap reduction at BP if needed. (Includes removal of WAH, etc where occurs.)*

Beam Web Check

$S_{rb} = (R'_{ub} + V_{ub}) / \text{Min}(\phi V_{nb}, \phi V_{nbc})$ — S_{rb}: 0.46

Transfer Force if Greater than 1.0

Vertical Force in Excess of Beam Web (or Connection) Capacity

ΔV_{ub}: $= 0$ kip if $t_{wbb} = 0$; $= 0$ kip if $R'_{ub} + V_{ub} - \min(\phi V_{nb}, \phi V_{nbc}) < 0$; $= R'_{ub} + V_{ub} - \min(\phi V_{nb}, \phi V_{nbc})$ otherwise — ΔV_{ub}: 0.0 kip *(0 kN)*

See Resultant Moment Shear Check on Beam/Col at End of Revised Weld Calculations

Column Web Shear Check

Point Load on Column from Opposing Gusset — $H_{uc,OGC}$: 0.0 kip *(0 kN)*

For equal capacity opposing brace = (Huc/β) $\phi_{OGC,Across}$*

$DCR_{CWV} = (H_{uc} + H_{uc,OGC}) / \phi V_{nc}$ — DCR_{cwv}: 0.00

If this DCR is >1.0 then column web must be reinforced or thickened.

4.5.0 REVISED FORCE CALCULATIONS TO ACCOUNT FOR FORCE TRANSFER TO COLUMN WELD

$\Delta M_{ub} = \Delta V_{ub} \cdot \alpha_{bar}$ (Zero if no force transferred to weld) — ΔM_{ub}: 0.0 kip-in *(0 kN-mm)*

Moment Demand on Weld at Beam:

$M_{ub2} = V_{ub} \cdot |\alpha_{nE} - \alpha_{bar}|$ — M_{ub2}: 269.8 kip-in *(30489 kN-mm)*

Equivalent Vertical Demand on Weld from M_{ub}:

$V_{ub_eq2} = 6 (M_{ub2} + \Delta M_{ub}) / (2\alpha_q) + (V_{ub} - \Delta V_{ub})$ — V_{ub_eq2}: 128.3 kip *(571 kN)*

Stresses at the interface between Gusset Plate and Column:

$f'_{vc} = (V_{uc} + \Delta V_{ub}) / 2\beta_g$ — f'_{vc}: 1.72 k/in *(0.3 kN/mm)*

$f'_{Hc} = H_{uc} / 2\beta_q$ — f'_{Hc}: 0.00 k/in *(0.0 kN/mm)*

$f'_{bc} = 6M_{uc} / (2\beta_q)^2$ — f'_{bc}: 0.00 k/in *(0.0 kN/mm)*

Stresses at the interface between Gusset Plate and Beam:

$f_{vb} = (V_{ub} - \Delta V_{ub}) / 2\alpha_q$ — f_{vb}: 2.27 k/in *(0.4 kN/mm)*

$f_{Hb} = H_{ub} / 2\alpha_g$ — f_{Hb}: 6.59 k/in *(1.2 kN/mm)*

$f_{bb} = 6(M_{ub2} + \Delta M_{ub}) / (2\alpha_q)^2$ — f_{bb}: 4.48 k/in *(0.8 kN/mm)*

4.6.0 WELD DESIGN/STRESS CHECKS FOR REVISED FORCES

6.1 FINAL FILLET WELD CALCULATIONS

Angle of Resultant Demand on Column:

$\theta_{wc} = \text{TAN}^{-1}[H_{uc_eq} / (V_{uc} + \Delta V_{ub})]$ — θ_{wc}: 0.000 rad *0.0°*

Weld Capacity Increase Factor for Angle at Column

$C_{wc} = 1 + 0.5[\text{SIN}(\theta_{wc})]^{1.5}$ — C_{wc}: 1.000

Angle of Resultant Demand on Beam:

$\theta_{wb} = \text{TAN}^{-1}(V_{ub_eq2} / H_{ub})$ — θ_{wb}: 0.797 rad *45.7°*

Weld Capacity Increase Factor for Angle at Beam

$C_{wb} = 1 + 0.5[\text{SIN}(\theta_{wb})]^{1.5}$ — C_{wb}: 1.303

Peak Stresses at the interface between Gusset Plate and Column:

$f'_{peak_c} = \sqrt{(f'_{bc} + f'_{Hc})^2 + f'^2_{vc}}$ — f'_{peak_c}: 1.72 k/in *(0.3 kN/mm)*

Average Stresses at the interface between Gusset Plate and Column:

$f'_{avg_c} = (\sqrt{(f'_{bc} - f'_{Hc})^2 + f'^2_{vc}} + f'_{peak_c}) / 2$ — f'_{avg_c}: 1.72 k/in *(0.3 kN/mm)*

Control Stresses at the interface between Gusset Plate and Column:

$f'_{cont_c} = \text{Max}(\mu_F f'_{avg_c}, f'_{peak_c})$ — f'_{cont_c}: 2.16 k/in *(0.4 kN/mm)*

Peak Stresses at the interface between Gusset Plate and Beam:

$f'_{peak_b} = \sqrt{(f'_{bb}+f'_{vb})^2+f'^2_{Hb}}$ — f'_{peak_b}: 9.43 k/in *(1.7 kN/mm)*

Average Stresses at the interface between Gusset Plate and Beam:

$f'_{avg_b} = (\sqrt{(f'_{bb}-f'_{vb})^2+f'^2_{Hb}})+f'_{peak_b})/2$ — f'_{avg_b}: 8.19 k/in *(1.4 kN/mm)*

Control Stresses at the interface between Gusset Plate and Beam:

$f'_{cont_b} = Max(\mu_F f'_{avg_b,} + f'_{peak_b})$ — f'_{cont_b}: 10.23 k/in *(1.8 kN/mm)*

Final Weld Required at Beam and Column (16ths)

$$D_{wc2} = \frac{f'_{cont_c}}{0.75\frac{(1in)0.7071}{16}0.6F_{eex}(2Lines)C_{wc}}$$

D_{wc2}: 0.77 (16ths) *(1 mm)*

$$D_{wb2} = \frac{f'_{cont_b}}{0.75\frac{(1in)0.7071}{16}0.6F_{eex}(2Lines)C_{wb}}$$

D_{wb2}: 2.82 (16ths) *(4 mm)*

Min Weld Size for Gusset — $D_{w\text{-}min}$: 4.00 (16ths) *(6 mm)*

If: $t_g \le 0.50"$, $D_{w\text{-}min} = 3/16"$
$0.50" < t_g \le 0.75"$, $D_{w\text{-}min} = 1/4"$
$t_g > 0.75"$, $D_{w\text{-}min} = 5/16"$

Final Weld Size to Use:

$D_{wc} = MAX(D_{wc1}, D_{wc2}, D_{w\text{-}min})$ — D_{wc}: 4.00 (16ths) *(6 mm)*
Rounded Up: D_{wc}: 4.00 (16ths) *(6 mm)*
Use: D_{wc}: 1/4 " *(6 mm)*

$D_{wb} = MAX(D_{wb1}, D_{wb2}, D_{w\text{-}min})$ — D_{wb}: 4.00 (16ths) *(6 mm)*
Rounded Up: D_{wb}: 4.00 (16ths) *(6 mm)*
Use: D_{wb}: 1/4 " *(6 mm)*

Gusset Weld Comparison (*Based on Non-Rounded Dwb & Dwc)*

$DCR_{wbmbg} = 2/\sqrt{2}\cdot(D_{wb}/16)\cdot F_{exx}/(t_g\cdot F_{ug})$ — DCR_{wbmbg}: 0.51

$DCR_{wbmcg} = 2/\sqrt{2}\cdot(D_{wc}/16)\cdot F_{exx}/(t_g\cdot F_{ug})$ — DCR_{wbmcg}: 0.51

Beam and Column Weld Filler Base Metal Compatiblity Check

$DCR_{wbm,Bm} = \sqrt{2}/2\cdot F_{exx}/F_{uBm}$ — $DCR_{wbm,Bm}$: 0.76
$DCR_{wbm,Col} = \sqrt{2}/2\cdot F_{exx}/F_{uCol}$ — $DCR_{wbm,Col}$: 0.85

4.7.0 Col & Bm Web Yielding and Crippling - AISC 360 J10

7.1 Web Yield Check - EQ J10-3

Beam Distance from Outer Face of the Flange to the Web Toe of the Fillet — k_{desb}: 1.02 in *(26 mm)*

Column Distance from Outer Face of the Flange to the Web Toe of the Fillet — k_{desc}: 1.00 in *(25 mm)*

Beam Web Local Yielding Capacity

$\phi R_{nyb} = (2.5k_{desb} + \alpha_g)\cdot(t_{wbb} + t_{wbPL})\cdot F_{yBm}$ — ϕR_{nyb}: 452.3 kip *(2012 kN)*

Beam Web Yielding Unity Check

$DCR_{wyb} = (max(V_{ub_eq}, V_{ub_eq2})/2)/\phi R_{nyb}$ — DCR_{wyb}: 0.14

Provide Stiffener if $DCR_{wyb} > 1.0$

Column Web Local Yielding Capacity

$\phi R_{nyc} = (2.5k_{desc} + \beta_q)\cdot(t_{wcb} + t_{wcPL})\cdot F_{yCol}$ — ϕR_{nyc}: 392.3 kip *(1745 kN)*

Column Web Yielding Unity Check

$DCR_{wyc} = (H_{uc_eq}/2)/\phi R_{nyc}$ — DCR_{wyc}: 0.00

Provide Stiffener if $DCR_{wyc} > 1.0$

4.7.2 Web Crippling Check - EQ J10-5b

LRFD Resistance Factor — ϕ_c: 0.75

Modulus of Elasticity of Steel — E: 29000 ksi *(199955 MPa)*

Beam Web Crippling Capacity

$$\phi R_{ncb} = \phi_c 0.4(t_{wbb} + 2t_{wbPL})^2 \left[1 + \left(\frac{4\alpha_g}{D_{bb}} - 0.2\right)\left(\frac{t_{wbb} + 2t_{wbPL}}{t_{fbb}}\right)^{1.5}\right]\sqrt{\frac{F_{yBm} t_{fbb} E}{t_{wbb} + 2t_{wbPL}}}$$

ϕR_{ncb}: 1055.2 kip *(4694 kN)*

Beam Web Crippling Unity Check

$DCR_{wcb} = (\max(V_{ub_eq}, V_{ub_eq2})/2)/\phi R_{ncb}$ — DCR_{wcb}: 0.06

Provide Stiffener if $DCR_{wcb} > 1.0$

Column Web Crippling Capacity

$$\phi R_{ncc} = \phi_c 0.4(t_{wcb} + t_{wcPL})^2 \left[1 + \left(\frac{4\beta_g}{D_{cb}} - 0.2\right)\left(\frac{t_{wcb} + t_{wcPL}}{t_{fcb}}\right)^{1.5}\right]\sqrt{\frac{F_{yCol} t_{fcb} E}{t_{wcb} + t_{wcPL}}}$$

ϕR_{ncc}: 3287.2 kip *(14622 kN)*

Column Web Crippling Unity Check

$DCR_{wcc} = (H_{uc_eq}/2)/\phi R_{ncc}$ — DCR_{wcc}: 0.00

Provide Stiffener if $DCR_{wcb} > 1.0$

4.7.3 Required Stiffener Thickness

Beam Stiffener Required?

Required if $DCR_{wwb} > 1.0$ or $DCR_{wcb} > 1.0$ — FALSE

Column Stiffener Required?

Required if $DCR_{wyc} > 1.0$ or $DCR_{wcc} > 1.0$ — FALSE

4.8.0 Summary

4.2.1 Whitmore Section Stress	DCR_W:	0.50
4.2.2 Gusset Plate Buckling	DCR_{qb}:	0.75
4.2.3 Gusset Plate Combined Buckling & Flexure	DCR_{qb+f}:	0.81
4.4.2 Column Web Shear Check	DCR_{cwv}:	0.00
4.6.1A Gusset Weld Base Metal Check at Beam (Gusset)	DCR_{wbmbq}:	0.51
Gusset Weld Base Metal Check at Beam (Flange)	DCR_{wbmbf}:	0.74
4.6.1B Gusset Weld Base Metal Check at Column (Gusset)	DCR_{wbmcq}:	0.51
Gusset Weld Base Metal Check at Column (Flange)	DCR_{wbmcf}:	0.68
4.6.1C Beam Weld Filler Material Base Metal Compatability Check	$DCR_{wbm,Bm}$:	0.76
Column Weld Filler Material Base Metal Compatability Check	$DCR_{wbm,Col}$:	0.85
4.7.1 Beam Web Yield Check	DCR_{wyb}:	0.14
4.7.1 Column Web Yield Check	DCR_{wyc}:	0.00
4.7.2 Beam Web Crippling Check	DCR_{wcb}:	0.06
4.7.2 Column Web Crippling Check	DCR_{wcc}:	0.00

Provide Stiffener if DCR_{wyb} or DCR_{wcb} > 1.0

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																			Constrained UFM Geometry																				Whitmore Tension Fracture																			
EOR-ID	Line	Grids	Lvls	Mark	Qty	n_i	n_o	s	θ_{CB}	θ_{UFM}	L_{tt}	L_{2t}	e	D_{ct}	D_{bt}	DN_{bt}	e_{Col}	e_{Bm}	W_L	Whtm Ang	l_{wc} min	l_{wb} min	Rot_c	α min	Y1	$WD_{Bm,In}$	$WD_{Bm,Out}$	α_g	α_{bar}	β min	X2	$WD_{Col,In}$	$WD_{Col,Out}$	β_g	β_{bar}	t_g	t_{r_Des}	L_{Br}	h_{Br}	h_{Bm}	h_{Col}	W'_{wh}	A'_{wh}	A_{wh}	P_{uc}	β	P_{ut}	F_{yg}	F_{ug}	Constrain	$\underline{P_{ut}}$
#		#	#	#	#	#	#	in	rad	rad	in	in	in	in	in	in	in	in	in	deg	in	in	deg	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	kip		kip	ksi	ksi	Whitmore	ϕR_n
BRB-2.00	4.1	D.3 to D(+)	Low Roof	1901	1	2	0	3.50	0.48	1.093	24.53	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	30	9.34	25.83	0	12.92	3.63	1.50	0.50	11.92	13.42	4.67	22.11	1.50	0.50	3.67	5.17	0.63	0.00	3.50	4.04	4.04	22.13	7.67	4.79	4.79	149	1.17	127	50	65	NO	0.59
BRB-2.00	4.1	D(+) to C.6	Low Roof	1901	1	2	0	3.50	0.48	1.093	24.53	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	30	9.34	25.83	0	12.92	3.63	1.50	0.50	11.92	13.42	4.67	22.11	1.50	0.50	3.67	5.17	0.63	0.00	3.50	4.04	4.04	22.13	7.67	4.79	4.79	149	1.17	127	50	65	NO	0.59
BRB-2.00	5	E to D.5	1	1903	1	2	0	3.50	0.63	0.941	19.02	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	30	9.69	19.47	0	9.74	4.29	1.50	0.50	8.74	10.24	4.84	15.09	1.50	0.50	3.84	5.34	0.63	0.00	3.50	4.04	4.69	15.18	7.67	4.79	4.79	134	1.11	121	50	65	NO	0.56
BRB-2.00	C	2.8 to 3(+)	Low Roof	1904	1	2	0	3.50	0.39	1.185	30.83	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	26	9.32	32.51	0	16.25	3.49	1.50	0.50	15.25	16.75	4.66	29.22	1.50	0.50	3.66	5.16	0.75	0.00	3.50	3.89	3.89	29.29	7.04	5.28	5.28	146	1.16	126	50	65	NO	0.53
BRB-2.00	C	3(+) to 3.2	Low Roof	1904	1	2	0	3.50	0.39	1.185	30.83	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	26	10.25	32.51	0	16.25	3.49	1.50	0.50	15.25	16.75	5.12	29.22	1.50	0.50	4.12	5.62	0.75	0.00	3.50	3.89	3.89	29.29	7.04	5.28	5.28	146	1.16	126	50	65	NO	0.53
BRB-2.00	C.2	3.3 to 3.7	Low Roof	1906	1	2	0	3.50	0.27	1.299	41.28	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	25	13.60	43.50	0	21.75	2.38	1.50	0.50	20.75	22.25	6.80	40.80	1.50	0.50	5.80	7.30	0.88	0.00	3.50	3.86	3.86	41.36	6.89	6.03	6.03	134	1.11	121	50	65	NO	0.44
BRB-2.00	C.2	3.7 to 4.1	Low Roof	1907	1	2	0	3.50	0.31	1.261	41.88	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	26	13.98	43.70	0	21.85	4.27	1.50	0.50	20.85	22.35	6.99	40.80	1.50	0.50	5.99	7.49	0.88	0.00	3.50	3.89	3.89	41.23	7.04	6.16	6.16	134	1.11	121	50	65	NO	0.43
BRB-2.00	E	4.7 to 5	1	1909	1	2	0	3.50	0.67	0.906	14.82	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	9.97	15.75	0	7.88	4.67	1.50	0.50	6.88	8.38	4.99	11.23	1.50	0.50	3.99	5.49	0.63	0.00	3.50	4.04	4.04	11.34	7.67	4.79	4.79	134	1.11	121	50	65	NO	0.56
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	2	0	3.50	0.43	1.136	20.72	5.88	1.188	8.0	11.9	11.9	0.0	6.0	6.00	30	8.87	21.81	0	10.91	3.10	1.50	0.50	9.91	11.41	4.44	18.29	1.50	0.50	3.44	4.94	0.75	0.00	3.50	4.04	4.04	18.36	7.67	5.75	5.75	138	1.12	123	50	65	NO	0.48
BRB-3.00	E	4.1 to 3.8	1	1911	1	3	0	3.50	0.88	0.695	12.31	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	13.27	21.02	0	10.51	8.64	1.50	0.50	9.51	11.01	6.64	8.73	1.50	0.50	5.64	7.14	0.75	0.00	7.00	8.08	8.08	9.30	11.71	8.78	8.78	199	1.17	170	50	65	NO	0.43
BRB-2.00	4	A.8 to A.99	1	1912	1	2	0	3.50	0.93	0.642	12.03	5.88	1.188	6.0	13.8	13.8	0.0	6.9	6.00	30	9.84	10.93	0	5.47	5.40	1.50	0.50	4.47	5.97	4.92	5.57	1.50	0.50	3.92	5.42	0.63	0.00	3.50	4.04	4.04	6.06	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	2	D to C.6	Low Roof	1915	1	2	0	3.50	0.27	1.297	43.57	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	20	9.97	45.68	0	22.84	3.09	1.50	0.50	21.84	23.34	4.98	42.97	1.50	0.50	3.98	5.48	1.00	0.00	3.50	3.72	3.72	43.09	6.17	6.17	6.17	134	1.11	121	50	65	NO	0.43
BRB-3.00	2	D to C.6	1	1916	1	3	0	3.50	0.67	0.899	28.64	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	20.84	29.25	0	14.63	15.55	1.50	0.50	13.63	15.13	10.42	24.71	1.50	0.50	9.42	10.92	1.00	0.00	7.00	8.08	8.08	24.98	11.71	11.71	11.71	197	1.17	168	50	65	NO	0.32
BRB-2.00	3.2	D to C.6	Low Roof	1917	1	2	0	3.50	0.24	1.326	59.31	5.88	1.188	6.0	21.6	21.6	0.0	10.8	6.00	20	12.73	61.21	0	30.61	2.93	1.50	0.50	29.61	31.11	6.37	58.66	1.50	0.50	5.37	6.87	1.00	0.00	3.50	3.72	3.72	58.98	6.17	6.17	6.17	134	1.11	121	50	65	NO	0.43
BRB-2.00	3.2	C.6 to C.2	Low Roof	1917	1	2	0	3.50	0.24	1.326	59.31	5.88	1.188	6.0	21.6	21.6	0.0	10.8	6.00	20	12.73	61.21	0	30.61	2.93	1.50	0.50	29.61	31.11	6.37	58.66	1.50	0.50	5.37	6.87	1.00	0.00	3.50	3.72	5.23	58.98	6.17	6.17	6.17	134	1.11	121	50	65	NO	0.43
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	2	0	3.50	0.34	1.227	32.44	5.88	1.188	6.0	16.4	16.4	0.0	8.2	6.00	23	8.47	34.42	0	17.21	2.60	1.50	0.50	16.21	17.71	4.24	31.35	1.50	0.50	3.24	4.74	0.75	0.00	3.50	3.80	3.80	31.40	6.60	4.95	4.95	134	1.11	121	50	65	NO	0.54
BRB-2.50	2	A.2 to A	1	1921	1	3	0	3.50	0.86	0.706	13.20	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	13.82	14.69	0	7.35	9.15	1.50	0.50	6.35	7.85	6.91	9.50	1.50	0.50	5.91	7.41	0.63	0.00	7.00	8.08	8.08	10.08	11.71	7.32	7.32	167	1.11	151	50	65	NO	0.46
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	3	0	3.50	0.29	1.276	40.49	9.38	1.188	6.0	16.4	16.4	0.0	8.2	6.00	20	10.09	45.88	0	22.94	4.19	1.50	0.50	21.94	23.44	5.05	43.06	1.50	0.50	4.05	5.55	1.00	0.00	7.00	7.45	7.45	43.12	8.72	8.72	8.72	167	1.11	151	50	65	NO	0.38
BRB-3.50	A	3 to 2.7	1	1923	1	3	0	3.50	0.68	0.892	29.26	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	21.42	29.58	0	14.79	16.15	1.50	0.50	13.79	15.29	10.71	25.01	1.50	0.50	9.71	11.21	1.00	0.00	7.00	8.08	8.08	25.31	11.71	11.71	11.71	232	1.17	198	50	65	NO	0.38
BRB-2.00	3	A.2 to A	Low Roof	1924	1	2	0	3.50	0.31	1.256	28.10	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	22	8.36	30.55	0	15.27	2.47	1.50	0.50	14.27	15.77	4.18	27.62	1.50	0.50	3.18	4.68	1.25	0.00	3.50	3.77	3.83	27.69	6.45	8.07	8.07	136	1.11	122	50	65	NO	0.34
BRB-2.00	3	A.2 to A	1	1925	1	2	0	3.50	0.69	0.883	27.56	5.88	1.188	6.0	24.5	24.5	0.0	12.3	6.00	30	12.06	25.38	0	12.69	6.81	1.50	0.50	11.69	13.19	6.03	20.78	1.50	0.50	5.03	6.53	1.25	0.00	3.50	4.04	4.04	21.06	7.67	9.58	9.58	135	1.11	121	50	65	NO	0.28

Table of Symbols

n = Number of bolts in a row ($_i$ inside row, $_o$ outside row)
s = Bolt spacing in a row
W_L = Width of lug
θ_{CB} = Angle of Cb from horizontal
θ_{UFM} = Angle used for uniform force method
L_{tb} = Total length from W.P. to top end of CB
L_{2b} = Length from end of lug to end of gusset
e = Edge distance
D_{cb} = Depth of column at bottom of CB
D_{bb} = Depth of beam at bottom of CB
$l_{wc,min}$ = Minimum possible length of weld on column
$l_{wb,min}$ = Minimum possible length of weld on beam
α min = Center of weld on beam based on geometry constraints
β min = Center of weld on column based on geometry constraints
α_g / β_g = 1/2 of weld length on beam / column, respectively
α_{bar} / β_{bar} = Actual center of weld on beam / column used, respectively
t_g = Thickness of gusset
t_r = Thickness of repad
A_{wm} = Area of whitmore line at gusset
L_{wm} = Width of whitmore section
P_{uc} = Ultimate CB compressive demand
β = Compression strength adjustment factor
P_{ut} = Ultimate CB tensile demand
F_{yg} = Yield stress of gusset
ϕR_n = Capacity of whitmore section
L' = Average buckling length of gusset
r = Radius of gyration of gusset
λ_c = Gusset slenderness parameter
f_{cr} = Buckling stress demand on gusset
ϕF_{cr} = Buckling stress capacity of gusset
K = UFM factor
K' = UFM reduced moment factor
D = UFM reduced moment factor
α = Center of weld on column
β = Center of weld on beam
r = Resultant length of **α** & **β**

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

															Gusset Buckling																	
EOR-ID	**Line**	**Grids**	**Lvls**	**Mark**	**Qty**	**L'**	**r**	**K_{gb}**	**λ_c**	**$\frac{f_{ez}}{\phi F_{cr}}$**	**S_A**	Factor	I_p	Wt_{BRB}	SW $F_{OOP\ (EA\ End)}$	$M_{Arm\text{-}OOP}$	SW M_{OOP}	SD	Factor	Drift Angle	Factor	P_H	M_{Arm_PH}	M_{PH}	L_b	L_c	Z_g	ϕ_b	ϕMn	M_r	$\frac{Mr}{\phi Mn}$	**M_r/M_c +**
#		#	#	#	#	in	in				(SDS)	on S_A		kips	kips	in	k-in	%	on SD	RAD	on ABS	kips	in	k-in	in	in	in^3		k-in	k-in		**P_r/P_c**
BRB-2.00	4.1	D.3 to D(+)	Low Roof	1901	1	9.58	0.18	1.00	0.70	0.90	1.02	0.40	1.00	0.60	0.12	15.88	1.94	1.00%	0.67	0.01	100%	0.99	2.94	2.91	8.38	7.57	1.56	0.90	70.09	4.85	0.07	0.96
BRB-2.00	4.1	D(+) to C.6	Low Roof	1901	1	9.58	0.18	1.00	0.70	0.90	1.02	0.40	1.00	0.60	0.12	15.88	1.94	1.00%	0.67	0.01	100%	0.99	2.94	2.91	8.38	7.57	1.56	0.90	70.09	4.85	0.07	0.96
BRB-2.00	5	E to D.5	1	1903	1	7.00	0.18	1.00	0.51	0.73	1.02	0.40	1.00	1.49	0.30	15.88	4.84	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.28	9.02	1.69	0.90	76.02	7.46	0.10	0.82
BRB-2.00	C	2.8 to 3(+)	Low Roof	1904	1	13.05	0.22	1.00	0.80	0.85	1.02	0.40	1.00	0.62	0.13	15.88	2.01	1.00%	0.67	0.01	100%	0.97	2.94	2.86	8.45	6.80	2.14	0.90	96.49	4.88	0.05	0.89
BRB-2.00	C	3(+) to 3.2	Low Roof	1904	1	13.05	0.22	1.00	0.80	0.85	1.02	0.40	1.00	0.62	0.13	15.88	2.01	1.00%	0.67	0.01	100%	0.97	2.94	2.86	8.45	7.80	2.28	0.90	102.82	4.88	0.05	0.89
BRB-2.00	C.2	3.3 to 3.7	Low Roof	1906	1	17.31	0.25	1.00	0.91	0.74	1.02	0.40	1.00	0.84	0.17	15.88	2.72	1.04%	0.67	0.01	100%	0.93	2.94	2.72	8.14	11.42	3.74	0.90	168.43	5.45	0.03	0.77
BRB-2.00	C.2	3.7 to 4.1	Low Roof	1907	1	19.42	0.25	1.00	1.02	0.79	1.02	0.40	1.00	0.89	0.18	15.88	2.88	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.87	10.21	3.65	0.90	164.30	5.50	0.03	0.82
BRB-2.00	E	4.7 to 5	1	1909	1	5.59	0.18	1.00	0.41	0.70	1.02	0.40	1.00	1.56	0.32	15.88	5.07	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.30	9.41	1.73	0.90	77.80	7.69	0.10	0.79
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	7.87	0.22	1.00	0.48	0.62	1.02	0.40	1.00	0.72	0.15	15.88	2.33	1.00%	0.67	0.01	100%	0.92	2.94	2.70	8.27	7.20	2.18	0.90	97.89	5.03	0.05	0.67
BRB-3.00	E	4.1 to 3.8	1	1911	1	2.80	0.22	1.00	0.17	0.54	1.02	0.40	1.00	1.30	0.27	19.38	5.16	1.00%	0.67	0.01	100%	1.32	4.69	6.21	17.01	11.36	3.99	0.90	179.54	11.37	0.06	0.60
BRB-2.00	4	A.8 to A.99	1	1912	1	3.14	0.18	1.00	0.23	0.68	1.02	0.40	1.00	1.18	0.24	15.88	3.83	1.00%	0.67	0.01	100%	0.90	2.94	2.64	7.58	8.69	1.59	0.90	71.52	6.47	0.09	0.76
BRB-2.00	2	D to C.6	Low Roof	1915	1	19.52	0.29	1.00	0.89	0.71	1.02	0.40	1.00	0.95	0.19	15.88	3.09	1.14%	0.67	0.01	100%	1.02	2.94	2.99	8.39	6.93	3.83	0.90	172.37	6.07	0.04	0.74
BRB-3.00	2	D to C.6	1	1916	1	18.09	0.29	1.00	0.83	0.53	1.02	0.40	1.00	1.96	0.40	19.38	7.76	1.00%	0.67	0.01	100%	1.31	4.69	6.16	15.47	12.26	6.93	0.90	311.90	13.92	0.04	0.57
BRB-2.00	3.2	D to C.6	Low Roof	1917	1	25.33	0.29	1.00	1.16	0.90	1.02	0.40	1.00	0.73	0.15	15.88	2.38	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.34	9.72	4.51	0.90	203.12	5.00	0.02	0.92
BRB-2.00	3.2	C.6 to C.2	Low Roof	1917	1	25.33	0.29	1.00	1.16	0.90	1.02	0.40	1.00	0.73	0.15	15.88	2.38	1.00%	0.67	0.01	100%	0.89	2.94	2.62	8.34	9.72	4.51	0.90	203.12	5.00	0.02	0.92
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	13.30	0.22	1.00	0.81	0.84	1.02	0.40	1.00	1.14	0.23	15.88	3.69	1.14%	0.67	0.01	100%	1.02	2.94	2.99	8.19	6.47	2.06	0.90	92.74	6.68	0.07	0.90
BRB-2.50	2	A.2 to A	1	1921	1	3.62	0.18	1.00	0.27	0.55	1.02	0.40	1.00	2.50	0.51	19.38	9.91	1.00%	0.67	0.01	100%	1.11	4.69	5.23	10.33	11.59	2.14	0.90	96.35	15.13	0.16	0.69
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	16.55	0.29	1.00	0.76	0.57	1.02	0.40	1.00	0.95	0.19	19.38	3.76	1.04%	0.67	0.01	100%	1.16	4.69	5.44	11.57	7.15	4.68	0.90	210.60	9.20	0.04	0.61
BRB-3.50	A	3 to 2.7	1	1923	1	18.85	0.29	1.00	0.86	0.64	1.02	0.40	1.00	1.99	0.41	19.38	7.88	1.00%	0.67	0.01	100%	1.54	4.69	7.24	15.85	12.38	7.06	0.90	317.53	15.12	0.05	0.68
BRB-2.00	3	A.2 to A	Low Roof	1924	1	12.22	0.36	1.00	0.45	0.43	1.02	0.40	1.00	0.83	0.17	15.88	2.69	1.00%	0.67	0.01	100%	0.91	2.94	2.66	8.16	6.24	5.62	0.90	253.12	5.35	0.02	0.45
BRB-2.00	3	A.2 to A	1	1925	1	11.98	0.36	1.00	0.44	0.36	1.02	0.40	1.00	1.52	0.31	15.88	4.92	1.00%	0.67	0.01	100%	0.90	2.94	2.64	9.11	9.66	7.33	0.90	329.81	7.56	0.02	0.38

V_{uc} = Vertical demand component on weld at column
H_{uc} = Horizontal demand component on weld at column
H_{ub} = Horizontal demand component on weld at beam
V_{ub} = Vertical demand component on weld at beam
M_{uc} = Moment demand on weld at column
M_{ub} = Moment demand on weld at beam
H_{uc}' = Equivalent horizontal demand on weld from Muc
V_{ub}' = Equivalent vertical demand on weld from Mub
θ_{wc} = Angle of resultant demand on column

θ_{wb} = Angle of resultant demand on beam
C_c = Weld capacity increase factor for rotation at column
C_b = Weld capacity increase factor for rotation at beam
μ_F = Ductility Factor
D_{wc} = # of sixteenths of weld required at column
D_{wb} = # of sixteenths of weld required at beam
$D_{wc,u}$ = # of sixteenths of weld actually used at column
$D_{wb,u}$ = # of sixteenths of weld actually used at beam
t_{wbb} = Thickness of beam web

$t_{wbb,PL}$ = Thickness of doubler plate at beam web
ϕV_{nb} = Shear capacity of beam
R_{ub} = Maximum shear in beam from Live & Dead Loads
ϕV_{nbc} = Shear capacity of beam at column connection
ΔV_{ub} = Amount shear needs to be reduced in beam
F_{ug} = Nominal min temsile stress of gusset

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

| | | | | | | Constrianed UFM with Minimized Eccentricity at Both Column and Beam | | | | | |

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

| | | | | | | Beam & Column Shear Capacity | | | | | |

Beam/Column Flange Top Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Constrained UFM with Reduced Shear in Beam																														
EOR-ID	Line	Grids	Lvls	Mark	Qty	$V_{uc}+\Delta V_{ub}$	H_{uc}	H_{ub}	$V_{ub}-\Delta V_{ub}$	M_{uc}	$M_{ub}+\Delta M_{ub}$	H_{uc}'	V_{ub}'	θ_{wc}	θ_{wb}	C_c	C_b	f'_{vc}	f'_{Hc}	f'_{bc}	f'_{vb}	f'_{Hb}	f'_{bb}	f'_{peak_c}	f'_{avg_c}	f'_{cont_c}	f'_{peak_b}	f'_{avg_b}	f'_{cont_b}	Fillet			
#		#	#	#	#	kip	kip	kip	kip	k-in	k-in	kip	kip	rad	rad			kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	D_{wc}	$D_{wc,u}$	D_{wb}	$D_{wb,u}$
BRB-2.00	4.1	D.3 to D(+)	Low Roof	1901	1	63	0	132	51	0	403	0	152	0.00	0.86	1.00	1.33	8.53	0.00	0.00	2.12	5.53	4.26	8.53	8.53	10.66	8.44	7.19	8.98	3.83	4	2.43	4
BRB-2.00	4.1	D(+) to C.6	Low Roof	1901	1	63	0	132	51	0	403	0	152	0.00	0.86	1.00	1.33	8.53	0.00	0.00	2.12	5.53	4.26	8.53	8.53	10.66	8.44	7.19	8.98	3.83	4	2.43	4
BRB-2.00	5	E to D.5	1	1903	1	22	0	108	56	0	311	0	163	0.00	0.98	1.00	1.38	2.93	0.00	0.00	3.22	6.19	6.10	2.93	2.93	3.66	11.19	9.01	11.26	1.31	4	2.93	4
BRB-2.00	C	2.8 to 3(+)	Low Roof	1904	1	69	0	135	41	0	421	0	124	0.00	0.74	1.00	1.28	9.49	0.00	0.00	1.35	4.44	2.72	9.49	9.49	11.86	6.02	5.33	6.67	4.26	5	1.87	4
BRB-2.00	C	3(+) to 3.2	Low Roof	1904	1	74	0	135	41	0	422	0	124	0.00	0.74	1.00	1.28	8.99	0.00	0.00	1.35	4.44	2.72	8.99	8.99	11.24	6.02	5.33	6.67	4.04	5	1.87	4
BRB-2.00	C.2	3.3 to 3.7	Low Roof	1906	1	104	0	129	29	0	408	0	88	0.00	0.60	1.00	1.21	8.97	0.00	0.00	0.70	3.11	1.42	8.97	8.97	11.22	3.76	3.47	4.34	4.03	5	1.29	5
BRB-2.00	C.2	3.7 to 4.1	Low Roof	1907	1	110	0	127	30	0	379	0	84	0.00	0.58	1.00	1.20	9.20	0.00	0.00	0.71	3.06	1.31	9.20	9.20	11.50	3.66	3.39	4.24	4.13	5	1.26	5
BRB-2.00	E	4.7 to 5	1	1909	1	69	0	105	52	0	190	0	135	0.00	0.91	1.00	1.35	8.61	0.00	0.00	3.79	7.65	6.04	8.61	8.61	10.76	12.45	10.22	12.77	3.87	4	3.40	4
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	52	0	125	42	0	269	0	123	0.00	0.78	1.00	1.29	7.58	0.00	0.00	2.11	6.32	4.12	7.58	7.58	9.47	8.87	7.75	9.69	3.40	4	2.69	4
BRB-3.00	E	4.1 to 3.8	1	1911	1	126	0	127	69	0	6	0	71	0.00	0.51	1.00	1.17	11.21	0.00	0.00	3.64	6.68	0.10	11.21	11.21	14.01	7.66	7.61	9.51	5.03	6	2.92	4
BRB-2.00	4	A.8 to A.99	1	1912	1	65	0	81	68	0	151	0	170	0.00	1.13	1.00	1.43	8.33	0.00	0.00	7.62	9.04	11.38	8.33	8.33	10.41	21.04	15.41	21.04	3.74	4	5.29	6
BRB-2.00	2	D to C.6	Low Roof	1915	1	89	0	129	28	0	412	0	84	0.00	0.58	1.00	1.20	11.13	0.00	0.00	0.63	2.95	1.30	11.13	11.13	13.91	3.52	3.27	4.09	5.00	5	1.22	5
BRB-3.00	2	D to C.6	1	1916	1	139	0	154	50	0	166	0	86	0.00	0.51	1.00	1.17	7.39	0.00	0.00	1.82	5.66	1.34	7.39	7.39	9.24	6.48	6.08	7.60	3.32	5	2.33	5
BRB-2.00	3.2	D to C.6	Low Roof	1917	1	114	0	130	26	0	585	0	86	0.00	0.58	1.00	1.20	10.62	0.00	0.00	0.44	2.19	1.00	10.62	10.62	13.28	2.63	2.44	3.05	4.77	5	0.91	5
BRB-2.00	3.2	C.6 to C.2	Low Roof	1917	1	6	0	130	26	0	585	0	86	0.00	0.58	1.00	1.20	0.57	0.00	0.00	0.44	2.19	1.00	0.57	0.57	0.71	2.63	2.44	3.05	0.26	5	0.91	5
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	64	0	126	35	0	414	0	112	0.00	0.72	1.00	1.27	9.87	0.00	0.00	1.08	3.88	2.36	9.87	9.87	12.34	5.19	4.64	5.80	4.43	5	1.64	4
BRB-2.50	2	A.2 to A	1	1921	1	108	0	109	65	0	139	0	130	0.00	0.88	1.00	1.34	9.09	0.00	0.00	5.09	8.55	5.18	9.09	9.09	11.37	13.36	10.96	13.69	4.08	5	3.68	4
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	94	0	160	35	0	482	0	101	0.00	0.56	1.00	1.20	11.62	0.00	0.00	0.81	3.65	1.50	11.62	11.62	14.53	4.32	4.01	5.02	5.22	6	1.51	5
BRB-3.50	A	3 to 2.7	1	1923	1	155	0	180	58	0	189	0	99	0.00	0.50	1.00	1.17	7.96	0.00	0.00	2.10	6.54	1.49	7.96	7.96	9.95	7.46	7.01	8.77	3.57	5	2.70	5
BRB-2.00	3	A.2 to A	Low Roof	1924	1	11	0	129	31	0	284	0	90	0.00	0.61	1.00	1.22	1.77	0.00	0.00	1.08	4.52	2.09	1.77	1.77	2.21	5.52	5.08	6.35	0.80	5	1.87	5
BRB-2.00	3	A.2 to A	1	1925	1	56	0	104	63	0	447	0	178	0.00	1.04	1.00	1.40	5.58	0.00	0.00	2.69	4.46	4.90	5.58	5.58	6.97	8.80	6.89	8.80	2.50	5	2.26	5

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																				UFM Geometry																	Whitmore Tension Fracture																				
EOR-ID	Line	Grids	Lvls	Mark	Qty	n_i	n_o	s	θ_{CB}	θ_{UFM}	L_{tb}	L_{2b}	e	D_{cb}	D_{bb}	DN_{bb}	e_{Col}	e_{Bm}	W_L	Whtm Ang	l_{wc} min	l_{wb} min	Rot$_c$	α min	Y1	$WD_{Bm,In}$	$WD_{Bm,Out}$	α_g	α_{bar}	β min	X2	$WD_{Col,In}$	$WD_{Col,Out}$	β_g	β_{bar}	t_g	t_{r_Des}	L_{Br}	h_{Br}	h_{Bm}	h_{Col}	W'_{wh}	A'_{wh}	A_{wh}	P_{uc}	β	P_{ut}	F_{yg}	F_{ug}	Constrain	P_{ut}
#		#	#	#	#	#	#	in	rad	rad	in	in	in	in	in	in	in	in	in	in	deg	in	in	deg	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in	in^2	in^2	kip		kip	ksi	ksi	Whitmore	ϕR_n
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	2	0	3.50	0.90	0.674	10.05	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	14.94	10.07	0	5.03	10.39	1.50	0.50	4.03	5.53	7.47	4.79	1.50	0.50	6.47	7.97	0.63	0.00	3.50	4.04	10.50	5.14	7.67	4.79	4.79	136	1.11	122	50	65	NO	0.57
BRB-2.00	4.1	D(+) to C.6	1	1902	1	2	0	3.50	0.90	0.674	10.05	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	14.94	10.07	0	5.03	10.39	1.50	0.50	4.03	5.53	7.47	4.79	1.50	0.50	6.47	7.97	0.63	0.00	3.50	4.04	10.50	5.14	7.67	4.79	4.79	136	1.11	122	50	65	NO	0.57
BRB-2.00	5	E to D.5	1	1903	1	2	0	3.50	0.63	0.941	7.31	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	11.00	10.01	0	5.01	5.60	1.50	0.50	4.01	5.51	5.50	5.63	1.50	0.50	4.50	6.00	0.63	0.00	3.50	4.04	6.12	5.66	7.67	4.79	4.79	134	1.11	121	50	65	NO	0.56
BRB-2.00	C	2.8 to 3(+)	1	1905	1	2	0	3.50	0.85	0.722	9.06	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.85	9.87	0	4.93	9.12	1.50	0.50	3.93	5.43	6.93	4.72	1.50	0.50	5.93	7.43	0.63	0.00	3.50	4.04	9.30	4.98	7.67	4.79	4.79	136	1.11	122	50	65	NO	0.57
BRB-2.00	C	3(+) to 3.2	1	1905	1	2	0	3.50	0.85	0.722	9.06	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.85	9.87	0	4.93	9.12	1.50	0.50	3.93	5.43	6.93	4.72	1.50	0.50	5.93	7.43	0.63	0.00	3.50	4.04	9.30	4.98	7.67	4.79	4.79	136	1.11	122	50	65	NO	0.57
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	2	0	3.50	0.72	0.853	9.56	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.16	11.26	0	5.63	8.00	1.50	0.50	4.63	6.13	6.58	6.54	1.50	0.50	5.58	7.08	0.63	0.00	3.50	4.04	8.46	6.67	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	2	0	3.50	0.72	0.853	9.56	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.16	11.26	0	5.63	8.00	1.50	0.50	4.63	6.13	6.58	6.54	1.50	0.50	5.58	7.08	0.63	0.00	3.50	4.04	8.46	6.67	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	E	4.7 to 5	1	1909	1	2	0	3.50	0.67	0.906	7.19	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	11.21	9.75	0	4.88	5.91	1.50	0.50	3.88	5.38	5.61	5.23	1.50	0.50	4.61	6.11	0.63	0.00	3.50	4.04	6.37	5.28	7.67	4.79	4.79	134	1.11	121	50	65	NO	0.56
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	2	0	3.50	0.43	1.136	24.94	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	28	10.65	26.64	0	10.51	4.87	1.50	0.50	9.51	11.01	5.32	23.12	1.50	0.50	4.32	5.82	0.75	0.00	3.50	3.96	3.96	23.15	7.35	5.51	5.51	138	1.12	123	50	65	NO	0.50
BRB-3.00	E	4.1 to 3.8	1	1911	1	3	0	3.50	0.88	0.695	10.94	9.38	1.188	8.0	0.0	0.0	0.0	0.0	6.00	30	18.17	12.08	0	6.04	13.54	1.50	0.50	5.04	6.54	9.08	6.85	1.50	0.50	8.08	9.58	0.75	0.00	7.00	8.08	13.74	7.30	10.92	8.19	8.78	199	1.17	170	50	65	NO	0.43
BRB-2.00	4	A.8 to A.99	1	1912	1	2	0	3.50	0.93	0.642	10.32	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	15.36	9.90	0	4.95	10.93	1.50	0.50	3.95	5.45	7.68	4.54	1.50	0.50	6.68	8.18	0.63	0.00	3.50	4.04	11.00	4.94	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	B	5 to 4.7	1	1913	1	2	0	3.50	0.72	0.850	7.94	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	12.12	10.01	0	5.01	6.97	1.50	0.50	4.01	5.51	6.06	5.28	1.50	0.50	5.06	6.56	0.63	0.00	3.50	4.04	7.36	5.39	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	B	4.7 to 4.4	1	1914	1	2	0	3.50	0.72	0.850	7.94	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	12.12	10.01	0	5.01	6.97	1.50	0.50	4.01	5.51	6.06	5.28	1.50	0.50	5.06	6.56	0.63	0.00	3.50	4.04	7.36	5.39	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	2	D to C.6	Low Roof	1915	1	2	0	3.50	0.27	1.297	45.46	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	22	14.66	47.50	0	23.75	5.85	1.50	0.50	22.75	24.25	7.33	44.79	1.50	0.50	6.33	7.83	1.00	0.00	3.50	3.77	3.77	45.06	6.45	6.45	6.45	134	1.11	121	50	65	NO	0.42
BRB-3.00	2	D to C.6	1	1916	1	3	0	3.50	0.67	0.899	8.69	9.38	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	14.37	13.63	0	6.81	9.08	1.50	0.50	5.81	7.31	7.18	9.08	1.50	0.50	6.18	7.68	1.00	0.00	7.00	8.08	9.76	9.18	11.71	11.71	11.71	197	1.17	168	50	65	NO	0.32
BRB-2.00	3.2	D to C.6	1	1918	1	2	0	3.50	0.71	0.864	9.07	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	12.75	10.96	0	5.48	7.56	1.50	0.50	4.48	5.98	6.37	6.28	1.50	0.50	5.37	6.87	0.63	0.00	3.50	4.04	8.02	6.39	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	3.2	C.6 to C.2	1	1919	1	2	0	3.50	0.71	0.864	9.07	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	12.75	10.96	0	5.48	7.56	1.50	0.50	4.48	5.98	6.37	6.28	1.50	0.50	5.37	6.87	0.63	0.00	3.50	4.04	8.02	6.39	7.67	4.79	4.79	135	1.11	121	50	65	NO	0.56
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	2	0	3.50	0.34	1.227	34.02	5.88	1.188	6.0	11.9	11.9	0.0	6.0	6.00	30	15.02	35.91	0	17.95	5.38	1.50	0.50	16.95	18.45	7.51	32.83	1.50	0.50	6.51	8.01	0.75	0.00	3.50	4.04	4.04	33.37	7.67	5.75	5.75	134	1.11	121	50	65	NO	0.47
BRB-2.50	2	A.2 to A	1	1921	1	3	0	3.50	0.86	0.706	11.41	9.38	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	18.41	13.53	0	6.77	13.74	1.50	0.50	5.77	7.27	9.21	8.34	1.50	0.50	8.21	9.71	0.63	0.00	7.00	8.08	13.97	8.85	11.71	7.32	7.32	167	1.11	151	50	65	NO	0.46
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	3	0	3.50	0.29	1.276	40.40	9.38	1.188	6.0	11.9	11.9	0.0	6.0	6.00	23	15.19	45.79	0	22.90	6.41	1.50	0.50	21.90	23.40	7.59	42.97	1.50	0.50	6.59	8.09	1.00	0.00	7.00	7.60	7.60	43.22	9.57	9.57	9.57	167	1.11	151	50	65	NO	0.35
BRB-3.50	A	3 to 2.7	1	1923	1	3	0	3.50	0.68	0.892	7.69	9.38	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	13.83	12.79	0	6.40	8.56	1.50	0.50	5.40	6.90	6.91	8.22	1.50	0.50	5.91	7.41	1.00	0.00	7.00	8.08	9.17	8.32	11.71	11.71	11.71	232	1.17	198	50	65	NO	0.38
BRB-2.00	3	A.2 to A	Low Roof	1924	1	2	0	3.50	0.31	1.256	69.96	5.88	1.188	6.0	24.5	24.5	0.0	12.3	6.00	24	20.71	70.36	0	35.18	9.11	1.50	0.50	34.18	35.68	10.36	67.43	1.50	0.50	9.36	10.86	1.25	0.00	3.50	3.83	3.83	67.80	6.74	8.43	8.43	136	1.11	122	50	65	NO	0.32
BRB-2.00	3	A.2 to A	1	1925	1	2	0	3.50	0.69	0.883	7.56	5.88	1.188	6.0	0.0	0.0	0.0	0.0	6.00	30	11.62	9.92	0	4.96	6.37	1.50	0.50	3.96	5.46	5.81	5.32	1.50	0.50	4.81	6.31	1.25	0.00	3.50	4.04	6.81	5.39	7.67	9.58	9.58	135	1.11	121	50	65	NO	0.28

Table of Symbols

n = Number of bolts in a row (i inside row, o outside row)
s = Bolt spacing in a row
W_L = Width of lug
θ_{CB} = Angle of Cb from horizontal
θ_{UFM} = Angle used for uniform force method
L_{tb} = Total length from W.P. to top end of CB
L_{2b} = Length from end of lug to end of gusset
e = Edge distance
D_{cb} = Depth of column at bottom of CB
D_{bb} = Depth of beam at bottom of CB
$l_{wc,min}$ = Minimum possible length of weld on column
$l_{wb,min}$ = Minimum possible length of weld on beam
α min = Center of weld on beam based on geometry constraints
β min = Center of weld on column based on geometry constraints
α_g / β_g = 1/2 of weld length on beam / column, respectively
α_{bar} / β_{bar} = Actual center of weld on beam / column used, respectively
t_g = Thickness of gusset
t_r = Thickness of repad
A_{wm} = Area of whitmore line at gusset
L_{wm} = Width of whitmore section
P_{uc} = Ultimate CB compressive demand
β = Compression strength adjustment factor
P_{ut} = Ultimate CB tensile demand
F_{yg} = Yield stress of gusset
ϕR_n = Capacity of whitmore section
L' = Average buckling length of gusset
r = Radius of gyration of gusset
λ_c = Gusset slenderness parameter
f_{cr} = Buckling stress demand on gusset
ϕF_{cr} = Buckling stress capacity of gusset
K = UFM factor
K' = UFM reduced moment factor
D = UFM reduced moment factor
α = Center of weld on column
β = Center of weld on beam
r = Resultant length of **α** & **β**

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Gusset Buckling																														
EOR-ID	Line	Grids	Lvls	Mark	Qty	L'	r	K_{gb}	λ_c	f_{cr}	S_A	Factor	I_p	Wt_{BRB}	SW $F_{OOP\ (EA\ End)}$	$M_{Arm\text{-}OOP}$	SW M_{OOP}	SD	Factor	Drift Angle	Factor	P_H	M_{Arm_PH}	M_{PH}	L_b	L_c	Z_g	ϕ_b	ϕMn	M_r	Mr	M_r/M_c +
#		#	#	#	#	in	in	in		ϕF_{cr}	(SDS)	on S_A		kips	kips	in	k-in	%	on SD	RAD	on ABS	kips	in	k-in	in	in	in^3		k-in	k-in	ϕMn	P_r/P_c
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	5.42	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.22	0.25	15.88	3.94	1.00%	0.67	0.01	100%	0.905	2.938	2.660	9.507	8.312	1.740	0.90	78.303	6.604	0.084	0.787
BRB-2.00	4.1	D(+) to C.6	1	1902	1	5.42	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.22	0.25	15.88	3.94	1.00%	0.67	0.01	100%	0.905	2.938	2.660	9.507	8.312	1.740	0.90	78.303	6.604	0.084	0.787
BRB-2.00	5	E to D.5	1	1903	1	3.34	0.18	1.00	0.24	0.67	1.02	0.40	1.00	1.49	0.30	15.88	4.84	1.00%	0.67	0.01	100%	0.892	2.938	2.620	8.748	7.583	1.595	0.90	71.767	7.455	0.104	0.766
BRB-2.00	C	2.8 to 3(+)	1	1905	1	4.64	0.18	1.00	0.34	0.70	1.02	0.40	1.00	1.32	0.27	15.88	4.28	1.00%	0.67	0.01	100%	0.905	2.938	2.660	9.670	8.150	1.740	0.90	78.313	6.938	0.089	0.779
BRB-2.00	C	3(+) to 3.2	1	1905	1	4.64	0.18	1.00	0.34	0.70	1.02	0.40	1.00	1.32	0.27	15.88	4.28	1.00%	0.67	0.01	100%	0.905	2.938	2.660	9.670	8.150	1.740	0.90	78.313	6.938	0.089	0.779
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	5.52	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.56	0.32	15.88	5.05	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.631	8.292	1.750	0.90	78.762	7.694	0.098	0.796
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	5.52	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.56	0.32	15.88	5.05	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.631	8.292	1.750	0.90	78.762	7.694	0.098	0.796
BRB-2.00	E	4.7 to 5	1	1909	1	3.21	0.18	1.00	0.24	0.67	1.02	0.40	1.00	1.56	0.32	15.88	5.07	1.00%	0.67	0.01	100%	0.892	2.938	2.620	8.763	7.631	1.601	0.90	72.044	7.687	0.107	0.767
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	12.39	0.22	1.00	0.76	0.75	1.02	0.40	1.00	0.72	0.15	15.88	2.33	1.00%	0.67	0.01	100%	0.920	2.938	2.704	4.724	7.196	1.676	0.90	75.431	5.033	0.067	0.809
BRB-3.00	E	4.1 to 3.8	1	1911	1	3.99	0.22	1.00	0.24	0.55	1.02	0.40	1.00	1.30	0.27	19.38	5.16	1.00%	0.67	0.01	100%	1.324	4.688	6.206	12.357	10.803	3.257	0.90	146.557	11.367	0.078	0.615
BRB-2.00	4	A.8 to A.99	1	1912	1	5.50	0.18	1.00	0.40	0.71	1.02	0.40	1.00	1.18	0.24	15.88	3.83	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.156	8.321	1.707	0.90	76.805	6.469	0.084	0.783
BRB-2.00	B	5 to 4.7	1	1913	1	3.88	0.18	1.00	0.28	0.68	1.02	0.40	1.00	1.45	0.30	15.88	4.69	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.054	7.867	1.652	0.90	74.362	7.334	0.099	0.772
BRB-2.00	B	4.7 to 4.4	1	1914	1	3.88	0.18	1.00	0.28	0.68	1.02	0.40	1.00	1.45	0.30	15.88	4.71	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.054	7.867	1.652	0.90	74.362	7.346	0.099	0.773
BRB-2.00	2	D to C.6	Low Roof	1915	1	26.79	0.29	1.00	1.23	0.92	1.02	0.40	1.00	0.95	0.19	15.88	3.09	1.14%	0.67	0.01	100%	1.016	2.938	2.985	9.807	8.933	4.685	0.90	210.830	6.074	0.029	0.942
BRB-3.00	2	D to C.6	1	1916	1	3.31	0.29	1.00	0.15	0.40	1.02	0.40	1.00	1.96	0.40	19.38	7.76	1.00%	0.67	0.01	100%	1.313	4.688	6.156	11.646	10.056	5.425	0.90	244.146	13.917	0.057	0.450
BRB-2.00	3.2	D to C.6	1	1918	1	5.04	0.18	1.00	0.37	0.70	1.02	0.40	1.00	1.56	0.32	15.88	5.06	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.422	8.140	1.715	0.90	77.177	7.703	0.100	0.790
BRB-2.00	3.2	C.6 to C.2	1	1919	1	5.04	0.18	1.00	0.37	0.70	1.02	0.40	1.00	1.57	0.32	15.88	5.08	1.00%	0.67	0.01	100%	0.899	2.938	2.640	9.422	8.140	1.715	0.90	77.177	7.721	0.100	0.790
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	18.34	0.22	1.00	1.12	0.93	1.02	0.40	1.00	1.14	0.23	15.88	3.69	1.14%	0.67	0.01	100%	1.017	2.938	2.987	9.385	10.465	2.791	0.90	125.616	6.679	0.053	0.973
BRB-2.50	2	A.2 to A	1	1921	1	5.56	0.18	1.00	0.41	0.58	1.02	0.40	1.00	2.50	0.51	19.38	9.91	1.00%	0.67	0.01	100%	1.115	4.688	5.226	12.583	11.150	2.318	0.90	104.293	15.134	0.145	0.705
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	21.12	0.29	1.00	0.97	0.61	1.02	0.40	1.00	0.95	0.19	19.38	3.76	1.04%	0.67	0.01	100%	1.160	4.688	5.439	12.380	10.150	5.633	0.90	253.464	9.202	0.036	0.641
BRB-3.50	A	3 to 2.7	1	1923	1	2.31	0.29	1.00	0.11	0.47	1.02	0.40	1.00	1.99	0.41	19.38	7.88	1.00%	0.67	0.01	100%	1.545	4.688	7.240	11.397	9.883	5.320	0.90	239.401	15.124	0.063	0.524
BRB-2.00	3	A.2 to A	Low Roof	1924	1	39.87	0.36	1.00	1.46	0.93	1.02	0.40	1.00	0.83	0.17	15.88	2.69	1.00%	0.67	0.01	100%	0.905	2.938	2.660	11.958	12.241	9.453	0.90	425.366	5.348	0.013	0.938
BRB-2.00	3	A.2 to A	1	1925	1	3.56	0.36	1.00	0.13	0.33	1.02	0.40	1.00	1.52	0.31	15.88	4.92	1.00%	0.67	0.01	100%	0.899	2.938	2.640	8.894	7.743	6.499	0.90	292.438	7.564	0.026	0.356

V_{uc} = Vertical demand component on weld at column
H_{uc} = Horizontal demand component on weld at column
H_{ub} = Horizontal demand component on weld at beam
V_{ub} = Vertical demand component on weld at beam
M_{uc} = Moment demand on weld at column
M_{ub} = Moment demand on weld at beam
H_{uc}' = Equivalent horizontal demand on weld from Muc
V_{ub}' = Equivalent vertical demand on weld from Mub
θ_{wc} = Angle of resultant demand on column

θ_{wb} = Angle of resultant demand on beam
C_c = Weld capacity increase factor for rotation at column
C_b = Weld capacity increase factor for rotation at beam
μ_F = Ductility Factor
D_{wc} = # of sixteenths of weld required at column
D_{wb} = # of sixteenths of weld required at beam
$D_{wc,u}$ = # of sixteenths of weld actually used at column
$D_{wb,u}$ = # of sixteenths of weld actually used at beam
t_{wbb} = Thickness of beam web

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

| | | | | | | Constrained UFM with Minimized Eccentricity at Both Column and Beam | | | | | |

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Beam & Column Shear Capacity																				t_q & Basemetal Check						Col & Bm Web Yielding & Cripling													
EOR-ID	Line	Grids	Lvls	Mark	Qty	Full Ht	t_{wbb}	t'_{wbb}	$t_{wbb,PL}$	Guss	ϕ_{vb}	ϕV_{nb}	$V_{ub\text{-}OGC}$	Aprnment	R_{ub}	R_{ub}'	ϕV_{nbc}	$V_{ub}+R_{ub}$	Trans	ΔV_{ub}	ϕ_{vc}	$\phi_{vc,BP}$	ϕV_{nc}	H_{uc}	F_{yBm}	F_{uBm}	F_{yCol}	F_{uCol}	$F_{ub,min}$	$F_{uc,min}$	$t_{ubt,min}$	$t_{pc,min}$	t_{fbt}	ϕR_{myb}	V_{ub}'	ϕR_{ncb}	V_{ub}'	B Stiff	t_{fc}	ϕR_{nyc}	H_{uc}'	ϕR_{ncc}	H_{uc}'	C Stiff
#		#	#	#	#	Guss?	in	in	in	Below		kips	kip	Factor	kip	kip	kip	$\phi V_{nb\ or\ nbc}$	V?	kip			kips	ϕV_{nc}	ksi	ksi	ksi	ksi	F_{ubBm}	F_{uCol}	t_g	t_g	in	kip	ϕR_{myb}	kip	ϕR_{ncb}	Req?	in	kip	ϕR_{nyc}	kip	ϕR_{ncc}	Req?
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.72	0.61	0.00	1634	-	NA	-	n.a.	0.63	516	0.00	4837	0.00	no
BRB-2.00	4.1	D(+) to C.6	1	1902	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.72	0.61	0.00	1634	-	NA	-	n.a.	0.63	516	0.00	4837	0.00	no
BRB-2.00	5	E to D.5	1	1903	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.92	0.61	0.00	1626	-	NA	-	n.a.	0.63	402	0.00	3413	0.00	no
BRB-2.00	C	2.8 to 3(+)	1	1905	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.78	0.61	0.00	1608	-	NA	-	n.a.	0.63	484	0.00	4444	0.00	no
BRB-2.00	C	3(+) to 3.2	1	1905	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.78	0.61	0.00	1608	-	NA	-	n.a.	0.63	484	0.00	4444	0.00	no
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.75	0.61	0.00	1783	-	NA	-	n.a.	0.63	465	0.00	4196	0.00	no
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.75	0.61	0.00	1783	-	NA	-	n.a.	0.63	465	0.00	4196	0.00	no
BRB-2.00	E	4.7 to 5	1	1909	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.93	0.61	0.00	1594	-	NA	-	n.a.	0.63	409	0.00	3492	0.00	no
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	yes	0.750	0.75	0.00	Yes	1.0	127	39	1.9	30.0	57.8	127	0.58	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.51	0.51	0.52	452	0.14	1055	0.06	no	0.63	392	0.00	3287	0.00	no
BRB-3.00	E	4.1 to 3.8	1	1911	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	248	0.00	50	65	46	58	0.76	0.85	0.72	0.54	0.00	1884	-	NA	-	n.a.	0.63	609	0.00	4543	0.00	no
BRB-2.00	4	A.8 to A.99	1	1912	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.70	0.61	0.00	1613	-	NA	-	n.a.	0.63	528	0.00	4988	0.00	no
BRB-2.00	B	5 to 4.7	1	1913	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.86	0.61	0.00	1627	-	NA	-	n.a.	0.63	435	0.00	3820	0.00	no
BRB-2.00	B	4.7 to 4.4	1	1914	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.86	0.61	0.00	1627	-	NA	-	n.a.	0.63	435	0.00	3820	0.00	no
BRB-2.00	2	D to C.6	Low Roof	1915	1	yes	1.000	1.00	0.00	Yes	1.0	169	20	1.9	30.0	74.4	169	0.36	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.48	0.48	0.52	1265	0.02	5483	0.00	no	0.63	508	0.00	4734	0.00	no
BRB-3.00	2	D to C.6	1	1916	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.57	0.48	0.00	2078	-	NA	-	n.a.	0.63	499	0.00	4631	0.00	no
BRB-2.00	3.2	D to C.6	1	1918	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.78	0.61	0.00	1745	-	NA	-	n.a.	0.63	453	0.00	4046	0.00	no
BRB-2.00	3.2	C.6 to C.2	1	1919	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.78	0.61	0.00	1745	-	NA	-	n.a.	0.63	453	0.00	4046	0.00	no
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	yes	0.750	0.75	0.00	No	1.0	241	0	1.0	30.0	123.1	241	0.63	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.51	0.52	0.52	731	0.05	1796	0.02	no	0.63	518	0.00	4866	0.00	no
BRB-2.50	2	A.2 to A	1	1921	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.64	0.61	0.00	2066	-	NA	-	n.a.	0.63	616	0.00	6090	0.00	no
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	yes	1.000	1.00	0.00	Yes	1.0	169	26	1.9	30.0	71.5	169	0.39	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.48	0.48	0.52	1222	0.03	5282	0.01	no	0.63	523	0.00	4926	0.00	no
BRB-3.50	A	3 to 2.7	1	1923	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.71	0.53	0.00	1974	-	NA	-	n.a.	0.63	484	0.00	4434	0.00	no
BRB-2.00	3	A.2 to A	Low Roof	1924	1	yes	1.250	0.50	0.00	Yes	1.0	174	26	1.9	30.0	109.4	174	0.50	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.38	0.38	0.96	2364	0.02	4449	0.01	no	0.63	682	0.00	6920	0.00	no
BRB-2.00	3	A.2 to A	1	1925	1	no	5.000	0.00	0.00	No	0.9	0	0	1.0	0.0	0.0	0	0.00	no	0	0.9	1.0	186	0.00	50	65	46	58	0.76	0.85	0.45	0.38	0.00	1616	-	NA	-	n.a.	0.63	420	0.00	3638	0.00	no

$t_{wbb,PL}$ = Thickness of doubler plate at beam web
ϕV_{nb} = Shear capacity of beam
R_{ub} = Maximum shear in beam from Live & Dead Loads
ϕV_{nbc} = Shear capacity of beam at column connection
ΔV_{ub} = Amount shear needs to be reduced in beam
F_{ug} = Nominal min temsile stress of gusset

Beam/Column Flange Bottom Connection

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Constrained UFM with Reduced Shear in Beam																															
EOR-ID	Line	Grids	Lvls	Mark	Qty	$V_{uc}+\Delta V_{ub}$	H_{uc}	H_{ub}	$V_{ub}-\Delta V_{ub}$	M_{uc}	$M_{ub}+\Delta M_{ub}$	H_{uc}'	V_{ub}'	θ_{wc}	θ_{wb}	C_c	C_b	f'_{vc}	f'_{Hc}	f'_{bc}	f'_{vb}	f'_{Hb}	f'_{bb}	f'_{peak_c}	f'_{avg_c}	f'_{cont_c}	f'_{peak_b}	f'_{avg_b}	f'_{cont_b}	Fillet			
#		#	#	#	#	kip	kip	kip	kip	k-in	k-in	kip	kip	rad	rad			kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	kip/in	D_{wc}	$D_{wc,u}$	D_{wb}	$D_{wb,u}$
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	106	0	85	0	0	0	0	0	0.00	0.00	1.00	1.00	8.20	0.00	0.00	0.00	10.51	0.00	8.20	8.20	10.25	10.51	10.51	13.13	3.68	4	4.72	5
BRB-2.00	4.1	D(+) to C.6	1	1902	1	106	0	85	0	0	0	0	0	0.00	0.00	1.00	1.00	8.20	0.00	0.00	0.00	10.51	0.00	8.20	8.20	10.25	10.51	10.51	13.13	3.68	4	4.72	5
BRB-2.00	5	E to D.5	1	1903	1	79	0	108	0	0	0	0	0	0.00	0.00	1.00	1.00	8.76	0.00	0.00	0.00	13.50	0.00	8.76	8.76	10.94	13.50	13.50	16.87	3.93	4	6.06	7
BRB-2.00	C	2.8 to 3(+)	1	1905	1	102	0	90	0	0	0	0	0	0.00	0.00	1.00	1.00	8.60	0.00	0.00	0.00	11.41	0.00	8.60	8.60	10.75	11.41	11.41	14.26	3.86	4	5.12	6
BRB-2.00	C	3(+) to 3.2	1	1905	1	102	0	90	0	0	0	0	0	0.00	0.00	1.00	1.00	8.60	0.00	0.00	0.00	11.41	0.00	8.60	8.60	10.75	11.41	11.41	14.26	3.86	4	5.12	6
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	89	0	102	0	0	0	0	0	0.00	0.00	1.00	1.00	7.94	0.00	0.00	0.00	10.97	0.00	7.94	7.94	9.92	10.97	10.97	13.71	3.56	4	4.92	5
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	89	0	102	0	0	0	0	0	0.00	0.00	1.00	1.00	7.94	0.00	0.00	0.00	10.97	0.00	7.94	7.94	9.92	10.97	10.97	13.71	3.56	4	4.92	5
BRB-2.00	E	4.7 to 5	1	1909	1	83	0	105	0	0	0	0	0	0.00	0.00	1.00	1.00	8.96	0.00	0.00	0.00	13.58	0.00	8.96	8.96	11.20	13.58	13.58	16.97	4.02	5	6.10	7
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	53	0	125	43	0	270	0	128	0.00	0.80	1.00	1.30	6.15	0.00	0.00	2.27	6.59	4.48	6.15	6.15	7.68	9.43	8.19	10.23	2.76	4	2.82	4
BRB-3.00	E	4.1 to 3.8	1	1911	1	153	0	127	0	0	0	0	0	0.00	0.00	1.00	1.00	9.44	0.00	0.00	0.00	12.62	0.00	9.44	9.44	11.80	12.62	12.62	15.77	4.24	5	5.66	6
BRB-2.00	4	A.8 to A.99	1	1912	1	108	0	81	0	0	0	0	0	0.00	0.00	1.00	1.00	8.08	0.00	0.00	0.00	10.22	0.00	8.08	8.08	10.10	10.22	10.22	12.77	3.63	4	4.59	5
BRB-2.00	B	5 to 4.7	1	1913	1	89	0	101	0	0	0	0	0	0.00	0.00	1.00	1.00	8.79	0.00	0.00	0.00	12.63	0.00	8.79	8.79	10.99	12.63	12.63	15.79	3.95	4	5.67	6
BRB-2.00	B	4.7 to 4.4	1	1914	1	89	0	101	0	0	0	0	0	0.00	0.00	1.00	1.00	8.79	0.00	0.00	0.00	12.63	0.00	8.79	8.79	10.99	12.63	12.63	15.79	3.95	4	5.67	6
BRB-2.00	2	D to C.6	Low Roof	1915	1	104	0	129	22	0	235	0	53	0.00	0.39	1.00	1.12	8.21	0.00	0.00	0.48	2.83	0.68	8.21	8.21	10.27	3.06	2.95	3.69	3.69	5	1.19	5
BRB-3.00	2	D to C.6	1	1916	1	123	0	154	0	0	0	0	0	0.00	0.00	1.00	1.00	9.91	0.00	0.00	0.00	13.26	0.00	9.91	9.91	12.39	13.26	13.26	16.58	4.45	5	5.95	6
BRB-2.00	3.2	D to C.6	1	1918	1	88	0	102	0	0	0	0	0	0.00	0.00	1.00	1.00	8.15	0.00	0.00	0.00	11.44	0.00	8.15	8.15	10.18	11.44	11.44	14.30	3.66	4	5.14	6
BRB-2.00	3.2	C.6 to C.2	1	1919	1	88	0	102	0	0	0	0	0	0.00	0.00	1.00	1.00	8.15	0.00	0.00	0.00	11.44	0.00	8.15	8.15	10.18	11.44	11.44	14.30	3.66	4	5.14	6
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	119	0	126	28	0	233	0	69	0.00	0.50	1.00	1.17	9.14	0.00	0.00	0.83	3.71	1.22	9.14	9.14	11.42	4.24	3.99	4.98	4.10	5	1.53	4
BRB-2.50	2	A.2 to A	1	1921	1	127	0	109	0	0	0	0	0	0.00	0.00	1.00	1.00	7.75	0.00	0.00	0.00	9.41	0.00	7.75	7.75	9.69	9.41	9.41	11.76	3.48	4	4.22	5
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	107	0	160	29	0	284	0	67	0.00	0.40	1.00	1.12	8.14	0.00	0.00	0.65	3.65	0.89	8.14	8.14	10.18	3.97	3.81	4.77	3.66	5	1.53	5
BRB-3.50	A	3 to 2.7	1	1923	1	145	0	180	0	0	0	0	0	0.00	0.00	1.00	1.00	12.30	0.00	0.00	0.00	16.71	0.00	12.30	12.30	15.37	16.71	16.71	20.89	5.52	6	7.50	8
BRB-2.00	3	A.2 to A	Low Roof	1924	1	128	0	129	29	0	547	0	77	0.00	0.54	1.00	1.18	6.85	0.00	0.00	0.42	1.89	0.70	6.85	6.85	8.57	2.20	2.06	2.57	3.08	5	0.78	5
BRB-2.00	3	A.2 to A	1	1925	1	86	0	104	0	0	0	0	0	0.00	0.00	1.00	1.00	8.89	0.00	0.00	0.00	13.15	0.00	8.89	8.89	11.12	13.15	13.15	16.44	3.99	5	5.90	6

PSE Operational Training Center

Calculation Submittal Package

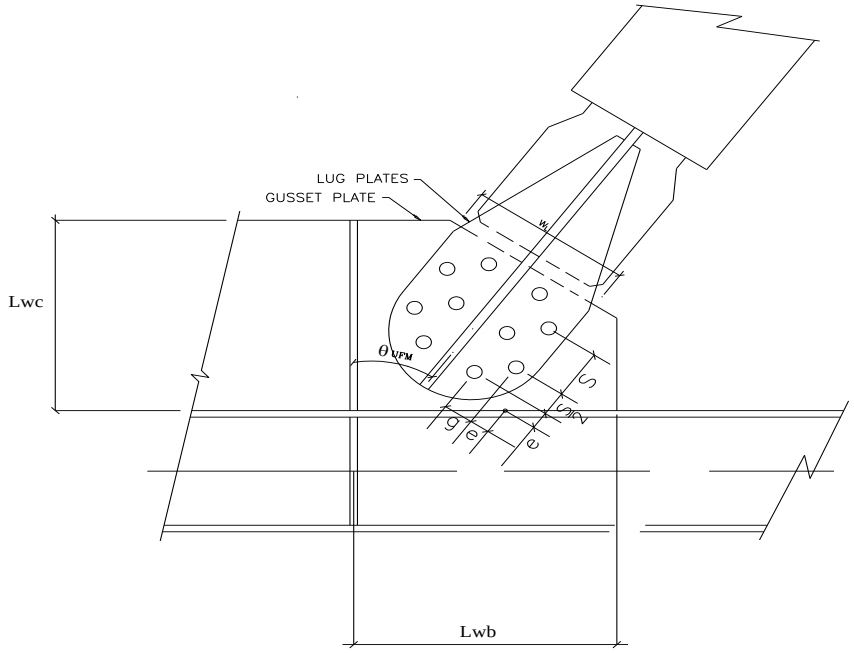
Description

Section 6. **V Gusset Connection Sample Calculation with V and Chevron Connection Summary Tables**

V Gusset Connection

(Chevron Connection Similar)

Example Mark #: 1901
Line 4.1, Grid D.3 to D(+), Level Low Roof



Uniform Force Method - AISC 360 - Bracing Section

6.0 DESIGN CRITERIA

Area of Yielding Steel Core	A_{sc}:	2.00 in²	*(1290 mm²)*
Maximum Yield Stress of Core Material	$F_{y\text{-}max}$:	46 ksi	*(317 MPa)*
Compresssion Strength Adjustment Factor	β:	1.17	
Strain Hardening Adjustment Factor	ω:	1.38	
Connection Strain Hardening Factor	CF:	1.00	
Axial Design Load Compression ($CF \cdot \beta\omega F_{y\text{-}max}A_{sc}$)	P_{uc}:	148.5 kip	*(661 kN)*
Axial Design Load Tension ($CF \cdot \omega F_{y\text{-}max}A_{sc}$)	P_{ut}:	127.0 kip	*(565 kN)*
Width of Lug	W_L:	6.00 in	*(152 mm)*
Stiffener Depth (Thickness)	D_{cb}:	0.50 in	*(13 mm)*
Beam Depth	D_{bb}:	16.40 in	*(417 mm)*
Nominal Depth of Beam	DN_{bb}:	16.40 in	*(417 mm)*
Beam Web Thickness	t_{wb}:	0.43 in	*(11 mm)*
Beam Flange Thickness	t_{fb}:	0.72 in	*(18 mm)*
Beam Flange Width	b_{fb}:	7.12 in	*(181 mm)*
Beam k-Zone Height	k_{des}:	1.12 in	*(28 mm)*
Angle Between the Beam and Brace CL	θ_{CB}:	0.478 rad	*27.4°*
Angle Between the Column and Brace CL	θ_{UFM}:	1.093 rad	*62.6°*
Min Clear Distance from Face of Beam to Edge of Lug	$b_{bot\text{-}Bm}$:	5.50 in	*(140 mm)*
Min Clear Distance from Face of Column to Edge of Lug	$b_{bot\text{-}Col}$:	1.00 in	*(25 mm)*
Thickness of Gusset Plate	$t_{g:}$	0.63 in	*(16 mm)*
Distance from Last Bolt to Start of Radius on Lug	b_r:	0.80 in	*(20 mm)*
Bolt Edge Distance	e:	1.19 in	*(30 mm)*

6.1.0 GEOMETRY CALCULATIONS - UNIFORM FORCE METHOD

Length from WP to Bottom Tip of Brace			
Length from WP to Outside Edge of Col along WorkLine			
$L_{cb} = (D_{cb}/2)/COS(\theta_{CB})$	L_{cb}:	0.28 in	*(7 mm)*
Length from Edge of Column to Tip of CB along WL			
$L_{1cb} = [b_{bot\text{-}Col} + (W_L/2)]/COS(\theta_{CB}) - (e + b_r)$	L_{1cb}:	2.52 in	*(64 mm)*
Length from WP to Top Edge of Beam along WL			
$L_{bb} = (DN_{bb}/2)/SIN(\theta_{CB})$	L_{bb}:	17.82 in	*(453 mm)*
Length from Edge of Beam to Tip of CB along WL			
$L_{1bb} = [b_{tot\text{-}Bm} + (W_L/2)]/SIN(\theta_{CB}) - (e + b_r)$	L_{1bb}:	16.49 in	*(419 mm)*
Controling Length is $MAX(L_{cb}+L_{1cb}\ ,\ L_{bb}+L_{1bb})$	L_{tb}:	34.31 in	*(871 mm)*
Length from Square Projection to Edge of Gusset (CB Lap on Gusset)	L_g:	5.88 in	*(149 mm)*
Horizontal Distance from Column to WP ($D_{cb}/2$)	e_c:	0.25 in	*(6 mm)*
Vertical Distance from Beam to WP ($DN_{bb}/2$)	e_b:	8.20 in	*(208 mm)*
Minimum Weld on Column from Geometry			
$L_{wc_min} = (L_{tb} + L_g)*SIN(\theta_{CB}) + (W_L/2 + 1)*COS(\theta_{CB}) - DN_{bb}/2$	L_{wc_min}:	13.84 in	*(352 mm)*
Minimum Weld on Beam from Geometry			
$L_{wb_min} = (L_{tb} + L_g)*COS(\theta_{CB}) + (W_L/2 + 1)*SIN(\theta_{CB}) - D_{cb}/2$	L_{wb_min}:	37.27 in	*(947 mm)*

6.2.0 WHITMORE CAPACITY CHECK

LRFD Resistance Factor	ϕ_W:	0.90	
Lug Width	W_L:	6.00 in	*(152 mm)*
Minimum Yield Strength of Gusset	F_{yg}:	50 ksi	*(345 MPa)*
Minimum Tensile Strength of Gusset	F_{ug}:	65 ksi	*(448 MPa)*
Thickness of Repad Plate for Design:	$t_{r:}$	0.00 in	*(0 mm)*
Whitmore Angle	θ_{Whtm}:	30.0°	*0.524 rad*
Total Length Between Outer Bolt Holes $L_{Br} = L_q - 2e$	L_{Br}:	3.50 in	*(89 mm)*
Whitmore Width $W_w = 2 \cdot L_{Br} \cdot TAN(\theta_{Whtm}) + (W_L - 2 \cdot e)$	W_w:	7.67 in	*(195 mm)*
Whitmore Area $A_w = W_w \cdot t_q$	A_W =	4.79 in²	*(3091 mm²)*
Whitmore Capacity $\phi R_{n\text{-}W} = \phi_W \cdot A_W \cdot F_{yg}$	$\phi R_{n\text{-}W}$:	215.6 kip	*(959 kN)*
Whitmore Stress Ratio			
$DCR_W = P_{ut}/\phi R_{n\text{-}W}$	DCR_W:	0.59	

6.3.0 GUSSET BUCKLING CHECKS

LRFD Resistance Factor	ϕ_{gb}:	0.90	
Modulus of Elasticity	E:	29000 ksi	(199955 MPa)
Buckling Length *Conservative Since Based on Edges of Lug Rather than Edges of Whitmore Section*	L_1:	17.68 in	(449 mm)
Radius of Gyration of Gusset $r_g = \sqrt{(t_g^2/12)}$	r_g:	0.18 in	(5 mm)
Effective Length Factor	K_v:	0.65 in	
Elastic Buckling Stress $F_e = \pi^2 \cdot E/(K_v L_1/r_g)^2$	F_e	70.6 kip	(314 kN)
Critical Euler Buckling Stress $F_{cr} = IF(F_y/F_e<2.25, (0.658\text{^}F_y/F_e)F_y, 0.877F_e)$	F_{cr}	37.2 kip	(165 kN)
Gusset Buckling Capacity $\phi R_{n\text{-}gb} = \phi_{gb} \cdot F_{cr} \cdot A_w$	$\phi R_{n\text{-}gb}$:	160.3 kip	(713 kN)
Gusset Buckling Demand Capacity Ratio $DCR_{gb} = P_{uc}/\phi R_{n\text{-}gb}$ *Provide Stiffener if DCR_{gb} >1 .0*	DCR_{gb}:	0.93	

6.4.0 FORCE CALCULATIONS - AISC 360 BRACING SECTION (Typical AISC Method)

Dist from Face of Col Fl to Centriod of Gusset-to-Beam Connection (UFM)						
$\alpha'_{min} = L_{wb_min}/2$	α'_{min}	18.63 in	*(473 mm)*			
α_{Hand} = Hand Input Value to Force	α_{Hand}	18.63 in	*(473 mm)*			
If Hand Input Value is Different from α_{min} use Hand Input Value				α_{min}:	18.63 in	*(473 mm)*
Dist from Face of Beam Fl to Centriod of Gusset-to-Column Connection (UFM)						
$\beta'_{min} = L_{wc_min}/2$	β'_{min}	6.92 in	*(176 mm)*			
β_{Hand} = Hand Input Value to Force	β_{Hand}	6.92 in	*(176 mm)*			
If Hand Input Value is Different from β_{min} use Hand Input Value				β_{min}:	6.92 in	*(176 mm)*
Beam Gusset Length						
$L_{wb} = INT(2\alpha_{min})$				L_{wb}:	37.00 in	*(940 mm)*
Gusset Stiffener Length						
$L_{wc} = INT(2\beta_{min})$				L_{wc}:	13.00 in	*(330 mm)*
Vertical Force from Brace in Compression						
$V_{u\text{-}c} = P_{uc} \cdot SIN(\theta_{CB})$				$V_{u\text{-}c}$:	68.4 kip	*(304 kN)*
Vertical Force from Brace in Tension						
$V_{u\text{-}t} = P_{ut} \cdot SIN(\theta_{CB})$				$V_{u\text{-}t}$:	58.4 kip	*(260 kN)*
Net Vertical Force at the Beam						
$V_b = V_{u\text{-}c} - V_{u\text{-}t}$				V_b:	9.9 kip	*(44 kN)*
Horizontal Force from Brace in Compression						
$H_{u\text{-}c} = P_{uc} \cdot COS(\theta_{CB})$				$H_{u\text{-}c}$:	131.9 kip	*(587 kN)*
Horzontal Force from Brace in Tension						
$H_{u\text{-}t} = P_{ut} \cdot COS(\theta_{CB})$				$H_{u\text{-}t}$:	112.7 kip	*(501 kN)*
Net Horizontal Force at the Beam						
$H_b = H_{u\text{-}c} + H_{u\text{-}t}$				H_b:	244.6 kip	*(1088 kN)*
Resultant Force on Beam						
$R_{ub} = \sqrt{(V_b^2 + H_b^2)}$				R_{ub}:	244.8 kip	*(1089 kN)*
Moment at Beam from Horizontal Loads						
$M_u = H_b \cdot (DN_{bb}/2)$				M_u:	2005.7 kip-in	*(226649 kN-mm)*
Stresses at the interface between Gusset Plate and Beam:						
$f_v = V_b/2L_{wb}$				f_v:	0.13 k/in	*(0.0 kN/mm)*
$f_H = H_b/2L_{wb}$				f_H:	3.31 k/in	*(0.6 kN/mm)*
$f_b = 6M_u/(2L_{wb})^2$				f_b:	2.20 k/in	*(0.4 kN/mm)*

6.5.0 WELD DESIGN & STRESS CHECKS - AISC 360

Weld Material Minimum Yield Strength	F_{exx}:	70 ksi	*(483 MPa)*
Minimum Yield Strength of Beam ASTM	F_{yBm}:	50 ksi	*(345 MPa)*
Minimum Tensile Strength of Beam ASTM	F_{uBm}:	65 ksi	*(448 MPa)*
Weld Stress Distribution Factor (Ductility Factor)	μ_F:	1.00	

6.6.0 BEAM SHEAR AND CHEVRON EFFECTS CHECKS

General

Maximum Unbalanced Vert Shear in Connection Region: $V_{ub} = (P_{uc} - P_{ut})\cdot SIN(\theta_{CB})$	V_{ub}:	9.9 kip	*(44.18 kN)*
Maximum Horizontal Shear in Connection Region: $H_{ub} = (P_{ut} + P_{uc})\cdot COS(\theta_{CB})$	H_{ub}:	244.6 kip	*(1088.04 kN)*
LRFD Resistance Factor	ϕ_{bv}:	1.00	
Gusset and Opposing Brace Conditions Opposing Gusset Case: "Yes" - There is a gusset plate directly below this plate. "No" - There is not a gusset plate directly below this plate.	OGC:	Yes	
$H_{ub,OGC}$: *(For Equal Braces Below, Equal to H_{ub})*	$H_{ub,OGC}$:	244.6 kip	*(1088 kN)*
Apportionment Factor: $\phi_{OGC} = H_{ub,OGC}/H_{ub} + 1$	ϕ_{OGC}:	2.0	
Moment on Beam: $M_{ub} = H_{ub}\cdot e_b\cdot\phi_{OGC}$	M_{ub}:	4011 kip-in	*(453219 kN-mm)*
Beam Web Shear Capacity: $\phi V_n = \phi_{bv}\cdot 0.6\cdot F_{yBm}\cdot t_{wb}\cdot D_b$	ϕV_n:	211.6 kip	*(941 kN)*
Actual Gusset Length $L_{g\text{-}act} = 4\cdot\alpha_{min}$	$L_{g\text{-}act}$:	74.5 in	*(1893 mm)*
Min Weld Size for Gusset If: $t_g \le 0.50"$, $D_{w\text{-}min} = 3/16"$ $0.50" < t_g \le 0.75"$, $D_{w\text{-}min} = 1/4"$ $t_g > 0.75"$, $D_{w\text{-}min} = 5/16"$	$D_{w\text{-}min}$:	4 (16ths)	*(7 mm)*
Weld Size to Develop Gusset: $D_{w\text{-}max} = 0.6\cdot t_g\cdot F_{ug}/(0.6\cdot\sqrt{2}/2\cdot F_{EXX}/16\cdot 2)$	$D_{w\text{-}max}$:	6.57 (16ths)	*(11 mm)*

Standard Chevron Effects Method w/Dist Load Over Each Gusset Half (Uniform Stress Method)

Shear Demand Based on Chevron Effect: $V_{u\text{-}CE} = 2\cdot M_{ub}/(L_{q\text{-}act})$	$V_{u\text{-}CE}$:	107.6 kip	*(479 kN)*
Min Length for No Reinforcement: $L_{CE} = 2\cdot M_{ub}/\phi V_n$	L_{CE}:	37.9 in	*(963 mm)*
Applicability of Std Chevron Effect Method w/out Reinforcement: $L_{CE}/L_{q\text{-}act} \le 1.0$	$L_{CE}/L_{q\text{-}act}$:	0.51	No Reinf Req'd

Doubler Plate and Stiffener Plate Requirements (where needed for Std Chev Method)

Shear Stress to be Taken by Doubler PL: $V_{dpl} = V_{u\text{-}CE} - \phi V_n \ge 0$	V_{dpl}:	0.0 kip	*(0 kN)*
Doubler Plate Height: $h_{Dblr,nom}$ = **1** x Beam Depth	H_{dpl}:	-	-
Calculated Thickness of Doubler Plate: $t_{dpl} = V_{dpl}/(\phi_{bv}\cdot 0.6\cdot F_{yBm}\cdot H_{dpl})$	t_{dpl}:	-	-
Doubler Plate Actual Thickness:	t_{dpl}:	-	-
Length of Doubler Plate to Develop Shear: $L_{dpl\text{-}V} = (1-\phi V_n/V_{u\text{-}CE})\cdot L_{q\text{-}act}$	$L_{dpl\text{-}V}$:	-	-
Doubler Plate Weld Size: *A larger weld may be specified if needed to meet minimums.*	D_{dpl}:	-	-
Length of Doubler Plate to Develop Force: $L_{dpl\text{-}F} = 2\cdot V_{dpl}/[\phi_w\cdot 0.6\cdot F_{exx}\cdot 0.7071\cdot D_{dpl}/16\cdot(2Lines)]$ *Doubler shear must be developed over half of doubler length. Considers only top and bottom welds.*	$L_{dpl\text{-}F}$:	-	-

Checks to Develop Beam Shear Capacity over 1/2 Gusset Length (as Point Load):

Web Local Yielding Check (AISC J10.2)

LRFD Resistance Factor	ϕ_{wyb}:	1.00	
Combined Beam Web and Doubler Thickness	t_{wb+dpl}:	0.430 in	*(11 mm)*
$\phi R_{nyb} = \phi_{wyb}\cdot(5\cdot k_{des} + L_{act}/2)\cdot t_{wb+dpl}\cdot F_{yBm}$	ϕR_{nyb}:	921.6 kip	*(4100 kN)*
$R_{uyb} = V_{u\text{-}CE}$	R_{uyb}:	107.6 kip	*(479 kN)*
$DCR_{wyb} = R_{uyb}/\phi R_{nyb}$ *Provide Stiffener if $DCR_{wyb} > 1.0$*	DCR_{wyb}:	0.12	

Web Local Crippling Check (AISC J10.3)

LRFD Resistance Factor	ϕ_c:	0.75	
$\phi R_{ncb} = \phi_c\cdot 0.80\cdot t_{wb+dpl}^2[1+3\cdot(0.5\cdot L_{q\text{-}act}/D_b)\cdot(t_{wb+dpl}/t_{fb})^{1.5}]\cdot\sqrt{(E\cdot F_{yBm}\cdot t_{fb}/t_{wb+dpl})}$	ϕR_{ncb}:	720.0 kip	*(3203 kN)*
$R_{ucb} = V_{u\text{-}CE}$	R_{ucb}:	107.6 kip	*(479 kN)*
$DCR_{wcb} = R_{ucb}/\phi R_{ncb}$	DCR_{wcb}:	0.15	

Provide Stiffener if DCR_{wcb} > 1.0

Shear Capacity to be Taken by Stiffener (If Required) $V_{stiff} = \max[\phi R_{nyb}(DCR_{wyb}-1),\phi R_{ncb}(DCR_{wcb}-1),0]$ *Applicable only if $L_{CE\text{-}Alt}/L_{act}$ <= 1.0*	V_{stiff}:	0.0 kip	*(0 kN)*
Required Stiffener Area $A_{st} = (V_{stiff}/2)/(\phi_{bv}\cdot F_{yBm})$	A_{st}:	0.00 in²	*(0 mm²)*
Required Stiffener Thickness $t_{st} = A_{st}/[(b_{fb} - t_{wb})/2-t_{dpl}]$	t_{st}:	0.00 in	*(0 mm)*

Required Weld Size for Standard Method

Vertical Load from Tension and Compression Braces $V_{method\ 1} = V_{ub}/L_{q,act} + V_{u,CE}/(L_{q,act}/2)$ *Note that $V_{u,CE}/(L_{q,act}/2)$ is the add'l load from the force couple and exists on both halfs fo the gussset.*	$V_{mthd\ 1}$:	3.02 k/in	*(0.53 kN/mm)*
Horzontal Load from Tension and Compression Braces $H_{method\ 1} = H_{ub}/L_{q,act}$	$H_{mthd\ 1}$:	3.28 k/in	*(0.57 kN/mm)*
Resultant Load on Weld: $R_{method\ 1} = \sqrt{(V_{method\ 1}^2 + H_{method\ 1}^2)}$	$R_{mthd\ 1}$:	4.46 k/in	*(0.78 kN/mm)*
Angle of Resultant Demand on Beam $\theta_{wc} = TAN^{-1}(V_{method\ 1}/H_{method\ 1})$	θ_{wc}:	0.744 rad	*42.6°*
Weld Capacity Increase Factor for Angle at Beam $C_{\theta R} = 1+0.5[SIN(\theta_{wc})]^{1.5}$	$C_{\theta R}$:	1.279	
Size of Weld at Beam: $D_{req}=R_{method\ 1}/[(2Lines)\cdot 0.75\cdot 0.6\cdot(1in)\cdot F_{EXX}\cdot\sqrt{2}/2\cdot C_{\theta R}/16]$	D_{req}:	1.25 (16ths)	*(2 mm)*

Chevron Effects Method with Distributed Loads at Gusset Edges over Length 'z', (Concentrated Stress Method)

Min Length for Alt Method: $L_{CE\text{-}Alt} = M_{ub}/(\phi V_n-0.5V_{ub}) + (\phi V_n-0.5V_{ub})/(\phi_{bv}\cdot F_{yBm}\cdot t_{wb})$	$L_{CE\text{-}Alt}$:	29.0 in	*(737 mm)*
Applicability of Alt Method: $L_{CE\text{-}Alt}/L_{g\text{-}act} \le 1.0$	$L_{CE\text{-}Alt}/L_{g\text{-}act}$:	0.39	
Length of Dist Load on Bm at End of Gusset: $z' = L_{q-act}/2-\sqrt{[L_{q-act}^2/4-M_{ub}/(\phi_{bv}\cdot F_{yBm}\cdot MIN(t_{wbt},t_q))]}$ Round z' up to nearest 0.25"	z': z:	2.59 in 2.75 in	*(66 mm)* *(70 mm)*

Checks to Develop Beam Shear Capacity over z Length (as Point Load):

Web Local Yielding Check (AISC J10.2)

$\phi R_{nyb} = \phi_{wyb}\cdot(5\cdot k_{des} + z)\cdot t_{wb}\cdot F_{yBm}$	ϕR_{nyb}:	179.5 kip	*(799 kN)*
$R_{uyb} = \phi V_n-0.5V_{ub}$	R_{uyb}:	206.6 kip	*(919 kN)*
$DCR_{wyb} = R_u/\phi R_{nyb}$ *Provide Stiffener if DCR_{wyb} > 1.0*	DCR_{wyb}:	1.15	

Web Local Crippling Check (AISC J10.3)

$\phi R_{ncb} = \phi_c\cdot 0.80\cdot t_{wb}^2[1+3\cdot(z/D_b)\cdot(t_{wb}/t_{fb})^{1.5}]\cdot\sqrt{(E\cdot F_{yBm}\cdot t_{fb}/t_{wb})}$	ϕR_{ncb}:	212.7 kip	*(946 kN)*
$R_{ucb} = \phi V_n-0.5V_{ub}$	R_{ucb}:	206.6 kip	*(919 kN)*
$DCR_{wcb} = R_{ucb}/\phi R_{ncb}$ *Provide Stiffener if DCR_{wcb} > 1.0*	DCR_{wcb}:	0.97	
Shear Capacity to be Taken by Stiffener (If Required) $V_{stiff\text{-}alt} = \max[\phi R_{nyb}(DCR_{wyb}-1),\phi R_{ncb}(DCR_{wcb}-1),0]$ *Applicable only if $L_{CE\text{-}Alt}/L_{act}$ <= 1.0*	$V_{stiff\text{-}alt}$:	27.1 kip	*(120 kN)*
Required Stiffener Area at z $A_{st} = (V_{stiff\text{-}Alt}/2)/(\phi_{bv}\cdot F_{yBm})$	A_{st}:	0.27 in²	*(175 mm²)*
Required Stiffener Thickness at z $t_{st} = A_{st}/[(b_{fb} - t_{wb})/2]$	t_{st}:	0.08 in	*(2 mm)*

Checks to Develop Beam Shear Capacity at center (as Point Load):

Web Local Yielding Check (AISC J10.2)

$\phi R_{nyb} = \phi_{wyb}\cdot(5\cdot k_{des} + z)\cdot t_{wb}\cdot F_{yBm}$	ϕR_{nyb}:	179.5 kip	*(799 kN)*
$R_{uyb} = V_{uc,ub}$	R_{uyb}:	9.9 kip	*(44 kN)*
$DCR_{wyb} = R_u/\phi R_{nyb}$ *Provide Stiffener if DCR_{wyb} > 1.0*	DCR_{wyb}:	0.06	

Web Local Crippling Check (AISC J10.3)

$\phi R_{ncb} = \phi_c\cdot 0.80\cdot t_{wb}^2[1+3\cdot(z/D_b)\cdot(t_{wb}/t_{fb})^{1.5}]\cdot\sqrt{(E\cdot F_{yBm}\cdot t_{fb}/t_{wb})}$	ϕR_{ncb}:	212.7 kip	*(946 kN)*
$R_{ucb} = V_{uc,ub}$	R_{ucb}:	9.9 kip	*(44 kN)*
$DCR_{wcb} = R_{ucb}/\phi R_{ncb}$ *Provide Stiffener if DCR_{wcb} > 1.0*	DCR_{wcb}:	0.05	
Shear Capacity to be Taken by Stiffener (If Required) $V_{stiff\text{-}alt,cntr} = \max[\phi R_{nyb}(DCR_{wyb}-1),\phi R_{ncb}(DCR_{wcb}-1),0]$ *Applicable only if $L_{CE\text{-}Alt}/L_{act}$ <= 1.0*	$V_{stiff\text{-}alt,cntr}$:	0.0 kip	*(0 kN)*
Required Stiffener Area at Center $A_{st,cntr} = (V_{stiff\text{-}Alt}/2)/(\phi_{bv}\cdot F_{yBm})$	$A_{st,cntr}$:	0.00 in²	*(0 mm²)*

Required Stiffener Thickness at Center $t_{st,cntr} = A_{st}/[(b_{fb} - t_{wb})/2]$	$t_{st,cntr}$:	0.00 in	*(0 mm)*

Required Weld Size for Concentrated Stress Method

Uniformly Distributed Horizontal Load On Gusset: $H_{qusset} = H_{ub}/L_{g-act}$	H_{qusset}:	3.28 k/in	*(0.57 kN/mm)*
Required Beam Weld in z-Region			
Vertical Load from Unbalanced Moment Resolved in z-Region			
$V_z = M_{ub}/((L_{g-act}-z')\cdot z')$	V_z:	21.50 k/in	*(3.77 kN/mm)*
Resultant Load on Weld: $R_z = \sqrt{(V_z^2 + H_{qusset}^2)}$	R_z:	21.75 k/in	*(3.81 kN/mm)*
Angle of Resultant Demand on Beam			
$\theta_{wc} = TAN^{-1}(V_z/H_{qusset})$	θ_{wc}:	1.419 rad	*81.3°*
Weld Capacity Increase Factor for Angle at Beam			
$C_{\theta R} = 1+0.5[SIN(\theta_{wc})]^{1.5}$	$C_{\theta R}$:	1.491	
Size of Weld at z-Region			
$D_{req-z}=R_z/[(2Lines)\cdot 0.75\cdot 0.6\cdot (1in)\cdot F_{EXX}\cdot\sqrt{2}/2\cdot C_{\theta R}/16]$	D_{req-z}:	5.24 (16ths)	*(9 mm)*
Required Beam Weld Center Region			
Vertical Load from Tension and Compression Braces			
$V_{cntr}=V_{ub}/(L_{g-act}-2\cdot z')$	V_{cntr}:	0.14 k/in	*(0.03 kN/mm)*
Resultant Load on Weld: $R_{cntr\ 1} = \sqrt{(V_{cntr}^2 + H_{gusset}^2)}$	R_{cntr}:	3.28 k/in	*(0.58 kN/mm)*
Angle of Resultant Demand on Beam			
$\theta_{wc} = TAN^{-1}(V_{cntr}/H_{gusset})$	θ_{wc}:	0.044 rad	*2.5°*
Weld Capacity Increase Factor for Angle at Beam			
$C_{\theta R} = 1+0.5[SIN(\theta_{wc})]^{1.5}$	$C_{\theta R}$:	1.005	
Size of Weld at Cntr Region: $D_{req}=R_{cntr}/[(2Lines)\cdot 0.75\cdot 0.6\cdot (1in)\cdot F_{EXX}\cdot\sqrt{2}/2\cdot C_{\theta R}/16]$	$D_{req-cntr}$:	1.17 (16ths)	*(2 mm)*

Summary

If L_{CE}/L_{act} > 1.0 Then Must Reinforce	Result:	**No Reinf Req'd**		
Doubler Plates will be used if L_{CE}/L_{act} > 1.0 and L_{CE-Alt}/L_{act} > 1.0:	Result:	**No Doubler Plate Req'd**		
If Reinforcing, Doubler Plate Thickness Equal to:		t_{dpl}:	-	-
If Reinforcing, Min Doubler Plate Length Equal to:		$L_{dpl-min}$:	-	-
If Reinforcing, Min Doubler Plate Weld Equal to:		D_{dpl}:	-	-
If Reinforcing, Min Stiffener Plate Thickness Equal to:		t_{st}:	-	-
If Reinforcing, Weld Size Required at Gusset to Beam:		D_{req}:	4 (16ths)	*(7 mm)*
If L_{CE-Alt}/L_{act} > 1.0 Then Cannot Use Alt Method	Result:	**No Doubler Plate Req'd**		
Stiffener Plates will be used at z if $V_{stiff-Alt}$ > 0	Result:	**Stiffener Plate Req'd at z**		
If Using Alt Method, Size Weld to Develop Gusset Strength Over Length:		z:	-	-
If Using Alt Method, Required Stiffener Thickness at z:		t_{st}:	-	-
If Reinforcing, Weld Size Required at Gusset to Beam in z-Region:		D_{req-z}:	-	-
If Reinforcing, Weld Size Required at Gusset to Beam in Center Region:		$D_{req-cntr}$:	-	-
If weld sizes in z-region and center-regions are nearly the same size, the larger size may be used over the entire region.				
Stiffener Plates will be used at cntr if $V_{stiff-Alt,cntr}$ > 0	Result:	**No Stiffener Plate Req'd at center**		
If Using Alt Method, Required Stiffener Thickness at Center:		$t_{st,cntr}$:	-	-

ALL OTHER CHECKS OK BY COMPARISON TO CONNECTION AT OPPOSITE END OF BRACE

V Beam Connection Bottom

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																				Whitmore Tension Fracture									Gusset Buckling								
EOR-ID	Line	Grids	Lvls	Mark	Qty	n_i	n_o	s	θ_{CB}	θ_{UFM}	L_{tb}	L_{2b}	e	D_{cb}	D_{bb}	$l_{wc,u}$	$l_{wb,u}$	β_{min}	α_{min}	t_g	t_{r_Des}	W_L	A_{wm}	F_{yg}	P_{uc}	β	P_{ut}	P_{ut}	L_1	r_y	K_{chev}	KL_1	F_e	F_y	F_{cr}	ϕP_{cr}	P_{uc}
#		#	#	#	#	#	#	in	rad	rad	in	in	in	in	in	in	in	in	in	in	in	in	in	in^2	ksi	kip		kip	ϕR_n	in	in		r_y	ksi	F_e	ksi	ksi	ϕP_{cr}
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	2	0	3.50	0.48	1.09	34.31	5.88	1.188	0.50	16.40	13.0	37.0	6.9	18.6	0.63	0.00	6.00	4.79	50	149	1.17	127	0.59	17.68	0.18	0.65	63.68	70.58	0.71	37.17	160.30	0.93
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	2	0	3.50	0.48	1.09	34.31	5.88	1.188	0.50	16.40	13.0	37.0	6.9	18.6	0.63	0.00	6.00	4.79	50	149	1.17	127	0.59	17.68	0.18	0.65	63.68	70.58	0.71	37.17	160.30	0.93
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	2	0	3.50	0.39	1.18	46.37	5.88	1.188	0.50	18.40	15.0	49.0	7.7	24.8	0.75	0.00	6.00	5.17	50	146	1.16	126	0.54	23.11	0.22	0.65	69.39	59.44	0.84	35.16	163.50	0.89
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	2	0	3.50	0.39	1.18	46.37	5.88	1.188	0.50	18.40	15.0	49.0	7.5	24.8	0.75	0.00	6.00	5.17	50	146	1.16	126	0.54	23.11	0.22	0.65	69.39	59.44	0.84	35.16	163.50	0.89
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	2	0	3.50	0.27	1.30	50.97	5.88	1.188	0.50	16.40	14.0	55.0	7.4	27.8	0.88	0.00	6.00	5.65	50	134	1.11	121	0.47	21.58	0.25	0.65	55.53	92.82	0.54	39.91	202.80	0.66
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	2	0	3.50	0.31	1.26	44.60	5.88	1.188	0.50	16.40	14.0	49.0	7.4	24.5	0.88	0.00	6.00	6.03	50	134	1.11	121	0.44	18.89	0.25	0.65	48.60	121.16	0.41	42.07	228.23	0.59
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	2	0	3.50	0.24	1.33	51.33	5.88	1.188	0.50	13.80	15.0	56.0	7.8	28.1	1.00	0.00	6.00	6.31	50	134	1.11	121	0.42	24.00	0.29	0.65	54.04	98.00	0.51	40.39	229.42	0.58
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	2	0	3.50	0.24	1.33	51.33	5.88	1.188	0.50	13.80	15.0	56.0	7.8	28.1	1.00	0.00	6.00	6.31	50	134	1.11	121	0.42	24.00	0.29	0.65	54.04	98.00	0.51	40.39	229.42	0.58

Table of Symbols

n = Number of bolts in a row ($_i$ inside row, $_o$ outside row)
s = Bolt spacing in a row
e = Edge distance
θ_{CB} = Angle between brace and beam, rad
θ_{UFM} = Angle used for uniform force method, rad
D_{ct} = Depth of column at top of CB, in
D_{bt} = Depth of beam at top of CB, in
$l_{wc,u}$ = Actual length of weld on column used
$l_{wb,u}$ = Actual length of weld on beam used

α min = Center of weld on beam based on geometry constraints
β min = Center of weld on column based on geometry constraints
t_g = Thickness of gusset
t_r = Thickness of repad
W_L = Width of lug
A_{wm} = Area of whitmore line at gusset
β = Compression strength adjustment factor
P_{uc} = Ultimate CB demand (compression)
P_{ut} = Ultimate CB demand (tension)

K = UFM factor
K' = UFM reduced moment factor
D = UFM reduced moment factor
α' = Center of weld on column with moments
β' = Center of weld on beam with moments
r = Resultant length of **α** & **β**

V Beam Connection Bottom

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Inputs			General										Method 1										Chevron Effects (V)
EOR-ID	Line	Grids	Lvls	Mark	Qty	Brace	b_{fbb}	$k_{des,BM}$	V_{ub}	H_{ub}	$H_{ub\text{-}OGC}$	Aprnment	e_b	M_{ub}	$\phi V_{n\text{-}Bm}$	$L_{g\text{-}act}$	D_{min}	$D_{develop\text{-}tg}$	$V_{u\text{-}CE}$	L_{CE}	$\frac{L_{CE}}{L_{act}}$	V_{stiff}	$A_{st\ rqd}$	$t_{st\ rqd}$	$V_{method\ 1}$	$H_{method\ 1}$	$R_{method\ 1}$	θ_R	$C_{\theta R}$	D_{req}
#		#	#	#	#	Below?	in	in	kip	kip	kip	Factor	in	k-in	kip	in	16ths	16ths	kip	in		kips	in^2	in	k/in	k/in	k/in	rad		16ths
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	Yes	7.12	1.12	9.9	244.6	244.6	2.0	8.20	4011	211.6	74.5	4	6.6	107.64	37.92	0.51	0.0	0.00	-	3.02	3.28	4.46	0.74	1.28	1.3
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	Yes	7.12	1.12	9.9	244.6	244.6	2.0	8.20	4011	211.6	74.5	4	6.6	107.64	37.92	0.51	0.0	0.00	-	3.02	3.28	4.46	0.74	1.28	1.3
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	Yes	7.59	1.15	7.6	252.2	252.2	2.0	9.20	4641	248.4	99.3	4	7.9	93.46	37.37	0.38	0.0	0.00	-	1.96	2.54	3.21	0.66	1.24	0.9
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	Yes	7.59	1.15	7.6	252.2	252.2	2.0	9.20	4641	248.4	99.3	4	7.9	93.46	37.37	0.38	0.0	0.00	-	1.96	2.54	3.21	0.66	1.24	0.9
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	Yes	7.12	1.12	3.6	245.0	245.0	2.0	8.20	4018	211.6	111.2	5	9.2	72.28	37.98	0.34	0.0	0.00	-	1.33	2.20	2.57	0.54	1.19	0.8
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	Yes	7.12	1.12	4.0	242.2	242.2	2.0	8.20	3972	211.6	98.1	5	9.2	80.99	37.55	0.38	0.0	0.00	-	1.69	2.47	2.99	0.60	1.21	0.9
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	Yes	8.03	1.19	3.2	246.7	246.7	2.0	6.90	3405	140.8	112.4	5	10.5	60.56	48.38	0.43	0.0	0.00	-	1.11	2.19	2.46	0.47	1.15	0.8
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	Yes	8.03	1.19	3.2	246.7	246.7	2.0	6.90	3405	140.8	112.4	5	10.5	60.56	48.38	0.43	0.0	0.00	-	1.11	2.19	2.46	0.47	1.15	0.8

V Beam Connection Bottom

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Method 2																		Summary				
EOR-ID	Line	Grids	Lvls	Mark	Qty	$L_{CE\text{-}Alt}$	$\frac{L_{CE\text{-}Alt}}{L_{act}}$	z	$z_{Rounded}$	$V_{stiff\text{-}Alt}$	$t_{st\ rqd,cntr}$	V_z	H_{gusset}	R_z	$\theta_{R\text{-}z}$	$C_{\theta R\text{-}z}$	$D_{Z,Req}$	V_{cntr}	H_{cntr}	R_{cntr}	$\theta_{R\text{-}cntr}$	$C_{\theta R\text{-}cntr}$	$D_{req\text{-}cntr}$	No Reinf	Method 1	Method 2	$t_{st,cntr}$	W_{cntr}
#		#	#	#	#	in	L_{act}	in	in	kips	in	k/in	k/in	k/in	rad	16ths	16ths	k/in	k/in	k/in	rad		16ths	Req'd	(Dblr Plate)	(z Reinf)	in	16ths
BRB-2.00	4.1	D.3 to D(+)	Low Roof	**1901**	1	29.03	0.39	2.59	2.75	0.0	-	21.50	3.28	21.75	1.42	1.49	5.24	0.14	3.28	3.28	0.04	1.00	1.17	✓	✗	✗	0.50	4.00
BRB-2.00	4.1	D(+) to C.6	Low Roof	**1901**	1	29.03	0.39	2.59	2.75	0.0	-	21.50	3.28	21.75	1.42	1.49	5.24	0.14	3.28	3.28	0.04	1.00	1.17	✓	✗	✗	0.50	4.00
BRB-2.00	C	2.8 to 3(+)	Low Roof	**1904**	1	29.84	0.30	2.12	2.25	0.0	-	22.50	2.54	22.64	1.46	1.50	5.44	0.08	2.54	2.54	0.03	1.00	0.91	✓	✗	✗	0.50	4.00
BRB-2.00	C	3(+) to 3.2	Low Roof	**1904**	1	29.84	0.30	2.12	2.25	0.0	-	22.50	2.54	22.64	1.46	1.50	5.44	0.08	2.54	2.54	0.03	1.00	0.91	✓	✗	✗	0.50	4.00
BRB-2.00	C.2	3.3 to 3.7	Low Roof	**1906**	1	28.91	0.26	1.71	1.75	0.0	-	21.50	2.20	21.61	1.47	1.50	5.19	0.03	2.20	2.20	0.01	1.00	0.79	✓	✗	✗	0.50	5.00
BRB-2.00	C.2	3.7 to 4.1	Low Roof	**1907**	1	28.70	0.29	1.92	2.00	0.0	-	21.50	2.47	21.64	1.46	1.50	5.20	0.04	2.47	2.47	0.02	1.00	0.89	✓	✗	✗	0.50	5.00
BRB-2.00	3.2	D to C.6	Low Roof	**1917**	1	32.65	0.29	1.81	2.00	0.0	-	17.00	2.19	17.14	1.44	1.49	4.12	0.03	2.19	2.19	0.01	1.00	0.79	✓	✗	✗	0.50	5.00
BRB-2.00	3.2	C.6 to C.2	Low Roof	**1917**	1	32.65	0.29	1.81	2.00	0.0	-	17.00	2.19	17.14	1.44	1.49	4.12	0.03	2.19	2.19	0.01	1.00	0.79	✓	✗	✗	0.50	5.00

Chevron Beam Connection Top

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

																			Whitmore Tension Fracture									Gusset Buckling								
EOR-ID	Line	Grids	Lvls	Mark	Qty	n_i	n_o	s	θ_{CB}	θ_{UFM}	L_{tt}	L_{2t}	e	D_{ct}	D_{bt}	$l_{wc,u}$	$l_{wb,u}$	β_{min}	α_{min}	t_g	t_{r_Des}	W_L	A_{wm}	F_{yg}	P_{uc}	β	P_{ut}	P_{ut}	L_1	r_y	K_{chev}	KL_1/r_y	F_e	F_y/F_e	F_{cr}	ϕP_{cr}	$P_{uc}/\phi P_{cr}$
#		#	#	#	#	#	#	in	rad	rad	in	in	in	in	in	in	in	in	in	in	in	in	in	in^2	ksi	kip		kip	ϕR_n	in	in			ksi		ksi	ksi	
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	2	0	3.50	0.90	0.67	13.95	5.88	1.188	0.5	16.4	9.0	15.0	4.9	7.6	0.63	0.00	6.00	4.79	50	136	1.11	122	0.57	4.64	0.18	0.65	16.72	1023.68	0.05	48.99	211.26	0.64
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	2	0	3.50	0.90	0.67	13.95	5.88	1.188	0.5	16.4	9.0	15.0	4.9	7.6	0.63	0.00	6.00	4.79	50	136	1.11	122	0.57	4.64	0.18	0.65	16.72	1023.68	0.05	48.99	211.26	0.64
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	2	0	3.50	0.85	0.72	15.93	5.88	1.188	0.5	18.4	9.0	17.0	4.9	8.6	0.63	0.00	6.00	4.79	50	136	1.11	122	0.57	4.86	0.18	0.65	17.52	932.94	0.05	48.89	210.84	0.64
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	2	0	3.50	0.85	0.72	15.93	5.88	1.188	0.5	18.4	9.0	17.0	4.9	8.6	0.63	0.00	6.00	4.79	50	136	1.11	122	0.57	4.86	0.18	0.65	17.52	932.94	0.05	48.89	210.84	0.64
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	2	0	3.50	0.72	0.85	18.30	5.88	1.188	0.5	16.4	10.0	20.0	5.4	10.3	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	7.30	0.18	0.65	26.31	413.34	0.12	47.53	204.97	0.66
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	2	0	3.50	0.72	0.85	18.30	5.88	1.188	0.5	16.4	10.0	20.0	5.4	10.3	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	6.72	0.18	0.65	24.19	489.02	0.10	47.91	206.59	0.65
BRB-2.00	B	5 to 4.7	1	**1913**	1	2	0	3.50	0.72	0.85	13.76	5.88	1.188	0.5	11.9	10.0	17.0	5.0	8.6	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	5.71	0.18	0.65	20.59	675.24	0.07	48.47	209.04	0.64
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	2	0	3.50	0.72	0.85	13.03	5.88	1.188	0.5	11.9	10.0	17.0	5.1	8.6	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	5.41	0.18	0.65	19.51	752.20	0.07	48.63	209.70	0.64
BRB-2.00	3.2	D to C.6	1	**1918**	1	2	0	3.50	0.71	0.86	17.82	5.88	1.188	0.5	13.8	11.0	20.0	5.8	10.2	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	8.11	0.18	0.65	29.21	335.46	0.15	46.98	202.58	0.67
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	2	0	3.50	0.71	0.86	16.86	5.88	1.188	0.5	13.8	11.0	20.0	5.8	10.1	0.63	0.00	6.00	4.79	50	135	1.11	121	0.56	7.68	0.18	0.65	27.65	374.27	0.13	47.28	203.89	0.66

Table of Symbols

- **n** = Number of bolts in a row ($_i$ inside row, $_o$ outside row)
- **s** = Bolt spacing in a row
- **e** = Edge distance
- θ_{CB} = Angle between brace and beam, rad
- θ_{UFM} = Angle used for uniform force method, rad
- D_{cb} = Depth of column at bottom of CB
- D_{bb} = Depth of beam at bottom of CB
- $l_{wc,u}$ = Actual length of weld on column used
- $l_{wb,u}$ = Actual length of weld on beam used
- **α min** = Center of weld on beam based on geometry constraints
- **β min** = Center of weld on column based on geometry constraints
- t_g = Thickness of gusset
- t_r = Thickness of repad
- W_L = Width of lug
- A_{wm} = Area of whitmore line at gusset
- **β** = Compression strength adjustment factor
- P_{uc} = Ultimate CB demand (compression)
- P_{ut} = Ultimate CB demand (tension)
- **K** = UFM factor
- **K'** = UFM reduced moment factor
- **D** = UFM reduced moment factor
- **α'** = Center of weld on column with moments
- **β'** = Center of weld on beam with moments
- **r** = Resultant length of **α** & **β**

Chevron Beam Connection Top

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Inputs			General										Method 1										Chevron Effects
EOR-ID	Line	Grids	Lvls	Mark	Qty	Brace	b_{fbt}	$k_{des,BM}$	V_{ub}	H_{ub}	$H_{ub\text{-}OGC}$	Aprnment	e_b	M_{ub}	$\phi V_{n\text{-}Bm}$	$L_{g\text{-}act}$	D_{min}	$D_{develop\text{-}tg}$	$V_{u\text{-}CE}$	L_{CE}	$\underline{L_{CE}}$ / L_{act}	V_{stiff}	$A_{st\ rqd}$	$t_{st\ rqd}$	$V_{method\ 1}$	$H_{method\ 1}$	$R_{method\ 1}$	θ_R	$C_{\theta R}$	D_{req}
#		#	#	#	#	Above?	in	in	kip	kip	kip	Factor	in	k-in	kip	in	16ths	16ths	kip	in		kips	in^2	in	k/in	k/in	k/in	rad		16ths
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	Yes	7.12	1.12	10.51	161	161	2.0	8.20	2643	211.56	30.50	4	6.6	173.31	24.99	0.82	0.00	0.00	-	11.71	5.28	12.85	1.15	1.44	3.21
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	Yes	7.12	1.12	10.51	161	161	2.0	8.20	2643	211.56	30.50	4	6.6	173.31	24.99	0.82	0.00	0.00	-	11.71	5.28	12.85	1.15	1.44	3.21
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	Yes	7.59	1.15	10.10	171	171	2.0	9.20	3138	248.40	34.31	4	6.6	182.91	25.27	0.74	0.00	0.00	-	10.96	4.97	12.03	1.14	1.43	3.01
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	Yes	7.59	1.15	10.10	171	171	2.0	9.20	3138	248.40	34.31	4	6.6	182.91	25.27	0.74	0.00	0.00	-	10.96	4.97	12.03	1.14	1.43	3.01
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	Yes	7.12	1.12	8.78	193	193	2.0	8.20	3166	211.56	41.19	4	6.6	153.72	29.93	0.73	0.00	0.00	-	7.68	4.69	8.99	1.02	1.39	2.32
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	Yes	7.12	1.12	8.78	193	193	2.0	8.20	3166	211.56	41.19	4	6.6	153.72	29.93	0.73	0.00	0.00	-	7.68	4.69	8.99	1.02	1.39	2.32
BRB-2.00	B	5 to 4.7	1	**1913**	1	No	8.01	1.02	8.82	192	0	1.0	5.95	1145	105.32	34.27	4	6.6	66.83	21.74	0.63	0.00	0.00	-	4.16	5.62	6.99	0.64	1.23	2.04
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	No	8.01	1.02	8.82	192	0	1.0	5.95	1145	105.32	34.50	4	6.6	66.38	21.74	0.63	0.00	0.00	-	4.10	5.58	6.93	0.63	1.23	2.03
BRB-2.00	3.2	D to C.6	1	**1918**	1	Yes	8.03	1.19	8.68	195	195	2.0	6.90	2688	140.76	40.72	4	6.6	132.05	38.20	0.94	0.00	0.00	-	6.70	4.78	8.23	0.95	1.37	2.16
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	Yes	8.03	1.19	8.68	195	195	2.0	6.90	2688	140.76	40.56	4	6.6	132.57	38.20	0.94	0.00	0.00	-	6.75	4.80	8.29	0.95	1.37	2.18

Chevron Beam Connection Top

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

						Method 2																	Summary				
EOR-ID	Line	Grids	Lvls	Mark	Qty	$L_{CE\text{-}Alt}$	$L_{CE\text{-}Alt}$	z	$z_{Rounded}$	$V_{stiff\text{-}Alt}$	$t_{st\ rqd,cntr}$	V_z	H_{gusset}	R_z	$\theta_{R\text{-}z}$	$C_{\theta R\text{-}z}$	$D_{Z,Req}$	V_{cntr}	H_{cntr}	R_{cntr}	$\theta_{R\text{-}cntr}$	$C_{\theta R\text{-}cntr}$	$D_{req\text{-}cntr}$	No Reinf	Method 1	Method 2	$t_{st,cntr}$	W_{cntr}
#		#	#	#	#	in	L_{act}	in	in	kips	in	k/in	k/in	k/in	rad	16ths	16ths	k/in	k/in	k/in	rad		16ths	Req'd	(Dblr Plate)	(z Reinf)	in	16ths
BRB-2.00	4.1	D.3 to D(+)	1	**1902**	1	22.41	0.73	4.78	5.00	0.00	-	21.50	5.28	22.14	1.33	1.48	5.38	0.50	5.28	5.31	0.09	1.01	1.88	✓	✗	✗	0.50	4.00
BRB-2.00	4.1	D(+) to C.6	1	**1902**	1	22.41	0.73	4.78	5.00	0.00	-	21.50	5.28	22.14	1.33	1.48	5.38	0.50	5.28	5.31	0.09	1.01	1.88	✓	✗	✗	0.50	4.00
BRB-2.00	C	2.8 to 3(+)	1	**1905**	1	23.71	0.69	4.71	4.75	0.00	-	22.50	4.97	23.04	1.35	1.48	5.58	0.41	4.97	4.99	0.08	1.01	1.77	✓	✗	✗	0.50	4.00
BRB-2.00	C	3(+) to 3.2	1	**1905**	1	23.71	0.69	4.71	4.75	0.00	-	22.50	4.97	23.04	1.35	1.48	5.58	0.41	4.97	4.99	0.08	1.01	1.77	✓	✗	✗	0.50	4.00
BRB-2.00	C.2	3.3 to 3.7	1	**1908**	1	24.92	0.60	3.95	4.00	0.00	-	21.50	4.69	22.00	1.36	1.48	5.33	0.26	4.69	4.69	0.06	1.01	1.67	✓	✗	✗	0.50	4.00
BRB-2.00	C.2	3.7 to 4.1	1	**1908**	1	24.92	0.60	3.95	4.00	0.00	-	21.50	4.69	22.00	1.36	1.48	5.33	0.26	4.69	4.69	0.06	1.01	1.67	✓	✗	✗	0.50	4.00
BRB-2.00	B	5 to 4.7	1	**1913**	1	18.19	0.53	2.44	2.50	0.00	-	14.75	5.62	15.78	1.21	1.45	3.90	0.30	5.62	5.62	0.05	1.01	2.01	✓	✗	✗	0.50	4.00
BRB-2.00	B	4.7 to 4.4	1	**1914**	1	18.19	0.53	2.42	2.50	0.00	-	14.75	5.58	15.77	1.21	1.45	3.90	0.30	5.58	5.59	0.05	1.01	1.99	✓	✗	✗	0.50	4.00
BRB-2.00	3.2	D to C.6	1	**1918**	1	27.73	0.68	4.35	4.50	0.00	-	17.00	4.78	17.66	1.30	1.47	4.31	0.27	4.78	4.79	0.06	1.01	1.71	✓	✗	✗	0.50	4.00
BRB-2.00	3.2	C.6 to C.2	1	**1919**	1	27.73	0.68	4.37	4.50	0.00	-	17.00	4.80	17.67	1.30	1.47	4.31	0.27	4.80	4.81	0.06	1.01	1.72	✓	✗	✗	0.50	4.00

PSE Operational Training Center

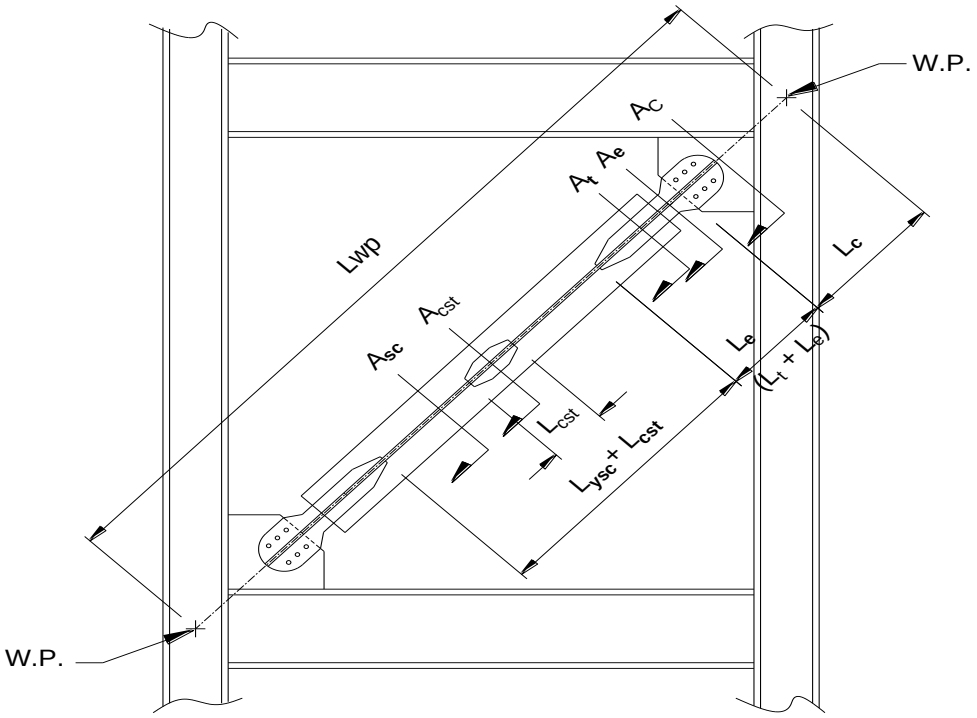
Calculation Submittal Package

Description

Section 7. **Stiffness Sample Calculation**
Stiffness Tables

Stiffness Calculation

Example Mark #: 1901
Line 4.1, Grid D.3 to D(+), Level Low Roof



Stiffness Calculation

7.0 DESIGN CRITERIA

Length Between Work Points at Top and Bottom of Brace	L_{wp}:	173.3 in	*(4402 mm)*
Modulus of Elasticity	E:	29000 ksi	*(199955 MPa)*
Yielding Core Stiffness			
Yielding Core Length	L'_{ysc}:	74.5 in	*(1891 mm)*
Yielding Core Area	A_{ysc}:	2.00 in²	*(1290 mm²)*
Yielding Core Stiffness $K_{ysc} = A_{ysc} \cdot E/L_{ysc}$	K_{ysc}:	779 k/in	*(136 kN/mm)*
End Zone Stiffness			
Length of Stiffener Plate Extension into Casing	L_e:	14.1 in	*(359 mm)*
End Zone Total Length $L_{eT} = 2L_e$	L_{eT}:	28.3 in	*(718 mm)*
End Zone Area	A_e:	5.11 in²	*(3294 mm²)*
End Zone Stiffness $K_e = A_e \cdot E/L_{eT}$	K_e:	5239 k/in	*(917 kN/mm)*
Transition Zone Stiffness (Where Occurs)			
Length from End of Stiffener Plate to Middle of Final Transition	L_t:	0.0 in	*(0 mm)*
Transition Zone Total Length $L_{tT} = 2L_t$	L_{tT}:	0.0 in	*(0 mm)*
Transition Zone Area	A_t:	0.00 in²	*(0 mm²)*
Transition Zone Stiffness $K_t = A_t \cdot E/L_{tT}$	K_t:	--	--
Connection Stiffness			
Length of Connection from Work Point to End of Gusset	L_c:	35.3 in	*(896 mm)*
Connection Region Total Length $L_{cT} = 2 \cdot L_C$	L_{cT}:	70.6 in	*(1793 mm)*
Connection Area	A_c:	15.32 in²	*(9883 mm²)*
Connection Stiffness $K_c = A_c \cdot E/L_{cT}$	K_c:	6294 k/in	*(1102 kN/mm)*
Center Region Stiffness (Not Applicable Where $L_{cst} = 0$)			
Length of Center Region	L_{cst}:	0.0 in	*(0 mm)*
Area of Center Region	A_{cst}:	2.00 in²	*(1290 mm²)*
Center Stiffness $K_{cst} = A_{cst} \cdot E/L_{cst}$	K_{cst}:	--	--
Total Stiffness $K_{eff} = 1/(1/K_{ysc} + 1/K_e + 1/K_t + 1/K_c + 1/K_{cst})$	K_{eff}:	612 k/in	*(107 kN/mm)*
Yielding Core Stiffness WP to WP $K_{LWP} = A_{ysc} \cdot E/L_{WP}$	K_{LWP}:	335 k/in	*(59 kN/mm)*
Stiffness Modification Factor $K_f = K_{eff}/K_{LWP}$	K_f:	1.83	

Length Verification

$$\frac{L_{ysc} + L_{eT} + L_{tT} + L_{cT} + L_{cst}}{L_{WP}} = 1.00$$ *Should be 1.0 if all regions are accounted for.*

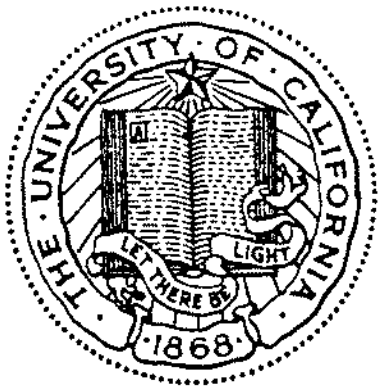
COREBRACE STIFFNESS CALCULATIONS

Project: PSE Operational Training Center
Location: Puyallup, WA
Job: 5872

										Core Stiffness		End Stiffness		Connection Stiffness			Transition Stiff		Cntr Stfnr Stff				SMF
EOR-ID	Line	Grids	Lvls	Mark	Qty	L_{wp}	L_g	β	ω	A_{sc}	L'_{ysc}	A_e	L_e	A_{CONN}	A_{conn}	L_{conn}	A_t	L_{tT}	$A_{sc+2cst}$	L_{cst}	K_{Eff}	K_{LWP}	K_{Eff}
#		#	#	#	#	in	in			in^2	in	in^2	in	Ae	in^2	in	in^2	in	in^2	in	k/in	k/in	K_{LWP}
BRB-2.00	4.1	D.3 to D(+)	Low Roof	1901	1	173.31	109.62	1.17	1.38	2.00	74.46	5.11	14.13	3.0	15.32	71	0.00	0.00	2.00	0.00	612	335	1.83
BRB-2.00	4.1	D(+) to C.6	Low Roof	1901	1	173.31	109.62	1.17	1.38	2.00	74.46	5.11	14.13	3.0	15.32	71	0.00	0.00	2.00	0.00	612	335	1.83
BRB-2.00	4.1	D.3 to D(+)	1	1902	1	246.48	217.62	1.11	1.33	2.00	182.46	5.11	14.13	3.0	15.32	36	0.00	0.00	2.00	0.00	293	235	1.24
BRB-2.00	4.1	D(+) to C.6	1	1902	1	246.48	217.62	1.11	1.33	2.00	182.46	5.11	14.13	3.0	15.32	36	0.00	0.00	2.00	0.00	293	235	1.24
BRB-2.00	5	E to D.5	1	1903	1	296.91	265.73	1.11	1.31	2.00	230.57	5.11	14.13	3.0	15.32	38	0.00	0.00	2.00	0.00	235	195	1.20
BRB-2.00	C	2.8 to 3(+)	Low Roof	1904	1	189.30	107.24	1.16	1.37	2.00	72.24	5.67	14.06	3.0	17.00	89	0.00	0.00	2.00	0.00	626	306	2.04
BRB-2.00	C	3(+) to 3.2	Low Roof	1904	1	189.30	107.24	1.16	1.37	2.00	72.24	5.67	14.06	3.0	17.00	89	0.00	0.00	2.00	0.00	626	306	2.04
BRB-2.00	C	2.8 to 3(+)	1	1905	1	265.47	235.63	1.11	1.33	2.00	200.47	5.11	14.13	3.0	15.32	37	0.00	0.00	2.00	0.00	268	218	1.23
BRB-2.00	C	3(+) to 3.2	1	1905	1	265.47	235.63	1.11	1.33	2.00	200.47	5.11	14.13	3.0	15.32	37	0.00	0.00	2.00	0.00	268	218	1.23
BRB-2.00	C.2	3.3 to 3.7	Low Roof	1906	1	242.64	145.52	1.11	1.31	2.00	110.52	5.67	14.06	3.0	17.00	104	0.00	0.00	2.00	0.00	437	239	1.83
BRB-2.00	C.2	3.7 to 4.1	Low Roof	1907	1	245.43	154.09	1.11	1.31	2.00	119.09	5.67	14.06	3.0	17.00	98	0.00	0.00	2.00	0.00	413	236	1.75
BRB-2.00	C.2	3.3 to 3.7	1	1908	1	310.24	277.52	1.11	1.32	2.00	242.36	5.11	14.13	3.0	15.32	40	0.00	0.00	2.00	0.00	224	187	1.20
BRB-2.00	C.2	3.7 to 4.1	1	1908	1	310.24	277.52	1.11	1.32	2.00	242.36	5.11	14.13	3.0	15.32	40	0.00	0.00	2.00	0.00	224	187	1.20
BRB-2.00	E	4.7 to 5	1	1909	1	305.05	278.18	1.11	1.31	2.00	243.02	5.11	14.13	3.0	15.32	34	0.00	0.00	2.00	0.00	224	190	1.18
BRB-2.00	E	3.8 to 4.1	Low Roof	1910	1	181.06	130.53	1.12	1.34	2.00	95.38	5.11	14.13	3.0	15.32	57	0.00	0.00	2.00	0.00	509	320	1.59
BRB-3.00	E	4.1 to 3.8	1	1911	1	256.62	225.02	1.17	1.23	3.00	184.96	6.67	14.83	3.0	20.00	42	0.00	0.00	3.00	0.00	425	339	1.25
BRB-2.00	4	A.8 to A.99	1	1912	1	238.68	211.47	1.11	1.32	2.00	176.31	5.11	14.13	3.0	15.32	34	0.00	0.00	2.00	0.00	302	243	1.24
BRB-2.00	B	5 to 4.7	1	1913	1	284.61	258.06	1.11	1.32	2.00	222.90	5.11	14.13	3.0	15.32	33	0.00	0.00	2.00	0.00	243	204	1.19
BRB-2.00	B	4.7 to 4.4	1	1914	1	284.61	258.79	1.11	1.32	2.00	223.63	5.11	14.13	3.0	15.32	33	0.00	0.00	2.00	0.00	243	204	1.19
BRB-2.00	2	D to C.6	Low Roof	1915	1	259.13	165.25	1.11	1.31	2.00	130.25	5.67	14.06	3.0	17.00	101	0.00	0.00	2.00	0.00	382	224	1.70
BRB-3.00	2	D to C.6	1	1916	1	318.70	273.02	1.17	1.22	3.00	232.96	6.67	14.83	3.0	20.00	56	0.00	0.00	3.00	0.00	342	273	1.25
BRB-2.00	3.2	D to C.6	Low Roof	1917	1	242.71	127.21	1.11	1.31	2.00	92.21	5.67	14.06	3.0	17.00	122	0.00	0.00	2.00	0.00	498	239	2.08
BRB-2.00	3.2	C.6 to C.2	Low Roof	1917	1	242.71	127.21	1.11	1.31	2.00	92.21	5.67	14.06	3.0	17.00	122	0.00	0.00	2.00	0.00	498	239	2.08
BRB-2.00	3.2	D to C.6	1	1918	1	309.76	278.02	1.11	1.32	2.00	242.86	5.11	14.13	3.0	15.32	39	0.00	0.00	2.00	0.00	224	187	1.20
BRB-2.00	3.2	C.6 to C.2	1	1919	1	309.76	278.98	1.11	1.32	2.00	243.82	5.11	14.13	3.0	15.32	38	0.00	0.00	2.00	0.00	223	187	1.19
BRB-2.00	E	1.5 to 2	Low Roof	1920	1	275.34	204.03	1.11	1.31	2.00	168.87	5.11	14.13	3.0	15.32	78	0.00	0.00	2.00	0.00	305	211	1.45
BRB-2.50	2	A.2 to A	1	1921	1	369.86	336.90	1.11	1.31	2.50	298.00	5.70	14.25	3.0	17.10	43	0.00	0.00	2.50	0.00	229	196	1.17
BRB-2.50	A	3 to 2.7	Low Roof	1922	1	250.78	161.54	1.11	1.31	2.50	122.90	6.25	14.12	3.0	18.74	100	0.00	0.00	2.50	0.00	492	289	1.70
BRB-3.50	A	3 to 2.7	1	1923	1	308.32	263.02	1.17	1.23	3.50	221.48	7.76	15.57	3.0	23.28	56	0.00	0.00	3.50	0.00	416	329	1.26
BRB-2.00	3	A.2 to A	Low Roof	1924	1	252.37	149.45	1.11	1.33	2.00	112.80	5.11	14.88	3.0	15.32	110	0.00	0.00	2.00	0.00	418	230	1.82
BRB-2.00	3	A.2 to A	1	1925	1	310.50	270.52	1.11	1.32	2.00	235.36	5.11	14.13	3.0	15.32	47	0.00	0.00	2.00	0.00	230	187	1.23

Table of Symbols

L_{wp} = Length between W.P.s at top and bottom of CB
L_g = Length between tips of gussets
β = Compression strength adjustment factor
ω = Tension strength adjustment factor
A_{cst} = Area of center stiffener
L_{ysc} = Length of yielding core w/out allowance for Cntr Stiffener
A_{sc} = Area of core plates at yielding section
L_e = Length at end stiffener
A_e = Area at end stiffener
L_{CONN} = Length at end connection
A_{CONN} = Area at end connection
L_{tT} = Transition length of both ends combined
L_{cst} = Length of center stiffeners
A_{cst} = Area of center stiffener at center
K_{LWP} = Theoretical CB stiffness from WP to WP
K_{Eff} = CB stiffness from WP to WP incl transitions & connection regions



STRUCTURAL SYSTEMS
RESEARCH PROJECT

Report No.
TR-20/04
Final Report

Qualification Testing of CoreBrace Bolted Buckling-Restrained Braces (P Series)

by

Ryan Mansing
Chao-Hsien Li
Mathew Reynolds
Chia-Ming Uang

Final Report Submitted to CoreBrace, LLC.

April 2021

Department of Structural Engineering
University of California, San Diego
La Jolla, California 92093-0085

University of California, San Diego
Department of Structural Engineering
Structural Systems Research Project

Report No. TR-20/04

Qualification Testing of CoreBrace Bolted Buckling-Restrained Braces (P Series)

by

Ryan Mansing
Graduate Student Researcher

Chao-Hsien Li
Graduate Student Researcher

Mathew Reynolds
Graduate Student Researcher

Chia-Ming Uang
Professor of Structural Engineering

Final Report Submitted to CoreBrace, LLC

Department of Structural Engineering
University of California, San Diego
La Jolla, California 92093-0085

ABSTRACT

Three buckling-restrained braces (BRBs) of different design strengths were tested in the SRMD Test Facility at the University of California, San Diego. Specimens 8P and 9P were tested in July 2019, while Specimen 10P was tested in April 2020. All specimens consisted of A36 steel core plates encased in grout-filled A500 Gr. B square HSS casings. Bolted end connections were implemented on both ends of the brace to connect each brace end to a bracket with a gusset plate in this P Series. Specimens 8P, 9P, and 10P were connected to gusset plates with a thickness of 1-in., 1¼-in., and 1-in., respectively. The west end of the brace was fastened to the strong wall and the east end was fastened to the SRMD shake table platen.

The cyclic loading protocol used for this test program was composed of three stages. The first stage loading was the same as that specified in the AISC *Seismic Provisions*. The second stage loading was developed to impose greater deformation demands then a code-prescribed requirement. The third stage loading had larger numbers of low-cycle inelastic deformation until core failure. Axial and transverse displacements were imposed to the specimens to simulate the in-plane frame action effect at the gusset connection.

All three specimens performed well during the AISC loading protocol (Stage 1) and Stage 2 loading, fracturing during Stage 3 testing. The braces achieved capacity parameters within the AISC *Seismic Provisions* requirements. For all specimens, the maximum values of compression strength adjustment factor, β, were less than the AISC limiting value of 1.5. The computed cumulative inelastic deformation for all specimens were greater than $200\Delta_{by}$. Note that Specimen 9P had been dropped form a height of multiple stories during construction before it was shipped back for testing, the brace performed well throughout the testing protocol and did not show any degradation in strength. The steel core of Specimen 10P was intentionally made from a plate with a low CVN toughness. This was lower than the New Zealand code requirement but above the AISC requirement. Tests results showed that this low-toughness BRB still exhibited a satisfactory cyclic performance.

ACKNOWLEDGMENTS

Funding for this project was provided by CoreBrace, LLC of West Jordan, Utah. The braces were provided by CoreBrace. CoreBrace engineers, Messrs. Brandt Saxey and Zac Vidmar provide technical assistance throughout the project. The authors would like to thank Messrs. Danny Innamorato and Edward Stovin, staff members of Seismic Response Modification Device (SRMD) Test Facility at the University of California, San Diego, for their technical assistance towards the completion of this test program.

TABLE OF CONTENTS

ABSTRACT ..... **i**
ACKNOWLEDGMENTS ..... **ii**
TABLE OF CONTENTS ..... **iii**
LIST OF TABLES ..... **v**
LIST OF FIGURES ..... **vi**
LIST OF SYMBOLS ..... **viii**
1 INTRODUCTION **1**
1.1 General 1
1.2 Scope and Objectives 1
2 TESTING PROGRAM **2**
2.1 Test Specimens 2
2.2 Material Properties 2
2.3 Test Setup 3
2.4 End Connections 3
2.5 Instrumentation 3
2.6 Loading Protocol 3
2.7 Data Reduction 5
3 TEST RESULTS **23**
3.1 General 23
3.2 Specimen 8P 24
3.3 Specimen 9P 24
3.4 Specimen 10P 25
4 COMPARISON OF TEST RESULTS **41**
4.1 Overall Performance 41
4.2 Hysteretic Energy, E_h, and Cumulative Inelastic Deformation, $\boldsymbol{\eta}$ 41
4.3 Acceptance Criteria 42
4.4 Cyclic Behavior of Low-Toughness BRB 42
5 SUMMARY AND CONCLUSIONS **46**
5.1 Summary 46

5.2 Conclusions..... 47
REFERENCES..... 48
APPENDIX SRMD Command Signal Input 49

LIST OF TABLES

Table 2.1 Specimen Dimensions: Core Plate and Casing Size 8
Table 2.2 Specimen Dimensions: Lengths 8
Table 2.3 Important Dates for Specimen 9P 8
Table 2.4 Specimen Dimensions: Connection Layout 8
Table 2.5 Mechanical Properties of Core Plates 9
Table 2.6 Yield Stress and Deformation 9
Table 2.7 CVN Toughness of Core Plate for Specimen 10P 9
Table 2.8 Target BRB Deformations 10
Table 2.9 Shake Table Input Displacements 11
Table 3.1 Specimen 8P: Response Quantities 26
Table 3.2 Specimen 9P: Response Quantities 27
Table 3.3 Specimen 10P: Response Quantities 28
Table 4.1 Summary of Specimen Performances 44

LIST OF FIGURES

Figure 2.1 Overall Brace Geometry 12
Figure 2.2 Specimen 8P: Detail of Gussets 13
Figure 2.3 Specimen 9P: Detail of Gussets 13
Figure 2.4 Specimen 10P: Detail of Gussets 13
Figure 2.5 SRMD Test Facility 14
Figure 2.6 Typical Overall View of SRMD (Looking South) 14
Figure 2.7 BRB End Connection 15
Figure 2.8 Typical Brace Instrumentation 17
Figure 2.9 Specimen 8P: Loading Protocol 18
Figure 2.10 Specimen 9P: Loading Protocol 19
Figure 2.11 Specimen 10P: Loading Protocol 20
Figure 2.12 Specimen 9P: Comparison of SRMD Input Motion Compared and Measured BRB Axial Deformation 21
Figure 2.13 Definition of Strength Adjustment Factors for the i-th Cycle 21
Figure 2.14 Specimen 9P: Damage due to Fall and Repaired Condition 22
Figure 3.1 Specimen 8P: Brace Deformation Time Histories 29
Figure 3.2 Specimen 8P: Hysteretic Response 30
Figure 3.3 Specimen 8P: Hysteretic Response Envelope 31
Figure 3.4 Specimen 8P: Cumulative Hysteretic Energy 31
Figure 3.5 Specimen 8P: Strength Adjustment Factors 32
Figure 3.6 Specimen 9P: Brace Deformation Time Histories 33
Figure 3.7 Specimen 9P: Hysteretic Response 34
Figure 3.8 Specimen 9P: Hysteretic Response Envelope 35
Figure 3.9 Specimen 9P: Cumulative Hysteretic Energy 35
Figure 3.10 Specimen 9P: Strength Adjustment Factors 36
Figure 3.11 Specimen 10P: Brace Deformation Time Histories 37
Figure 3.12 Specimen 10P: Hysteretic Response 38
Figure 3.13 Specimen 10P: Hysteretic Response Envelope 39
Figure 3.14 Specimen 10P: Cumulative Hysteretic Energy 39
Figure 3.15 Specimen 10P: Strength Adjustment Factors 40

Figure 4.1 Comparison of Hysteretic Energy and Cumulative Ductility..... 45
Figure 4.2 Tensile Peak Force Increment Ratio versus Core Strain Relationship..... 45
Figure A.1 Specimen 8P 49
Figure A.2 Specimen 9P 49
Figure A.3 Specimen 10P 49

LIST OF SYMBOLS

A_{sc} Area of yielding element

C_{max} Maximum brace compressive force at peak cyclic deformation

E_h Total hysteretic energy dissipated by brace

E_{hi} Total hysteretic energy dissipated by brace for the ith cycle

E_s Young's modulus of elasticity of steel

E_{si} Elastic strain energy for the ith cycle

F_{ya} Actual or measured yield strength of steel core (average of coupon tests)

F_{yn} Nominal yield strength of steel core

L_b Total length of brace

L_y Length of yielding element

P_{ya} Actual brace yield force, $F_{ya}A_{sc}$

P_{yn} Nominal brace yield force, $F_{yn}A_{sc}$

P Axial brace force

R_y Material overstrength factor, F_{ya}/F_{yn}

T_{max} Maximum brace tensile force at peak cyclic displacement

β Compression strength adjustment factor, C_{max}/T_{max}

Δ Axial brace deformation

Δ_b Deformation quantity used to control loading of test specimen

Δ_{bm} Value of deformation quantity, Δ_b, corresponding to the design story drift

Δ_{by} Value of deformation quantity, Δ_b, at first significant yield of test specimen

Δ^+ Maximum tensile axial deformation for the ith cycle

Δ^- Absolute value of the maximum compressive axial deformation for the ith cycle

ε Axial brace strain

η_D Cumulative inelastic axial deformation (CID), based on cyclic deformation

η_E Cumulative inelastic axial deformation (CID), based on hysteretic energy

μ_i Inelastic axial deformation of the ith cycle

ω Strain hardening adjustment factor, T_{max}/P_{ya}

1 INTRODUCTION

1.1 General

Three buckling-restrained braces (BRBs) of different design strengths were tested to evaluate their cyclic performance. Bolted (P series) end connections were implemented on both ends of the brace. Provisions for the design and qualifying cyclic testing of BRBs are included in the AISC 341-16 *Seismic Provisions for Structural Steel Buildings* (AISC 2016). The AISC provisions require subassemblage testing to be conducted to verify the performance of BRBs, which demonstrates the BRB's ability to accommodate combined axial and rotational deformation demands imposed during a seismic event. Specimens 8P and 9P were tested in July 2019 (Mansing *et al*. 2019). Specimen 10P was tested in April 2020. This report includes test results of all three specimens.

1.2 Scope and Objectives

All the specimens were designed and fabricated by CoreBrace, LLC and tested at the University of California, San Diego. The testing was performed at the Caltrans Seismic Response Modification Device (SRMD) Testing Facility. The objective of the testing was to evaluate the cyclic performance and the capacity parameters of these BRBs based on the acceptance criteria of the AISC Seismic Provisions.

2 TESTING PROGRAM

2.1 Test Specimens

All specimens consisted of A36 steel core plates encased in grout-filled square HSS casing. Specimens 8P, 9P, and 10P had a core cross-sectional area of 7 in.^{2}, 8 in.^{2}, and 2.25 in.^{2} and of an outer casing made from HSS 10×10×1/4, 10×10×3/16, and 8×8×1/4, respectively. Bolted end connections were implemented on both ends of the brace to connect each brace end to a bracket with a gusset plate. Table 2.1 and Table 2.2 provide detailed brace information, and Figure 2.1 shows the overall brace geometry. Specimen 9P was dropped at the construction site from a height of multiple stories prior to testing, landing on one end of the BRB on a set of precast concrete stairs. As a result, there was damage to the connection lugs and outer casing. This damage included a bend to the lugs at one end (closing the gap from the specified 1-7/16" to approximately 11/16"), gouges to the casing, and a shift in the casing of approximately 5/16" (see Figure 2.14). Additionally, the damaged brace was left out in the elements for 2-3 months at the jobsite in a tropical climate and then for nearly 2 years after its return to CoreBrace while awaiting testing, and as such, noticeable rusting had occurred. Only the bend in the lugs was repaired (as required to fit over the gusset), which employed typical heat flare methods available to site erection crews. The relevant dates and associated events for Specimen 9P are listed in Table 2.3.

2.2 Material Properties

The steel cores and HSS casings were manufactured with ASTM A36 plate and A500 Gr. B steel, respectively. Measured steel properties from the mill reports and tensile coupon tests of the steel core plate materials are summarized in Table 2.5. Based on measured yield stress, F_{ya}, the material overstrength factor, R_y, and brace deformation at first significant yield, Δ_{by}, are listed in Table 2.6. Table 2.7 lists the measured Charpy V-notch (CVN) toughness of the core plate for Specimen 10P and the associated code-prescribed requirements from the United States (AISC 2016) and New Zealand (Standards New Zealand 2009). Specimen 10P was intentionally made from a core plate with a CVN toughness lower than the New Zealand requirement in order to investigate the cyclic behavior of low-toughness BRBs.

2.3 Test Setup

The SRMD facility, which has a shake table platen capable of imposing displacement in six degrees of freedom, is shown in Figure 2.5. Figure 2.6 shows a BRB specimen installed between the platen and strong wall. Either end uses nearly rigid steel fixtures between the strong wall and table platen to fasten the gusset plates, where the BRB end plates are ultimately affixed. Horizontal motion was applied to all specimens in displacement-control mode, resulting in axial and transverse deformations in the brace.

2.4 End Connections

The BRB end connections used for the test program consisted of a pair of connection plates, or lugs. Specimens 8P, 9P, and 10P were connected to gusset plates with a thickness of 1-in., 1¼-in., and 1-in., respectively. For all specimens, the lugs were connected to the gusset plate with 1-1/8 in. diameter ASTM F3148 TNA bolts. Figure 2.7 shows the strong wall end after the TNA bolts were fully tensioned. Bolt holes in the lug plates were standard size, while those in the gusset plates were oversized. The bolted connections were designed to resist slip at the yield strength of the brace.

2.5 Instrumentation

Two string potentiometers, labeled as L1 and L2 in Figure 2.8, were used to measure the axial deformation of the braces. Figure 2.12 shows a comparison between the SRMD input motion and the measured deformation by the string potentiometers for Specimen 9P. Similar comparison of all testing protocol can be found in Appendix. An additional string potentiometer, L3, provided displacement information between BRB end brackets. Brace forces were measured by the load cell in each of the four actuators that drove the shake table and were recorded by the system. Synchronized data was collected in a triggered mode for pseudo-static tests.

2.6 Loading Protocol

According to the AISC Seismic Provisions, the design of BRBs shall be based upon results from qualifying cyclic tests. The loading requirements in such cyclic tests are based on the effects of far-field ground motions on building frames. These motions are usually symmetric, with

consistent relatively small amplitude cycles with low to moderate strain rates. According to Section K3.4c of the AISC Seismic Provisions, the test must be conducted by controlling the level of axial or rotational deformation, Δ_b, imposed on the test specimen.

Loads shall be applied to the test specimen to produce the following deformations, where the deformation is the steel core axial deformation of the test specimen:

(1) 2 cycles of loading at the deformation corresponding to $\Delta_b = 1.0\Delta_{by}$,

(2) 2 cycles of loading at the deformation corresponding to $\Delta_b = 0.5\Delta_{bm}$,

(3) 2 cycles of loading at the deformation corresponding to $\Delta_b = 1.0\Delta_{bm}$,

(4) 2 cycles of loading at the deformation corresponding to $\Delta_b = 1.5\Delta_{bm}$,

(5) 2 cycles of loading at the deformation corresponding to $\Delta_b = 2.0\Delta_{bm}$, and

(6) additional complete cycles of loading at the deformation corresponding to $\Delta_b = 1.5\Delta_{bm}$ as required for the brace test specimen to achieve a cumulative inelastic axial deformation of at least 200 times the deformation at first yield.

The deformation at first yield, Δ_{by}, is computed using the actual yield strength of the material, F_{ya}, and the core yielding length, L_y. The deformation corresponding to the frame drift, Δ_{bm}, would typically be derived based on a structural model of a building. For the purposes of establishing a boundary for the AISC loading protocol used in this testing program, Δ_{bm} is taken as $7.5\Delta_{by}$, $6\Delta_{by}$, and $7\Delta_{by}$ for Specimens 8P, 9P, and 10P, respectively. This loading protocol is usually applied to BRBs pseudo-statically in recognition of the increased costs of applying the loads dynamically (AISC 341, 2016). In this testing program, the entire loading protocol consisted of three stages. The first stage loading was the same as that specified in the AISC *Seismic Provisions*, while the second stage loading imposed a greater deformation demand to the BRB specimens. Stage 3 loading corresponds to larger numbers of low cycle deformation until core fracture.

Using the calculated Δ_{by} value for each specimen (see Table 2.6), the total shake table input displacement was established by adding additional components to account for the following:

(1) deformation of the gusset plates,

(2) deformation due to the flexibility of the end supports and reaction wall at the SRMD testing facility based on a known total system flexibility (1/6800 in./kip), and

(3) deformation of bolt slippage.

Transverse displacements corresponding to the prescribed axial displacement were calculated based on the plastic-hinge-to-plastic-hinge length, which was approximately equal to the length L_b shown in Figure 2.1, and it represents the length between the effective centers of lateral rotation at each end of the brace. Since the loading system was very rigid in the transverse direction, no additional transverse displacement was added to establish the shake table input transverse displacements.

2.7 Data Reduction

Brace Axial Deformation, Δ_b

In the following chapter, the brace specimen deformation, Δ_b, corresponding to the average of those measured by displacement transducers (L1 and L2) is reported. The brace axial strain was calculated per Eq. 2.1.

$$\varepsilon = \frac{\Delta_b}{L_y} \tag{2.1}$$

where L_y equals the length of the steel core plate in the yielding zone. The brace axial deformation is also normalized by the yield deformation. Note that Δ_b includes some minor elastic deformation outside the yielding length, L_y.

Brace Force, P

The brace force was determined by the resultant force along the brace length in the deformed position, which was calculated by combining the force components along the brace from the measured longitudinal and transverse forces.

Platen Friction

The SRMD shake table is a steel platen which rests on hydrostatic bearings that vertically support it and the specimen. This system has an inherent friction force that must be overcome by the machine to move the platen and deform the brace specimen. The friction forces are relatively small compared to the forces experienced by the BRBs, hence it was neglected in computing the brace forces.

Tension and Compression Strength Adjustment Factors, ω, β

Two parameters, ω and β, are defined in the AISC Seismic Provisions (AISC, 2016). The first parameter, ω, is the strain hardening adjustment factor relating the maximum tension force in the brace to the actual brace yield force (see Eq. 2.2). The second parameter, β, is the compression strength adjustment factor which compares the maximum compression force to the maximum tension force of each cycle in the brace (see Eq. 2.3). Therefore, the maximum compression is related to brace yield force by the multiplication of ω and β (see Eq. 2.4).

$$\omega = \frac{T_{max}}{P_{ya}} = \frac{T_{max}}{F_{ya}A_{sc}} \tag{2.2}$$

$$\beta = \frac{C_{max}}{T_{max}} = \frac{\omega\beta}{\omega} \tag{2.3}$$

$$\omega\beta = \frac{C_{max}}{P_{ya}} \tag{2.4}$$

where F_{ya} is the measured yield stress, and A_{sc} is the area of the yielding core. The AISC Seismic Provisions limit the value of β to 1.5 for the cycles of deformation that exceed the yielding deformation.

Hysteretic Energy, E_h

The area enclosed by the P versus Δ_b response curve represents the dissipated hysteretic energy (see Eq. 2.5).

$$E_h = \int P d\Delta \tag{2.5}$$

Cumulative Inelastic Axial Deformation, η_D and η_E

The normalized total inelastic axial deformation for a cycle with a deformation level greater than the yield deformation is given by:

$$\mu_i = \frac{2|\Delta_i^+ - \Delta_i^-|}{\Delta_{by}} - 4 \tag{2.6}$$

where Δ_i^+ and Δ_i^- are the absolute values of the maximum and minimum deformations for the ith cycle, respectively, and Δ_{by} is the deformation corresponding to yielding of the brace. The deformation-based cumulative inelastic axial deformation, η_D, is calculated as the summation of the normalized inelastic axial deformation for each cycle:

$$\eta_D = \sum \mu_i \tag{2.7}$$

For uniaxial testing of BRBs, the AISC Seismic Provisions require that the cumulative normalized inelastic deformation reach a value of at least 200.

Alternatively, the cumulative inelastic deformation (CID) is also calculated as a normalized cumulative dissipated energy as per Eq. 2.8. The value of η_E is also reported in this study.

$$\eta_E = \frac{E_h}{P_{ya}\Delta_{by}} \tag{2.8}$$

Table 2.1 Specimen Dimensions: Core Plate and Casing Size

	W_L (in.)	W_1 (in.)	t_L (in.)	W_2 (in.)	t_{sc} (in.)	Core Plate	HSS Casing Size
8P	8-7/8	8-1/4	3/4	5-5/8	1-1/4	Flat	10×10×1/4
9P	8-7/8	7-13/16	3/4	6-3/8	1-1/4	Flat	10×10×3/16
10P	7-1/2	3-11/16	1/2	3	3/4	Flat	8×8×1/4

Table 2.2 Specimen Dimensions: Lengths

	L_b (in.)	L_c (in.)	L_y (in.)	L_L (in.)	a (in.)	L_T (in.)
8P	236-5/8	192-1/2	165-1/16	14-9/16	4	17-1/4
9P	214-9/16	169-3/8	144	15-5/16	4	16
10P	239-5/8	206-5/16	174-1/4	9-3/8	4	11-7/16

Table 2.3 Relevant Dates for Specimen 9P

Date	Event
2016-06-22	Fabrication Completed
2016-07-15 thru 08-08	Shipping: CB Facility to Jobsite Port
2017-02-25	Damaged During Erection
2017-05-14 thru 06-19	Return Shipping: Jobsite Port to CB Facility
2019-05-17	Repair: Lugs Flared to Fit Gusset
2019-06-07	Test

Table 2.4 Specimen Dimensions: Connection Layout

	Lug PL Hole Dia. (in.)	Gusset PL Hole Dia. (in.)	Rows of Bolts	s (in.)	g_i (in.)	g_o (in.)
8P	1-1/4	1-7/16	4	3-1/4	2-13/16	–
9P	1-1/4	1-7/16	4	3-1/2	2-13/16	–
10P	1-1/4	1-7/16	2	5	2-1/8	–

Table 2.5 Mechanical Properties of Core Plates

	Mill Test Report Average					Tensile Coupon Average				
	Heat No.	F_{ya} (ksi)	F_{ua} (ksi)	F_{ua}/F_{ya}	Elong.[a] (%)	Plate No.	F_{ya} (ksi)	F_{ua} (ksi)	F_{ua}/F_{ya}	Elong.[a] (%)
8P	N18901	41.6	62.5	1.50	35 (8")	4687	41.7	63.6	1.52	36.5 (2")
9P	N05872	40.8	62.5	1.53	34 (8")	1777	44.4	66.6	1.50	34.5 (2")
10P	A9M0361	41.9	59.9	1.43	40 (2")	3597	38.1	57.4	1.50	34 (2")

a) Value in parenthesis indicates gage length of sample

Table 2.6 Yield Stress and Deformation

	A_{sc} (in.²)	F_{yn} (ksi)	$P_{yn}{}^{a}$ (kip)	$P_{ya}{}^{b}$ (kip)	$R_y{}^{c}$	Δ_{by} (in.)
8P	7.00	36	252	292	1.16	0.24
9P	8.00	36	288	355	1.23	0.22
10P	2.25	36	81	86	1.06	0.23

a) $P_{yn} = A_{sc}F_{yn}$
b) $P_{ya} = A_{sc}F_{ya}$
c) $R_y = F_{ya}/F_{yn}$, where F_{yn} is the nominal yield stress of the specified steel.

Table 2.7 CVN Toughness of Core Plate for Specimen 10P

CVN Test Results				Code Requirements
CVN Toughness @ 32°F (0°C) [ft-lb (J)]				NZS 3404.1: 2009: For plate thickness > 12 mm, 51.6 ft-lb (70J) @ 32°F (0°C) – Average of three tests 36.9 ft-lb (50J) @ 32°F (0°C) – Individual test
Sample 1	Sample 2	Sample 3	Average	
13 (17.6)	15 (20.3)	10 (13.6)	12.7 (17.2)	
CVN Toughness @ 70°F (21°C) [ft-lb (J)]				AISC 341-16: For plate thickness ≥ 2 in., 20 ft-lb (27 J) @ 70°F (21°C)
Sample 1	Sample 2	Sample 3	Average	
32 (43.4)	43 (58.3)	29 (39.3)	34.7 (47.0)	

Table 2.8 Target BRB Deformations

(a) Axial Deformation (in.)

	Standard Protocol					Extended Protocol			
	Stage 1					Stage 2			Stage 3
No. of Cycles	2	2	2	2	2	2	2	2	10 (until Fracture)
8P	0.24 ($1\Delta_{by}$)	0.89 ($3.75\Delta_{by}$)	1.78 ($7.5\Delta_{by}$)	2.67 ($11.25\Delta_{by}$)	3.56 ($15\Delta_{by}$)	4.27 ($18\Delta_{by}$)	4.98 ($21\Delta_{by}$)	–	2.67 ($11.25\Delta_{by}$)
9P	0.22 ($1\Delta_{by}$)	0.66 ($3\Delta_{by}$)	1.32 ($6\Delta_{by}$)	1.98 ($9\Delta_{by}$)	2.65 ($12\Delta_{by}$)	3.31 ($15\Delta_{by}$)	3.97 ($18\Delta_{by}$)	2.65 ($12\Delta_{by}$)	2.65 ($12\Delta_{by}$)
10P	0.23 ($1\Delta_{by}$)	0.80 ($3.5\Delta_{by}$)	1.60 ($7\Delta_{by}$)	2.41 ($10.5\Delta_{by}$)	3.21 ($14\Delta_{by}$)	4.24 ($18.5\Delta_{by}$)	5.27 ($23\Delta_{by}$)	–	3.21 ($14\Delta_{by}$)

(b) Transverse Deformation (in.)

	Standard Protocol					Extended Protocol			
	Stage 1					Stage 2			Stage 3
No. of Cycles	2	2	2	2	2	2	2	2	10 (until Fracture)
8P	0.24	0.89	1.80	2.71	3.64	4.39	5.14	–	2.71
9P	0.22	0.66	1.34	2.01	2.69	3.38	4.08	2.69	2.69
10P	0.23	0.81	1.62	2.44	3.27	4.35	5.45	–	3.27

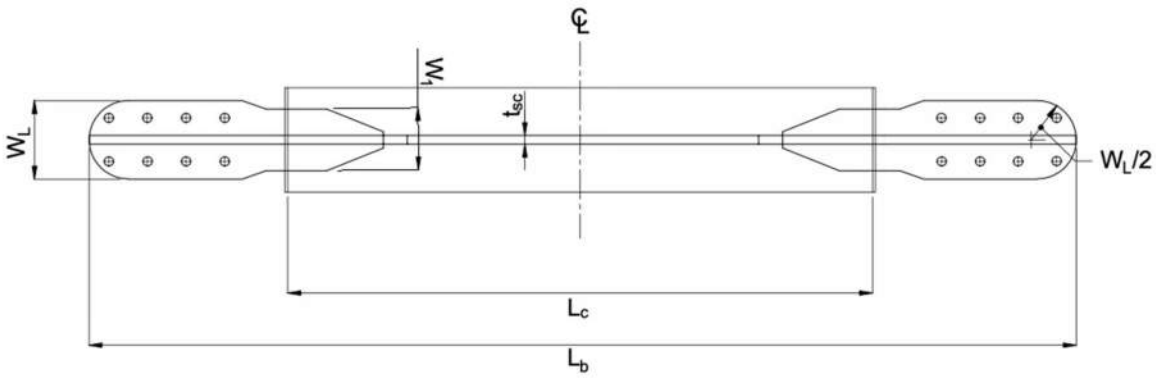
Table 2.9 Shake Table Input Displacements

(a) Axial Deformation (in.)

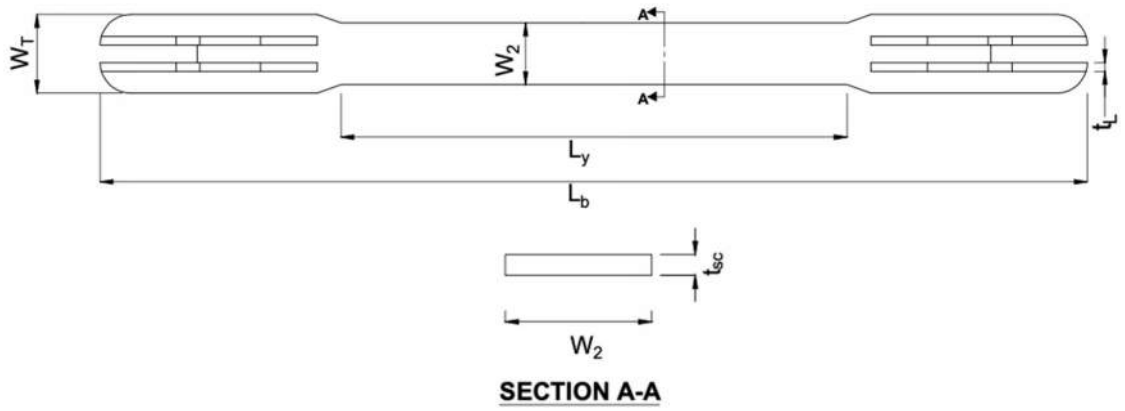
	Standard Protocol					Extended Protocol			
	Stage 1					Stage 2			Stage 3
No. of Cycles	2	2	2	2	2	2	2	2	10 (until Fracture)
8P	0.32/ –0.32	0.98/ –0.99	1.88/ –1.89	3.01/ –3.02	3.90/ –3.92	4.60/ –4.63	5.31/ –5.34	–	3.01/ –3.02
9P	0.32/ –0.33	0.77/ –0.78	1.67/ –1.70	2.34/ –2.39	3.01/ –3.07	3.67/ –3.75	4.36/ –4.47	3.01/ –3.07	3.01/ –3.07
10P	0.28/ –0.28	0.86/ –0.86	1.66/ –1.67	2.47/ –2.47	3.55/ –3.55	4.57/ –4.57	5.58/ –5.59	–	3.55/ –3.55

(b) Transverse Deformation (in.)

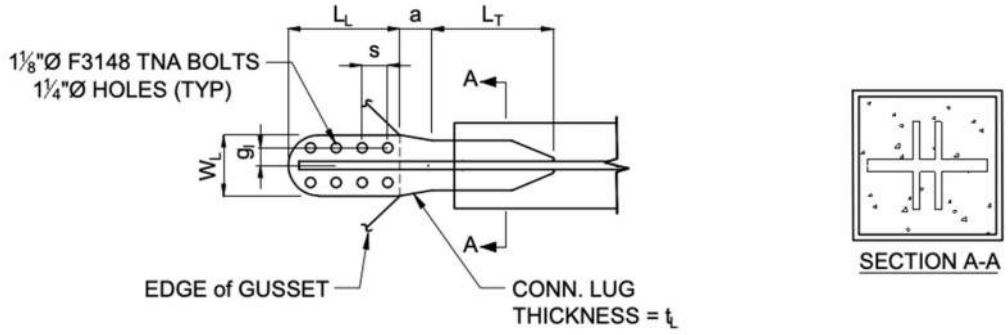
	Standard Protocol					Extended Protocol			
	Stage 1					Stage 2			Stage 3
No. of Cycles	2	2	2	2	2	2	2	2	10 (until Fracture)
8P	0.24	0.89	1.80	2.71	3.64	4.39	5.14	–	2.71
9P	0.22	0.66	1.34	2.01	2.69	3.38	4.08	2.69	2.69
10P	0.23	0.81	1.62	2.44	3.27	4.35	5.45	–	3.27



(a) Elevation View



(b) Plan View



(c) End Detail and Cross Section

Figure 2.1 Overall Brace Geometry

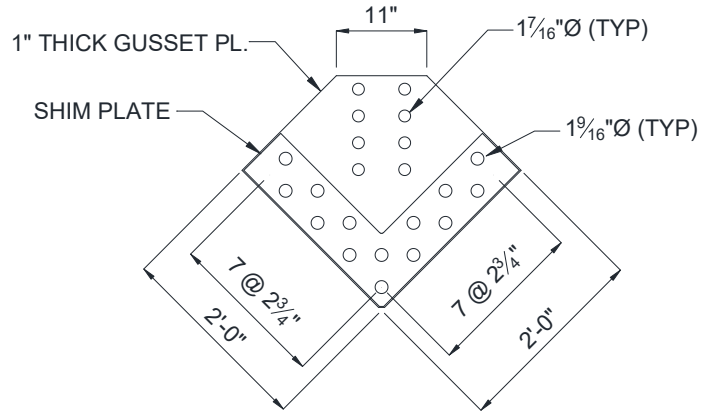


Figure 2.2 Specimen 8P: Detail of Gussets

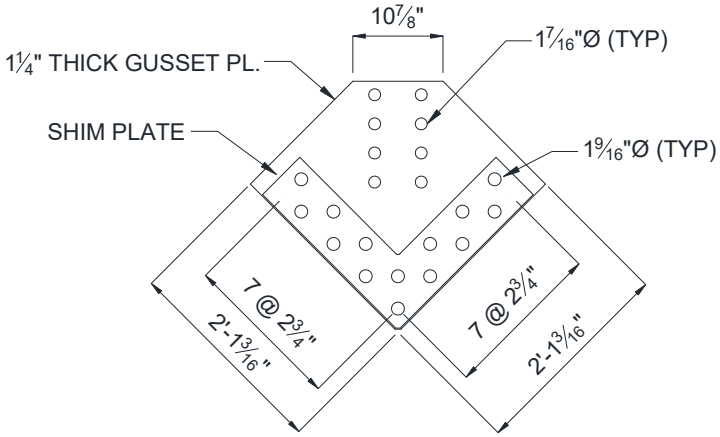


Figure 2.3 Specimen 9P: Detail of Gussets

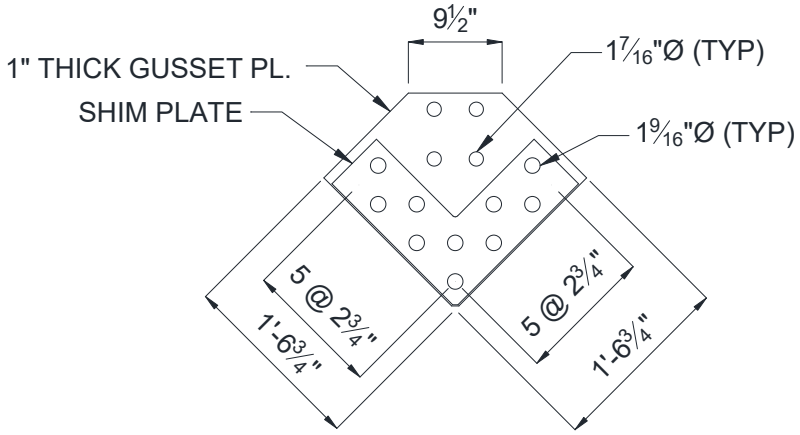


Figure 2.4 Specimen 10P: Detail of Gussets

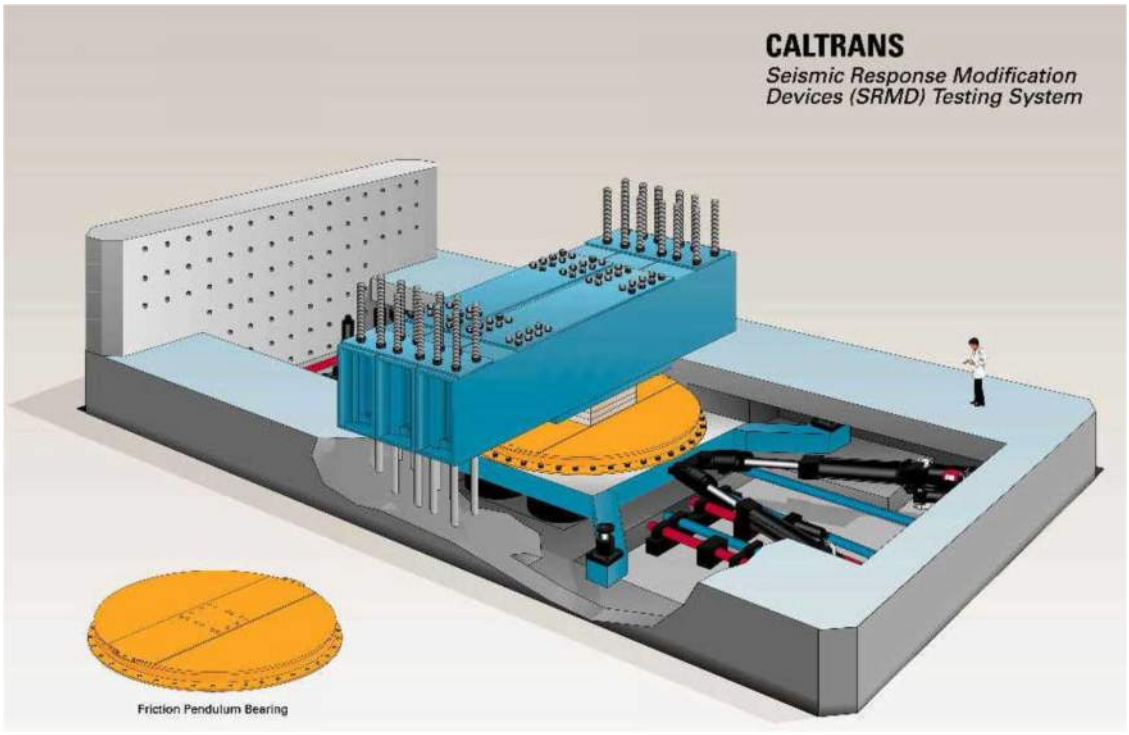


Figure 2.5 SRMD Test Facility

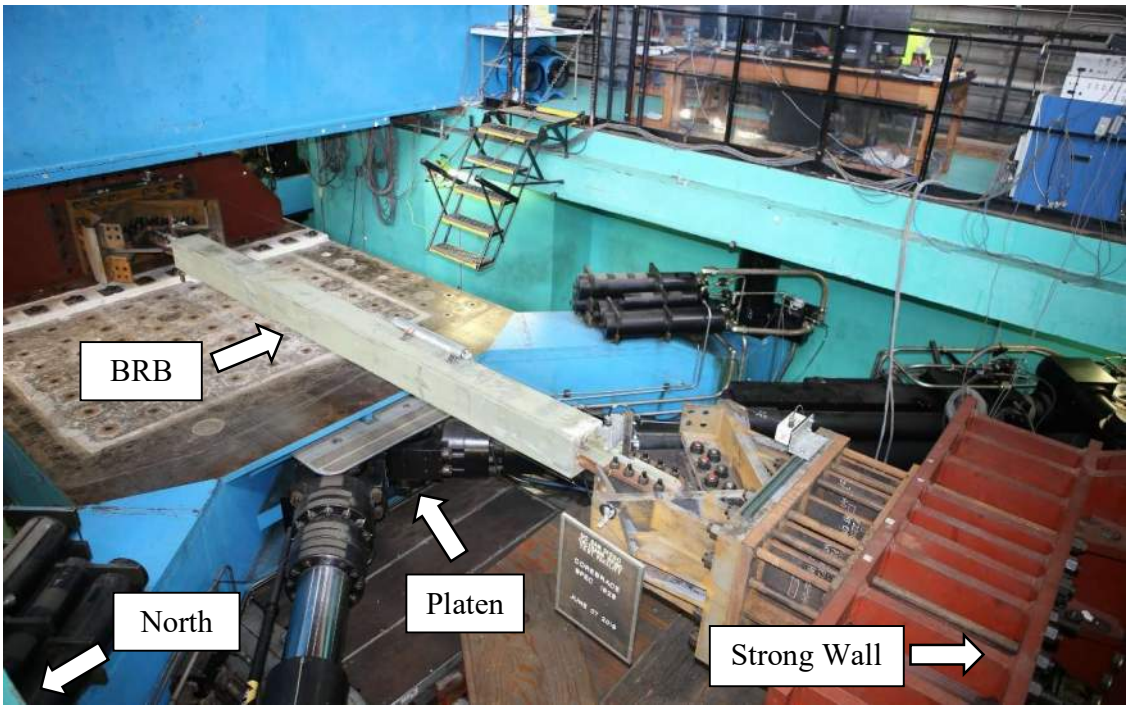
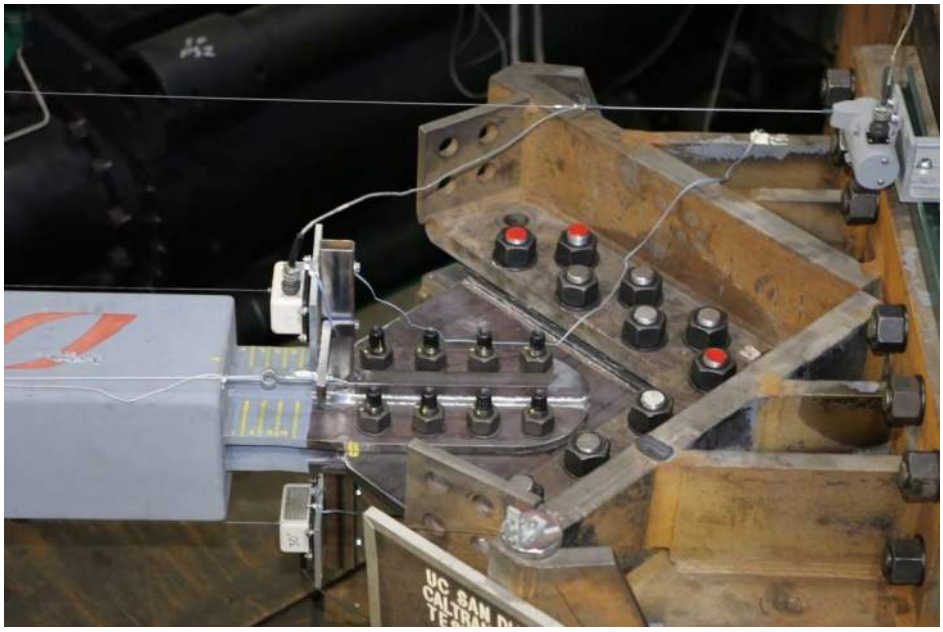
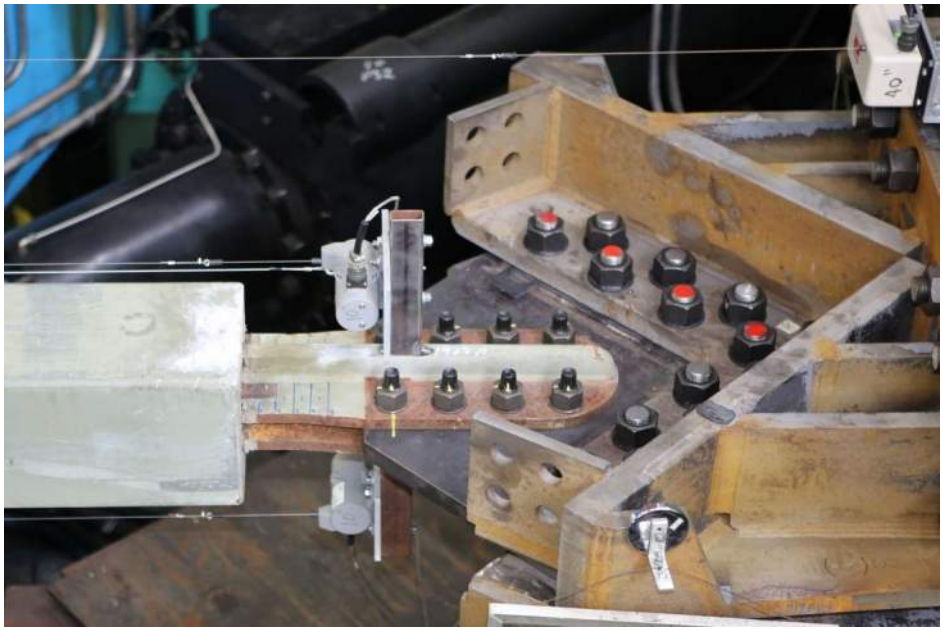


Figure 2.6 Typical Overall View of SRMD (Looking South)



(a) Specimen 8P (West End)



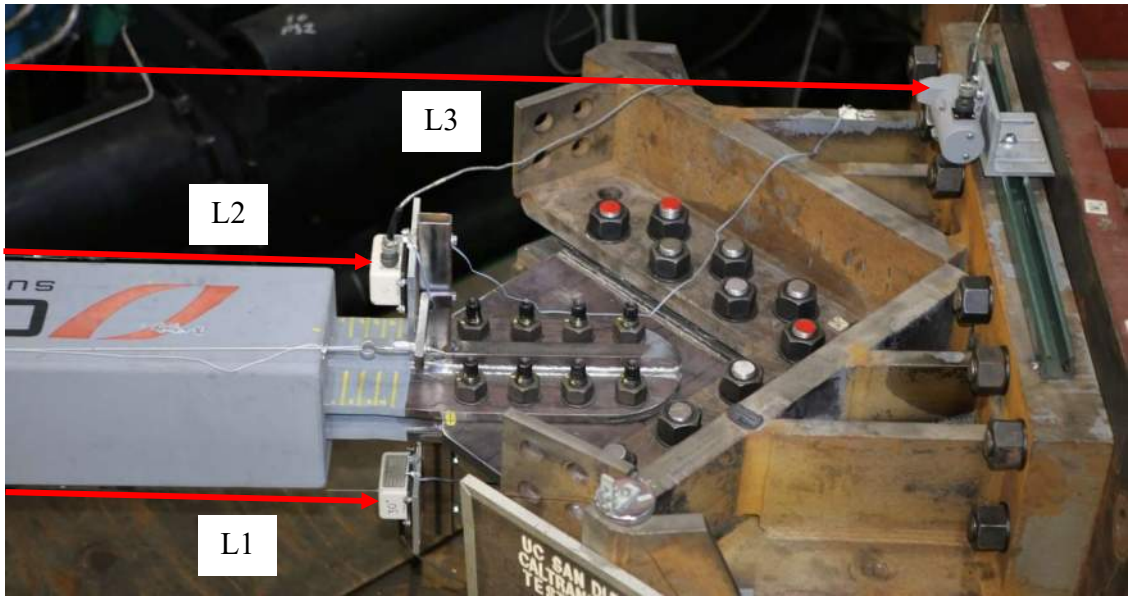
(b) Specimen 9P (West End)

Figure 2.7 BRB End Connection

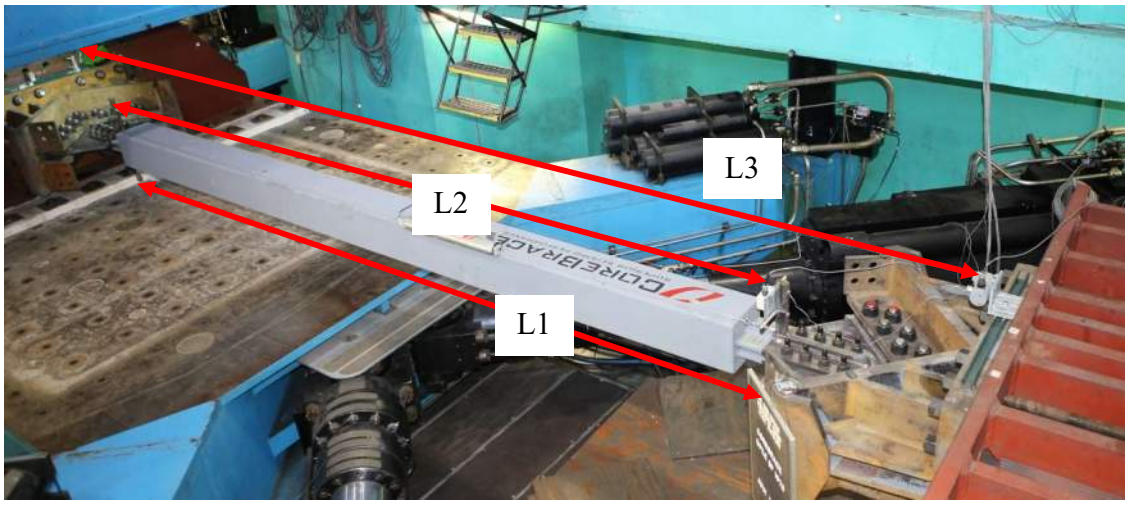


(c) Specimen 10P (West End)

Figure 2.7 BRB End Connection (continued)

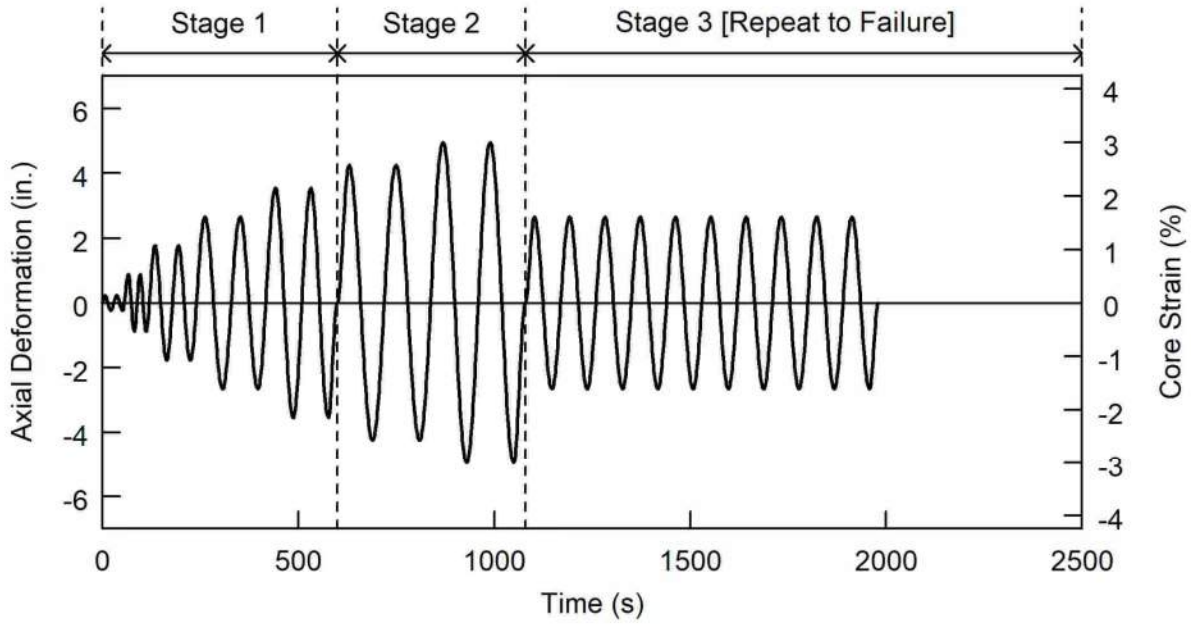


(a) West End

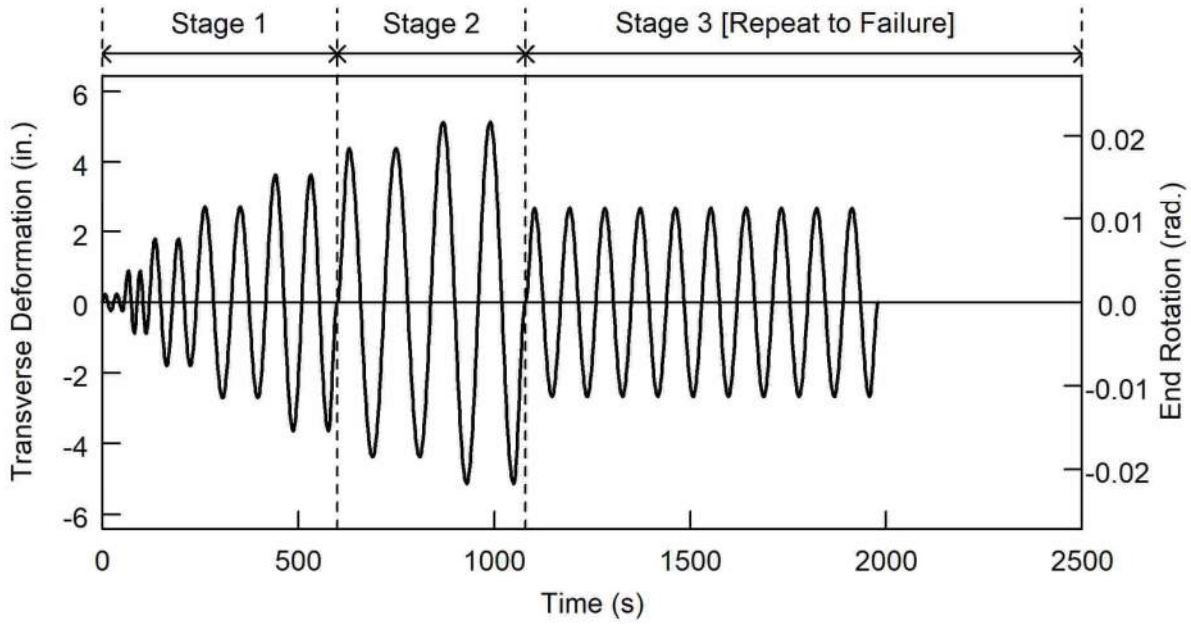


(b) Overall View

Figure 2.8 Typical Brace Instrumentation

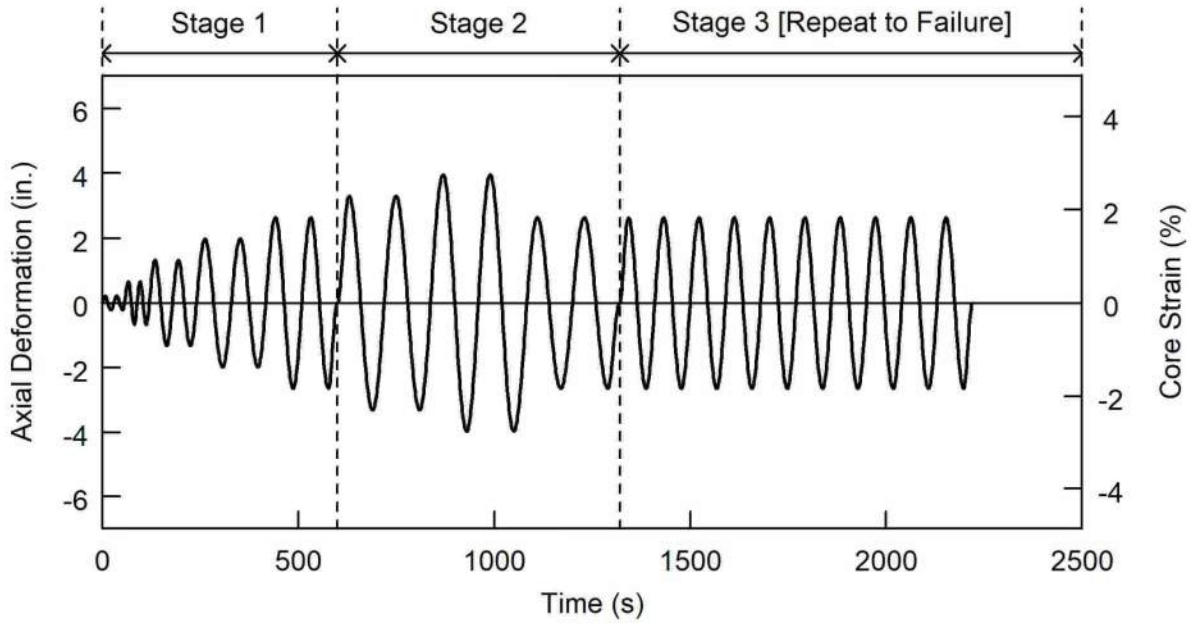


(a) Longitudinal Direction

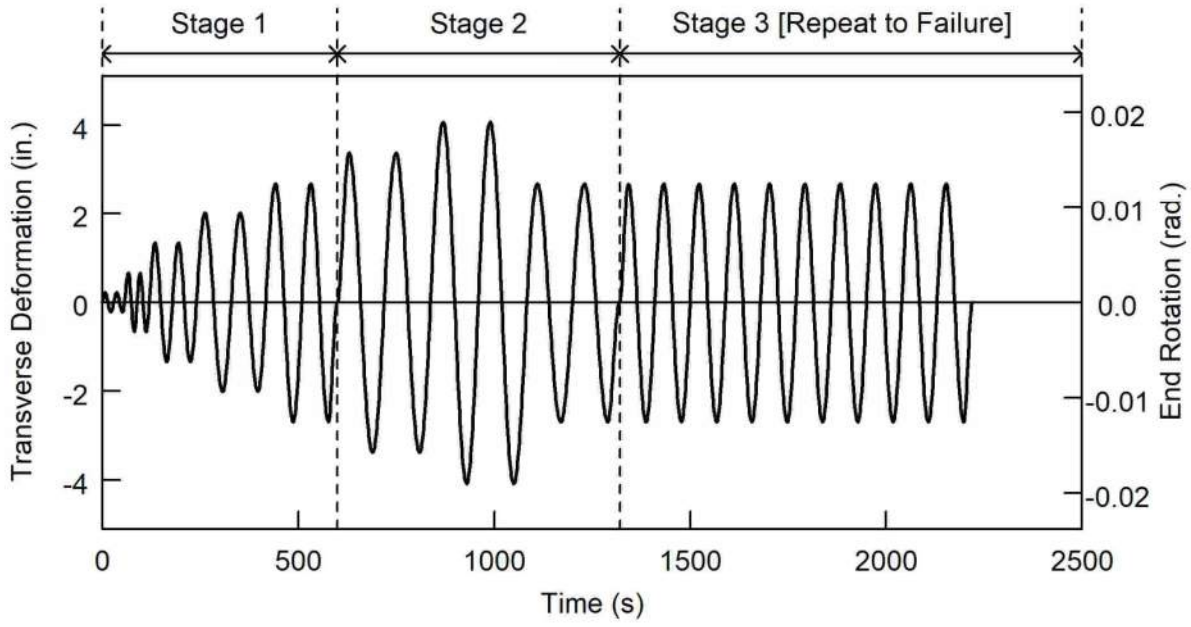


(b) Transverse Direction

Figure 2.9 Specimen 8P: Loading Protocol

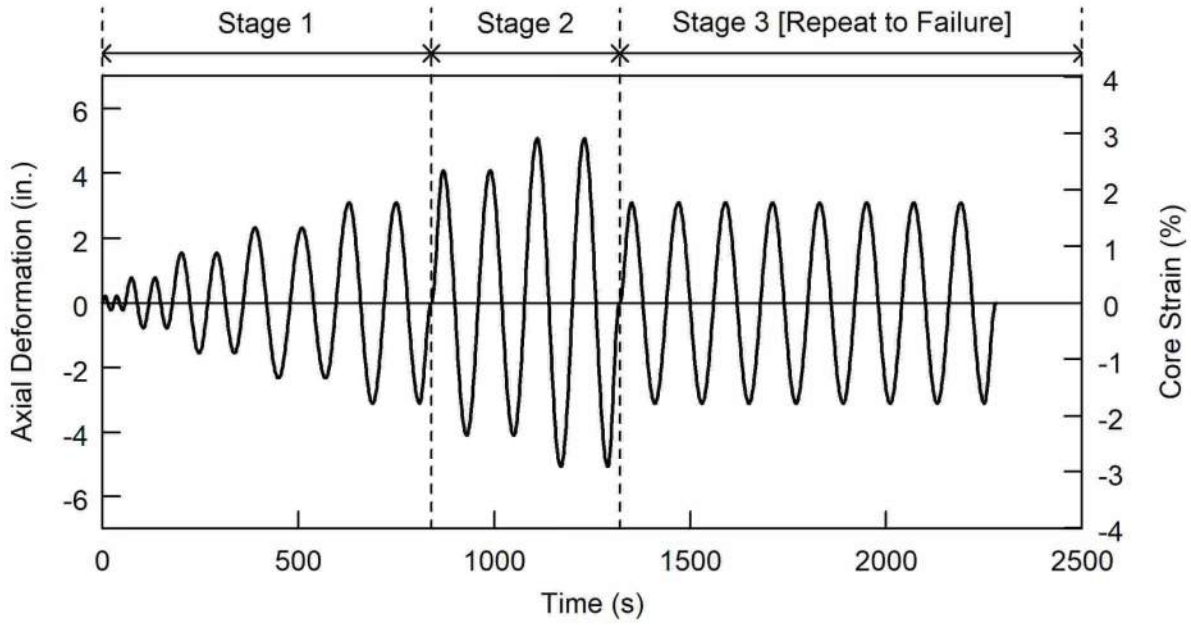


(a) Longitudinal Direction

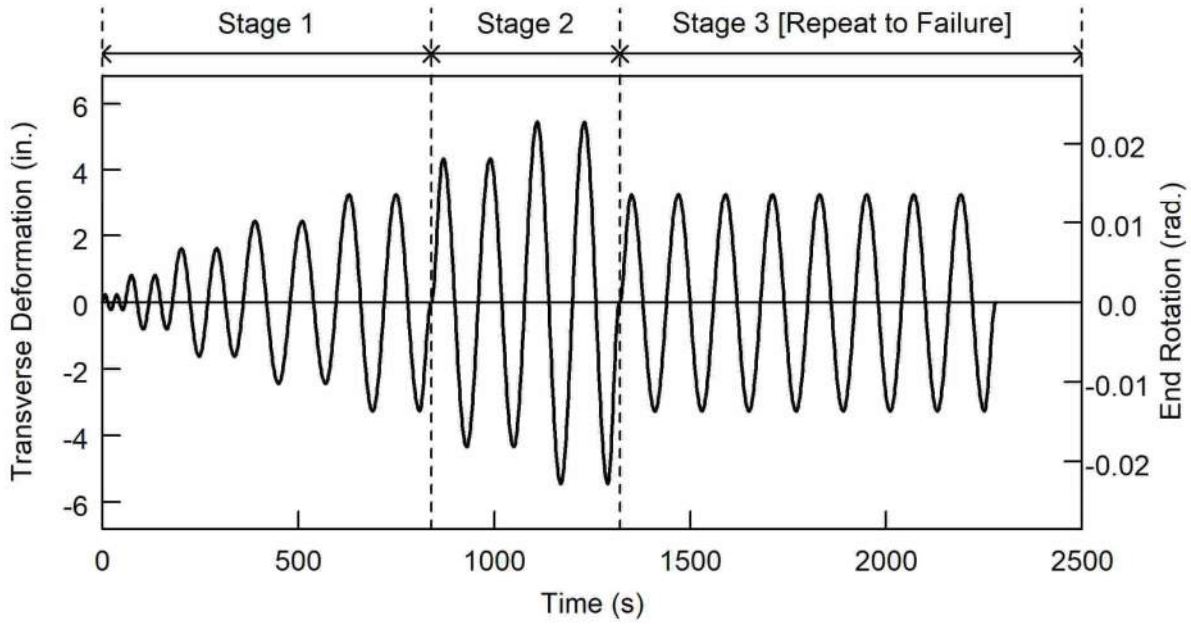


(b) Transverse Direction

Figure 2.10 Specimen 9P: Loading Protocol



(a) Longitudinal Direction



(b) Transverse Direction

Figure 2.11 Specimen 10P: Loading Protocol

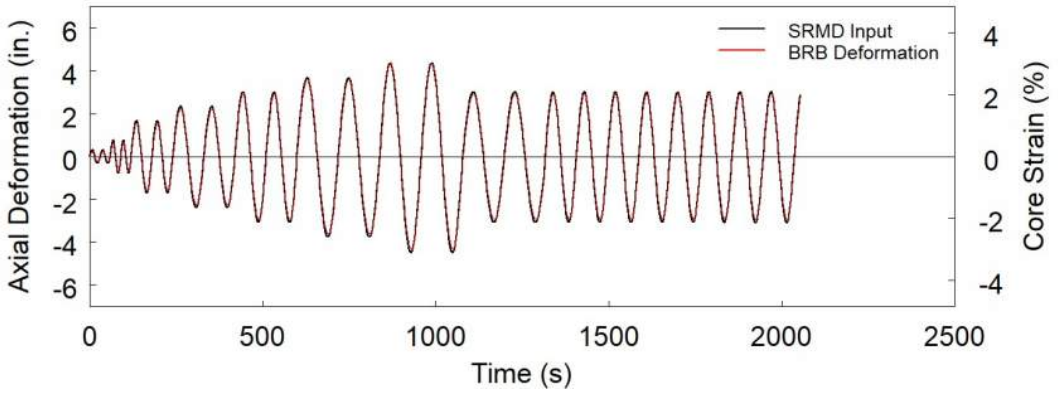


Figure 2.12 Specimen 9P: Comparison of SRMD Input Motion Compared and Measured BRB Axial Deformation

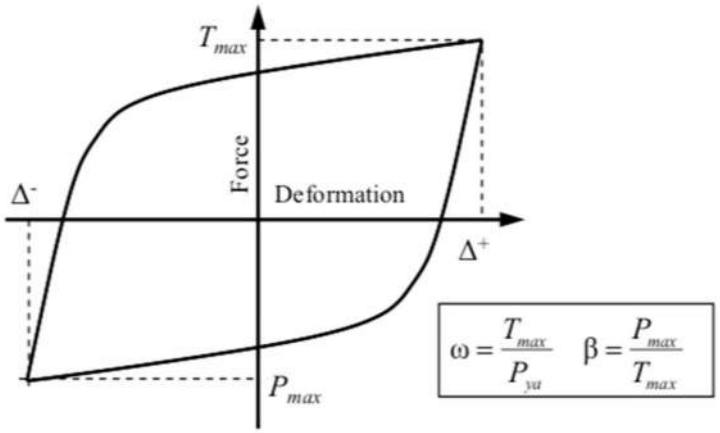


Figure 2.13 Definition of Strength Adjustment Factors for the i-th Cycle



(a) Casing Shift (Approx. 5/16”)



(b) Casing Gouge (Approx. 1/8” Deep)



(c) Lug Bend: Overall View



(d) Heat Flare on Bent Lug



(e) Lug Measurement before Repair



(f) Lug Measurement after Repair

Figure 2.14 Specimen 9P: Damage due to Fall and Repaired Condition

3 TEST RESULTS

3.1 General

For each specimen, a table summarizing the brace forces, corresponding strength adjustment factors and cumulative inelastic axial deformation for each cycle of test run, as described in Section 2.7, is provided (see Table 3.1 through Table 3.3). The table also reports the axial deformation in terms of core axial strain (Eq. 2.1), deformation-based (Eqs. 2.6 to 2.7), and dissipated energy-based (Eq. 2.8) cumulative inelastic deformation. In addition, the following results are presented.

(1) Measured brace displacement time histories in the longitudinal and transverse directions. These displacements represent the actual deformations and end rotations experienced by the brace.

(2) Brace force versus deformation hysteretic responses in the longitudinal and transverse directions.

(3) Cumulative hysteretic energy, E_h, computed in accordance with Eq. 2.5 and the normalized cumulative dissipated energy, η_E, computed in accordance with Eq. 2.8 at the instance of core fracture.

(4) Axial brace response envelope, or backbone curve.

(5) Strength adjustment factors (ω, β, and $\beta\omega$) versus brace axial deformation (see Figure 3.5 through Figure 3.15). ω, β, and $\beta\omega$, were computed in accordance with Eqs. 2.2, 2.3, and 2.4, respectively.

3.2 Specimen 8P

Specimen 8P was tested on July 2nd, 2019. The specimen fractured during the first cycle of Stage 3 of the loading protocol. The failure occurred in the beginning of the cycle as it was approaching the peak tensile force which occurred at $22\Delta_{by}$. An initial peak force jump was observed at the start of Stage 3 of the loading protocol, right before the core fractured, as shown in Figure 3.2(a).

A maximum tension (ω) and compression (β) overstrength factor of 1.49 and 1.24 were achieved, respectively, during the loading protocol (see Table 3.1). The maximum tension force during the loading protocol was 435 kips at a displacement of 5.29 in., which corresponded to a core strain of 3.21%. The maximum compression force during the loading protocol was 538 kips at a displacement of −5.18 in., which corresponded to a core strain of −3.14%.

Figure 3.4 shows the computed hysteretic energy and cumulative dissipated energy for the loading protocol. A total of 53,180 kip-in. of hysteretic energy was absorbed, which corresponds to a cumulative ductility of $772\Delta_{by}$. About 55% energy came from Stage 2 of the loading protocol, as shown in Figure 4.1.

3.3 Specimen 9P

Specimen 9P was tested on June 7th, 2019. The specimen fractured during the 9th cycle of Stage 3 of the loading protocol. The failure occurred in the beginning of the cycle as it was approaching the peak tensile force which occurred at $12\Delta_{by}$ (after completing $20\Delta_{by}$ cycles in Stage 2).

A maximum tension (ω) and compression (β) overstrength factor of 1.37 and 1.27 were achieved, respectively, during the loading protocol (see Table 3.2). The maximum tension force during the loading protocol was 488 kips at a displacement of 4.32 in., which corresponded to a core strain of 3.00%. The maximum compression force during the loading protocol was 610 kips at a displacement of −4.29 in., which corresponded to a core strain of −2.98%.

Figure 3.9 shows the computed hysteretic energy and cumulative dissipated energy for the loading protocol. A total of 91,710 kip-in. of hysteretic energy was absorbed, which corresponds to a cumulative ductility of $1{,}173\Delta_{by}$. The energy from Stages 2 and 3 of the loading protocols were very similar, but larger than from Stage 1 of the loading protocol, as shown in Figure 4.1.

3.4 Specimen 10P

Specimen 10P was tested on April 14th, 2020. The specimen completed Stages 1 and 2 loadings and fractured during the 2nd cycle of Stage 3 loading. The failure occurred just before the brace reached the peak tensile force which occurred at $14\Delta_{by}$ in that cycle (after completing $24\Delta_{by}$ cycles in Stage 2).

A maximum tension (ω) and compression (β) overstrength factor of 1.52 and 1.48 were achieved, respectively, during the loading protocol (see Table 3.3). The β values for Specimen 10P was higher than those for Specimens 8P and 9P. This could be due to the nature of small core BRB for Specimen 10P. The maximum tension force during the loading protocol was 130 kips at a displacement of 5.60 in., which corresponds to a core strain of 3.21%. The maximum compression force during the loading protocol was 193 kips at a displacement of -5.52 in., which corresponds to a core strain of -3.17%.

Figure 3.9 shows the computed hysteretic energy and cumulative dissipated energy for the loading protocol. A total of 16,730 kip-in. of hysteretic energy was absorbed, which corresponds to a cumulative ductility of $851\Delta_{by}$. About 54% energy came from Stage 2 of the loading protocol, as shown Figure 4.1.

Table 3.1 Specimen 8P: Response Quantities

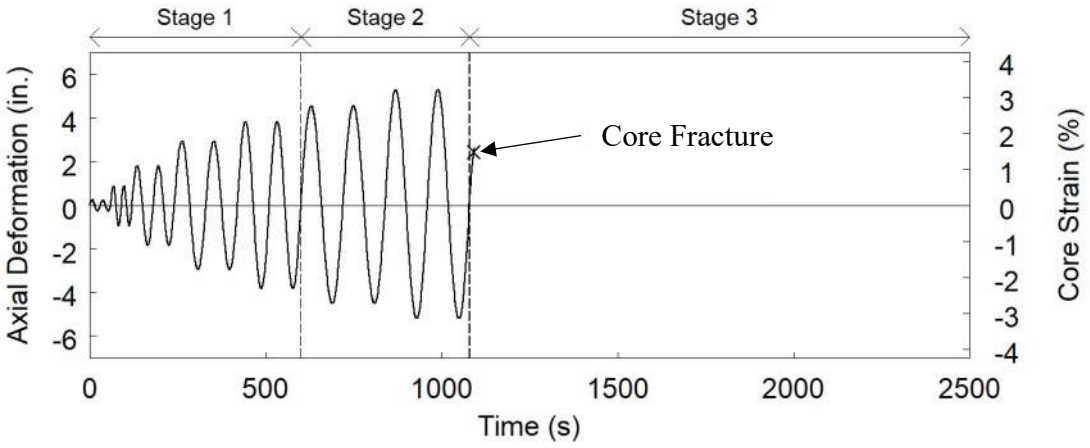
Test		Cycle No.	T_{max} (kips)	C_{max} (kips)	ω	β	βω	Brace Deformation								μ_i	η_D	η_E
								Axial						Transverse				
								Positive			Negative							
								(in.)	(Δ_{by})	(%)	(in.)	(Δ_{by})	(%)	(in.)	(rad)			
Loading Protocol	Stage 1 (AISC)	1	287	297	0.98	1.04	1.02	0.26	1.08	0.15	0.26	1.08	0.15	0.23	0.001	0.32	0	1
		2	278	284	0.95	1.02	0.97	0.24	1.03	0.15	0.25	1.06	0.15	0.23	0.001	0.19	1	1
		3	296	305	1.02	1.03	1.05	0.89	3.78	0.54	0.94	3.97	0.57	0.88	0.004	11.51	12	10
		4	302	313	1.04	1.04	1.07	0.89	3.76	0.54	0.94	3.97	0.57	0.87	0.004	11.46	23	21
		5	326	369	1.12	1.13	1.27	1.81	7.67	1.10	1.83	7.77	1.11	1.79	0.008	26.89	50	44
		6	349	376	1.20	1.08	1.29	1.80	7.62	1.09	1.84	7.78	1.11	1.78	0.008	26.80	77	71
		7	368	422	1.26	1.15	1.45	2.93	12.43	1.78	2.93	12.43	1.78	2.70	0.011	45.73	123	117
		8	384	430	1.32	1.12	1.47	2.93	12.42	1.78	2.93	12.42	1.78	2.69	0.011	45.69	169	170
		9	397	465	1.36	1.17	1.59	3.83	16.21	2.32	3.80	16.12	2.31	3.61	0.015	60.66	229	240
		10	408	474	1.40	1.16	1.62	3.83	16.22	2.32	3.80	16.09	2.30	3.61	0.015	60.62	290	315
	Stage 2	11	419	508	1.44	1.21	1.74	4.55	19.28	2.76	4.50	19.06	2.73	4.38	0.019	72.68	363	407
		12	428	513	1.47	1.20	1.76	4.55	19.27	2.76	4.50	19.06	2.73	4.38	0.019	72.67	435	503
		13	433	533	1.48	1.23	1.83	5.29	22.41	3.21	5.18	21.93	3.14	5.12	0.022	84.69	520	615
		14	435	538	1.49	1.24	1.84	5.29	22.43	3.21	5.18	21.93	3.14	5.11	0.022	84.71	605	733

Table 3.2 Specimen 9P: Response Quantities

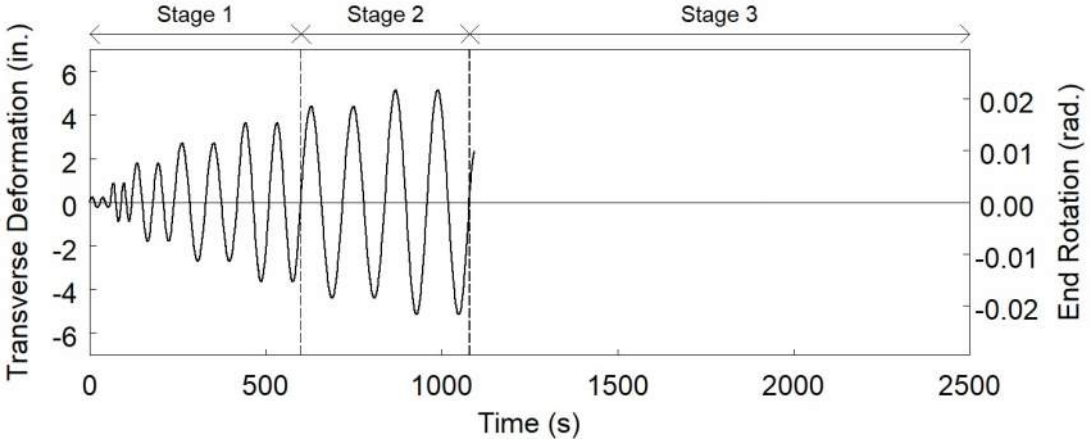
Test		Cycle No.	T_{max} (kips)	C_{max} (kips)	ω	β	βω	Brace Deformation								μ_i	η_D	η_E
								Axial						Transverse				
								Positive			Negative							
								(in.)	(Δ_{by})	(%)	(in.)	(Δ_{by})	(%)	(in.)	(rad)			
Loading Protocol	Stage 1 (AISC)	1	329	350	0.93	1.06	0.98	0.23	1.06	0.16	0.24	1.07	0.16	0.21	0.001	0.26	0	1
		2	326	337	0.92	1.04	0.95	0.23	1.04	0.16	0.24	1.08	0.17	0.20	0.001	0.24	0	2
		3	335	353	0.94	1.05	0.99	0.67	3.07	0.47	0.69	3.13	0.48	0.65	0.003	8.39	9	8
		4	332	354	0.94	1.07	1.00	0.68	3.07	0.47	0.68	3.11	0.48	0.64	0.003	8.36	17	16
		5	355	423	1.00	1.19	1.19	1.57	7.16	1.09	1.59	7.22	1.10	1.34	0.006	24.75	42	35
		6	390	437	1.10	1.12	1.23	1.56	7.08	1.08	1.59	7.21	1.10	1.34	0.006	24.58	67	59
		7	408	484	1.15	1.19	1.36	2.24	10.17	1.55	2.25	10.25	1.57	2.01	0.009	36.83	103	94
		8	422	490	1.19	1.16	1.38	2.23	10.12	1.55	2.26	10.25	1.57	2.00	0.009	36.74	140	133
		9	437	529	1.23	1.21	1.49	2.91	13.24	2.02	2.92	13.28	2.03	2.68	0.013	49.03	189	184
		10	448	535	1.26	1.19	1.51	2.91	13.21	2.02	2.92	13.27	2.03	2.68	0.012	48.96	238	239
	Stage 2	11	466	578	1.31	1.24	1.63	3.60	16.36	2.50	3.59	16.33	2.50	3.37	0.016	61.37	300	309
		12	474	582	1.34	1.23	1.64	3.60	16.35	2.50	3.59	16.30	2.49	3.36	0.016	61.30	361	384
		13	482	610	1.36	1.27	1.72	4.32	19.65	3.00	4.29	19.51	2.98	4.07	0.019	74.31	435	474
		14	488	610	1.37	1.25	1.72	4.32	19.65	3.00	4.29	19.48	2.98	4.06	0.019	74.26	509	569
		15	479	555	1.35	1.16	1.56	2.91	13.23	2.02	2.91	13.22	2.02	2.68	0.012	48.91	558	636
		16	469	552	1.32	1.18	1.56	2.91	13.24	2.02	2.91	13.23	2.02	2.68	0.012	48.95	607	693
	Stage 3	17	473	557	1.33	1.18	1.57	2.91	13.23	2.02	2.91	13.20	2.02	2.68	0.012	48.87	656	751
		18	467	556	1.31	1.19	1.57	2.91	13.21	2.02	2.91	13.24	2.02	2.68	0.012	48.88	705	808
		19	463	554	1.30	1.20	1.56	2.91	13.21	2.02	2.91	13.21	2.02	2.67	0.012	48.83	754	865
		20	461	553	1.30	1.20	1.56	2.91	13.22	2.02	2.90	13.18	2.01	2.68	0.013	48.80	803	922
		21	459	554	1.29	1.21	1.56	2.91	13.21	2.02	2.91	13.22	2.02	2.69	0.013	48.86	851	978
		22	458	555	1.29	1.21	1.56	2.92	13.25	2.03	2.91	13.24	2.02	2.67	0.012	48.99	900	1035
		23	455	550	1.28	1.21	1.55	2.92	13.27	2.03	2.91	13.25	2.02	2.67	0.012	49.03	949	1091
		24	454	560	1.28	1.23	1.58	2.92	13.27	2.03	2.93	13.31	2.03	2.67	0.012	49.16	999	1148

Table 3.3 Specimen 10P: Response Quantities

Test		Cycle No.	T_{max} (kips)	C_{max} (kips)	ω	β	βω	Brace Deformation								μ_i	η_D	η_E
								Axial						Transverse				
								Positive			Negative							
								(in.)	(Δ_{by})	(%)	(in.)	(Δ_{by})	(%)	(in.)	(rad)			
Loading Protocol	Stage 1 (AISC)	1	76	78	0.88	1.03	0.91	0.26	1.12	0.15	0.27	1.17	0.15	0.22	0.001	0.56	1	1
		2	76	76	0.89	1.00	0.89	0.26	1.12	0.15	0.26	1.12	0.15	0.21	0.001	0.47	1	2
		3	98	102	1.14	1.04	1.19	0.85	3.71	0.49	0.85	3.69	0.49	0.80	0.003	10.80	12	10
		4	100	99	1.16	1.00	1.16	0.85	3.71	0.49	0.85	3.70	0.49	0.80	0.003	10.82	23	19
		5	103	114	1.20	1.11	1.33	1.64	7.18	0.94	1.63	7.13	0.94	1.61	0.007	24.63	47	41
		6	107	115	1.24	1.08	1.34	1.65	7.19	0.94	1.63	7.13	0.94	1.61	0.007	24.62	72	66
		7	110	126	1.28	1.14	1.46	2.47	10.77	1.42	2.44	10.65	1.40	2.43	0.010	38.84	111	105
		8	112	125	1.31	1.11	1.46	2.47	10.78	1.42	2.44	10.65	1.40	2.44	0.010	38.86	150	148
		9	115	139	1.34	1.21	1.62	3.53	15.42	2.03	3.50	15.26	2.01	3.27	0.014	57.36	207	210
		10	118	140	1.38	1.19	1.64	3.52	15.38	2.02	3.50	15.27	2.01	3.27	0.014	57.29	264	280
	Stage 2	11	122	156	1.42	1.28	1.82	4.57	19.95	2.62	4.49	19.59	2.57	4.36	0.018	75.08	339	371
		12	125	161	1.45	1.29	1.88	4.56	19.93	2.62	4.49	19.62	2.58	4.36	0.018	75.09	414	470
		13	128	182	1.49	1.43	2.13	5.60	24.45	3.21	5.52	24.09	3.17	5.45	0.023	93.09	508	595
		14	130	193	1.52	1.48	2.24	5.59	24.43	3.21	5.52	24.12	3.17	5.46	0.023	93.10	601	729
	Stage 3	15	130	163	1.51	1.26	1.90	3.51	15.33	2.01	3.53	15.39	2.02	3.28	0.014	57.45	658	818

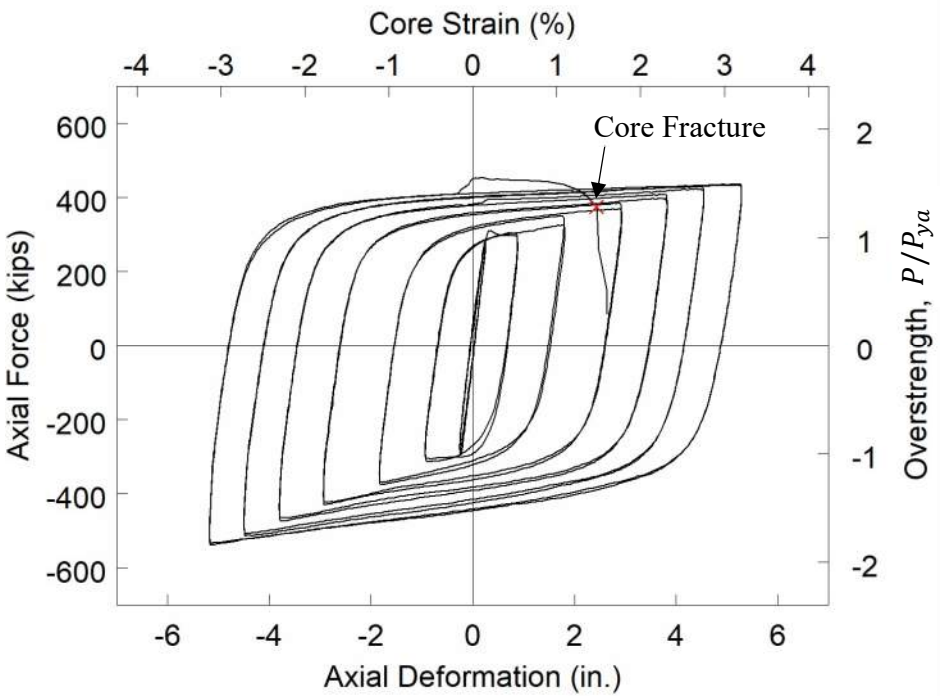


(a) Longitudinal Direction

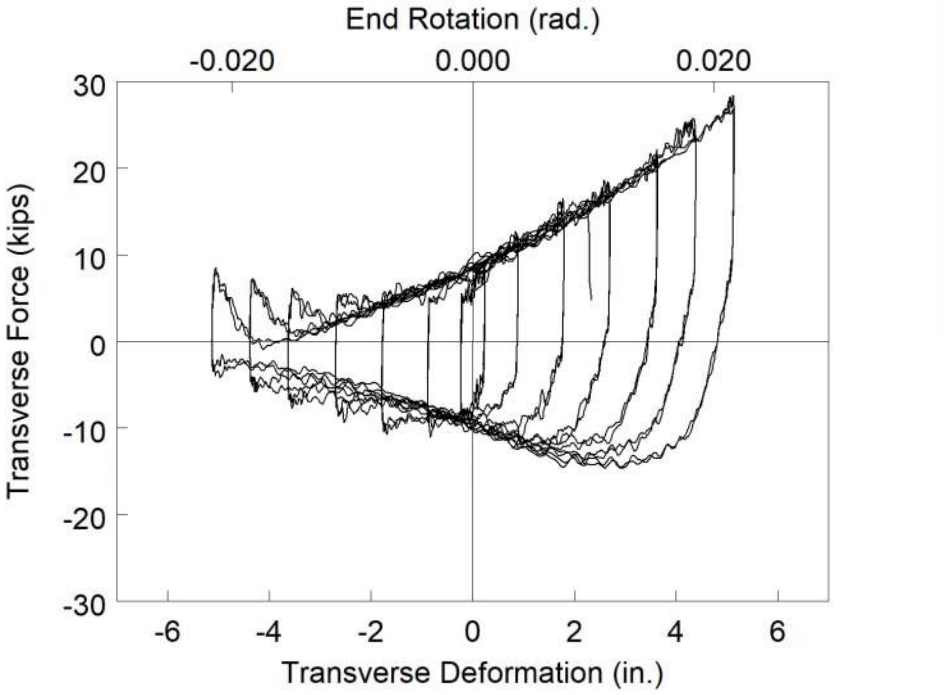


(b) Transverse Direction

Figure 3.1 Specimen 8P: Brace Deformation Time Histories



(a) Axial Force vs. Axial Deformation



(b) Transverse Force vs. Transverse Deformation

Figure 3.2 Specimen 8P: Hysteretic Response

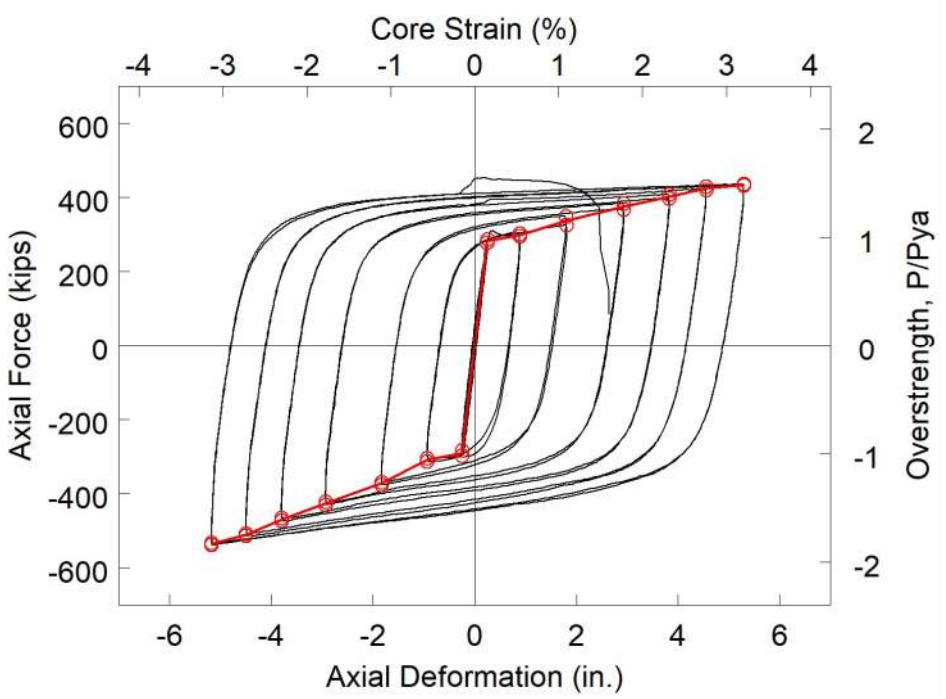


Figure 3.3 Specimen 8P: Hysteretic Response Envelope

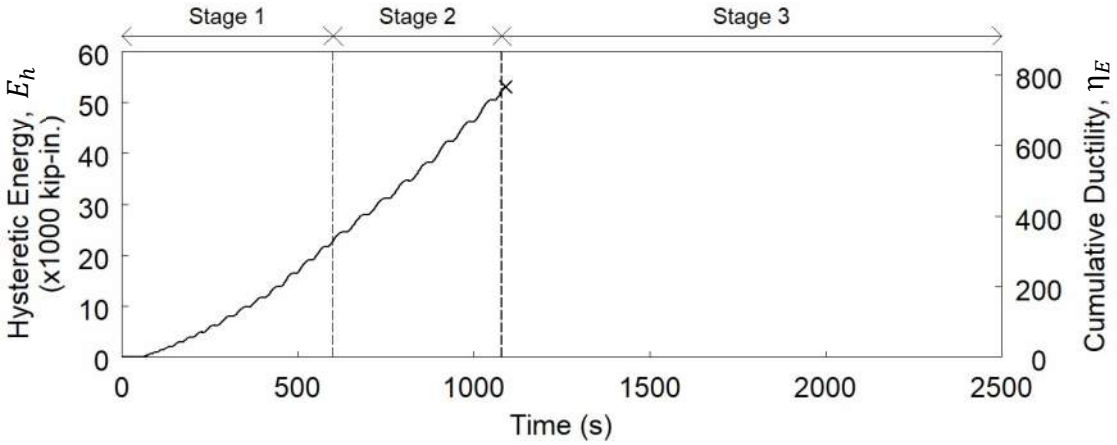
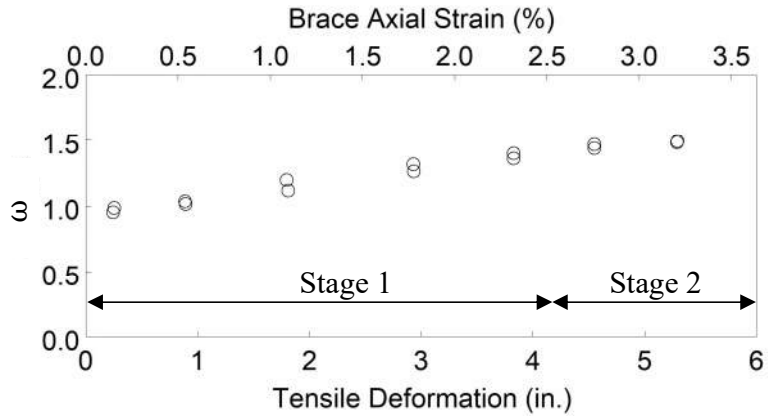
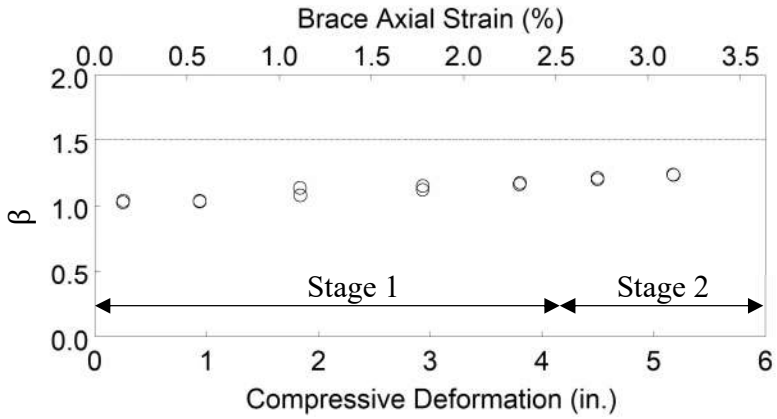


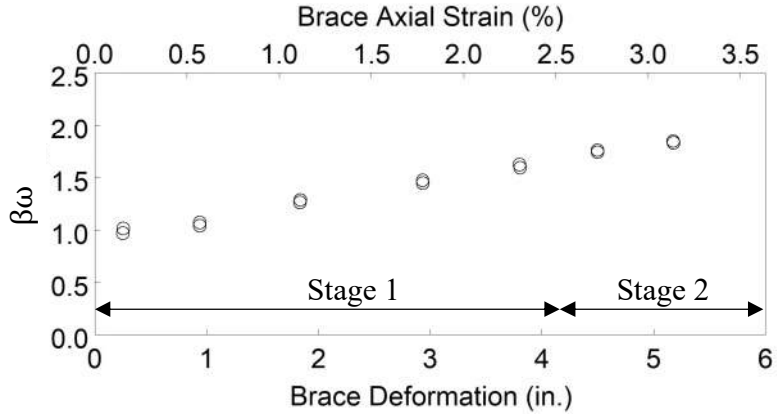
Figure 3.4 Specimen 8P: Cumulative Hysteretic Energy



(a) ω vs. Axial Deformation

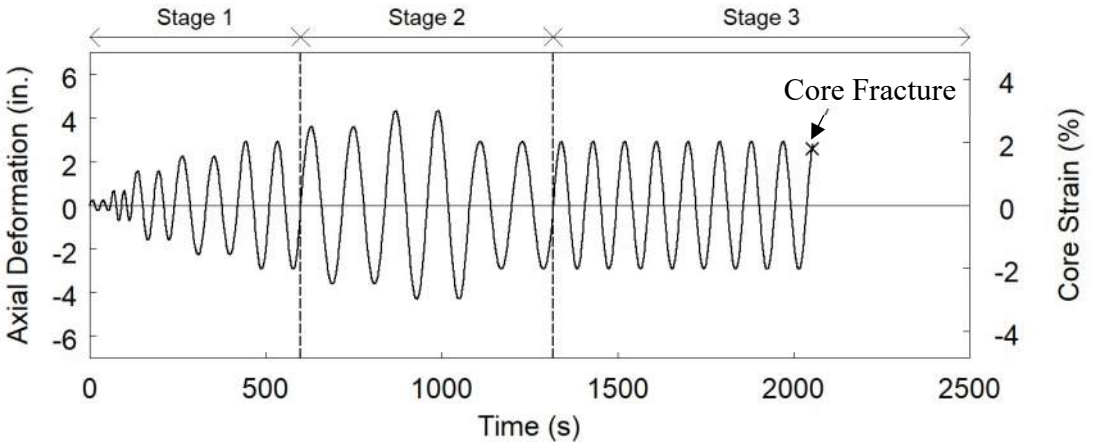


(b) β vs. Axial Deformation

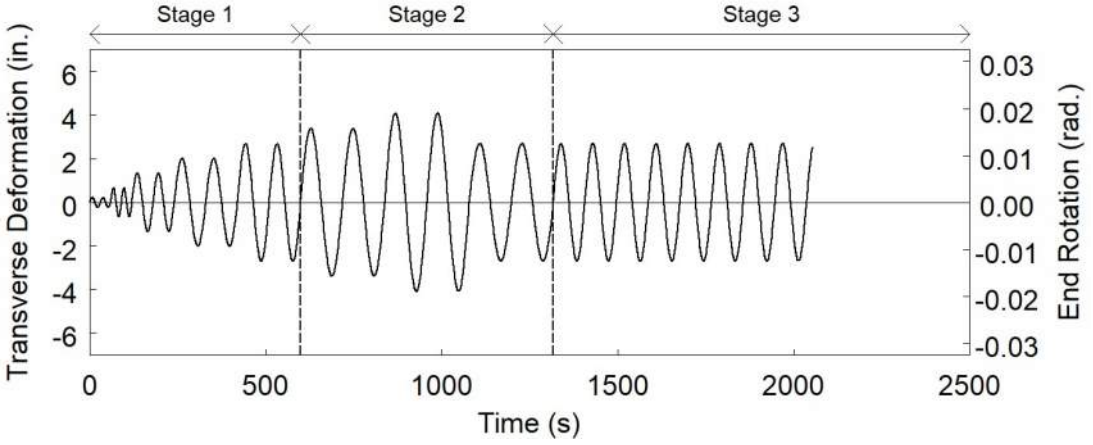


(c) βω vs. Axial Deformation

Figure 3.5 Specimen 8P: Strength Adjustment Factors

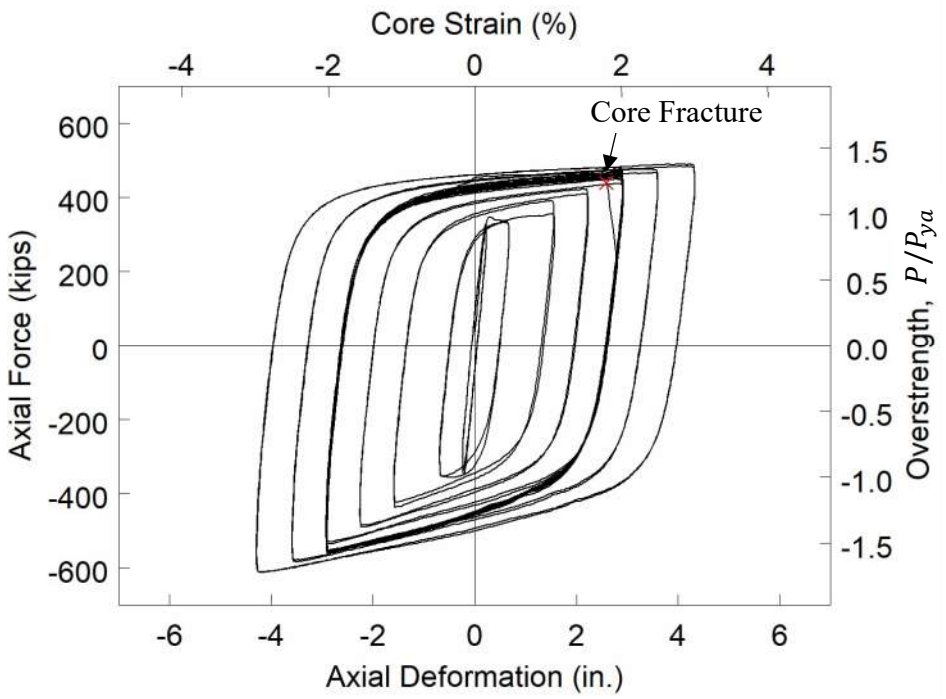


(a) Longitudinal Direction

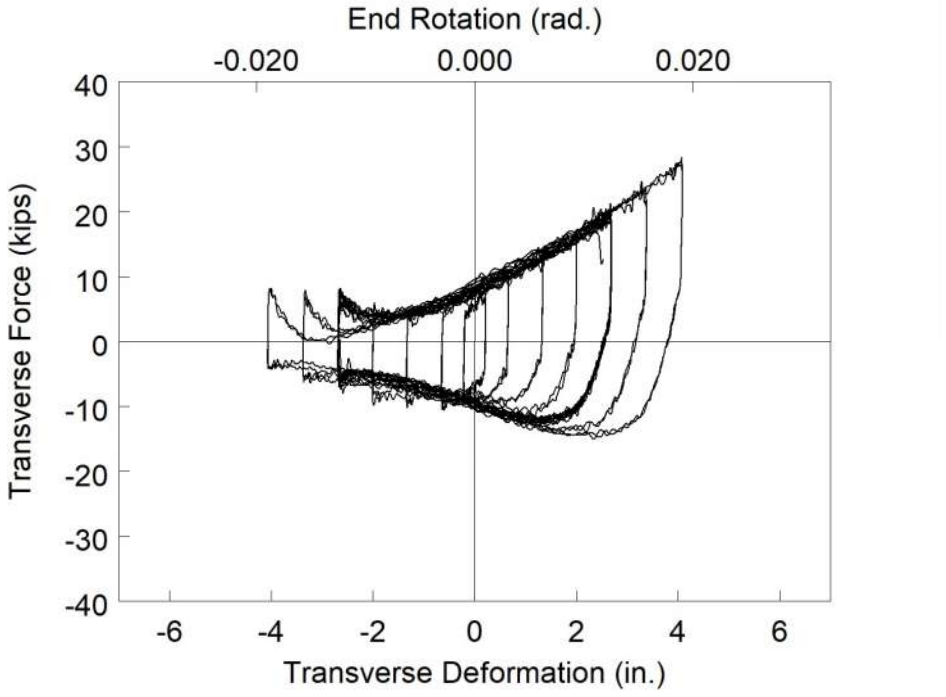


(b) Transverse Direction

Figure 3.6 Specimen 9P: Brace Deformation Time Histories



(a) Axial Force vs. Axial Deformation



(b) Transverse Force vs. Transverse Deformation

Figure 3.7 Specimen 9P: Hysteretic Response

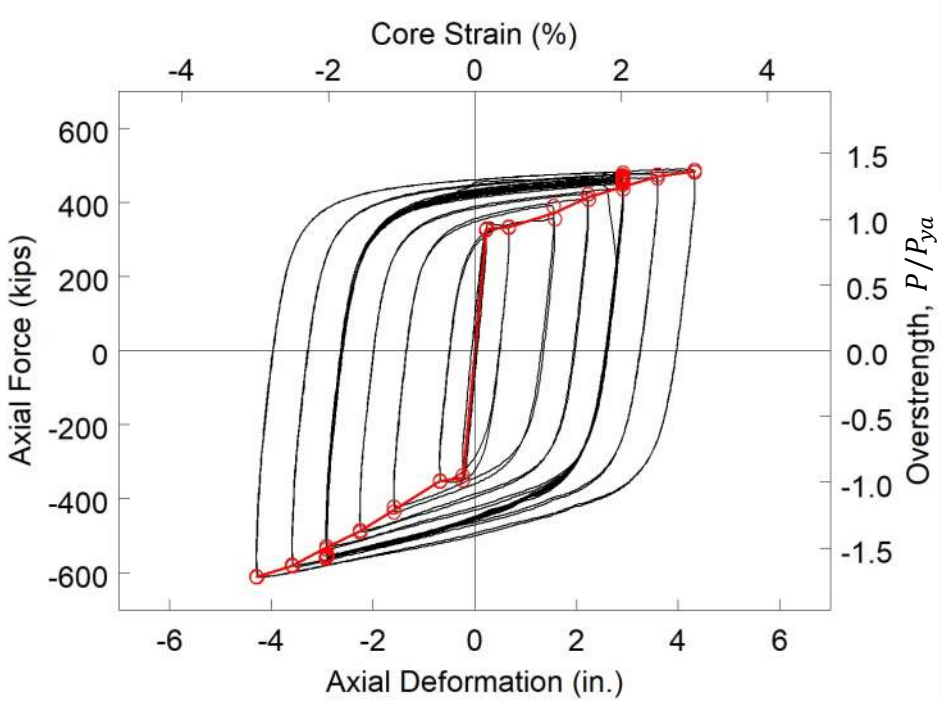


Figure 3.8 Specimen 9P: Hysteretic Response Envelope

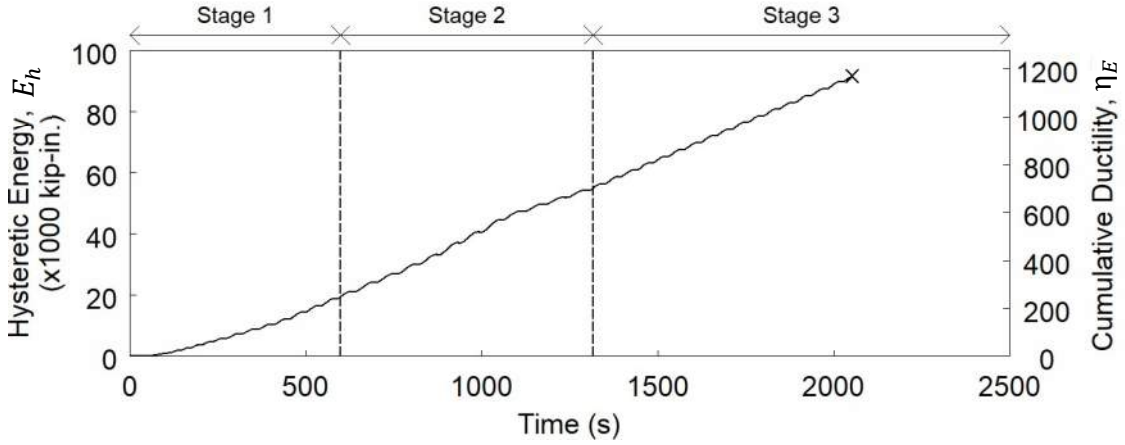
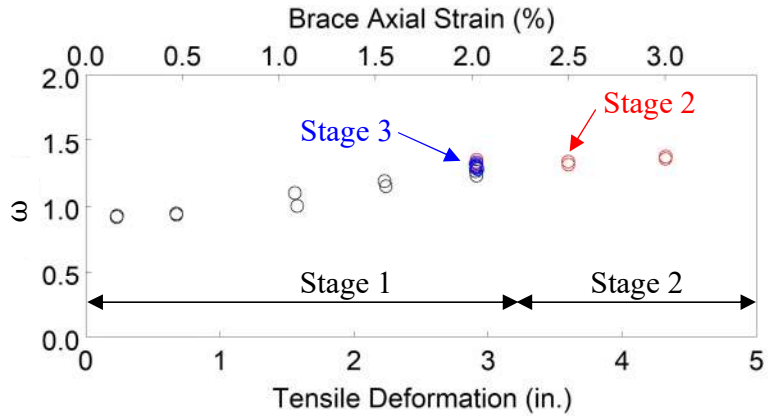
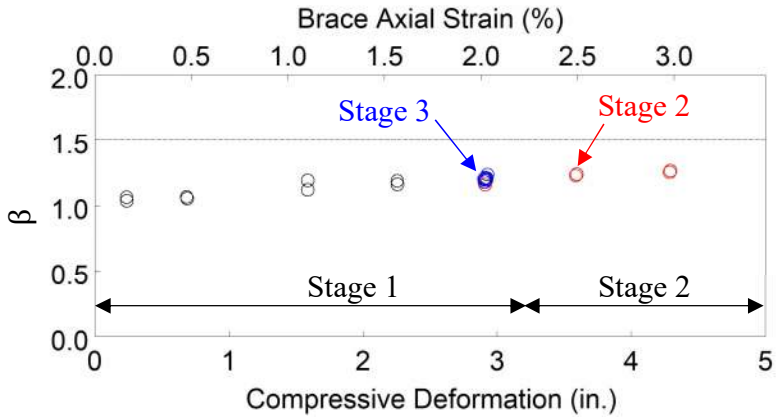


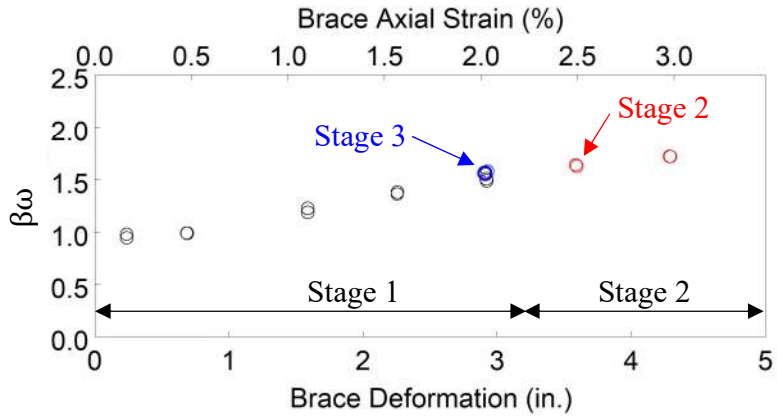
Figure 3.9 Specimen 9P: Cumulative Hysteretic Energy



(a) ω vs. Axial Deformation

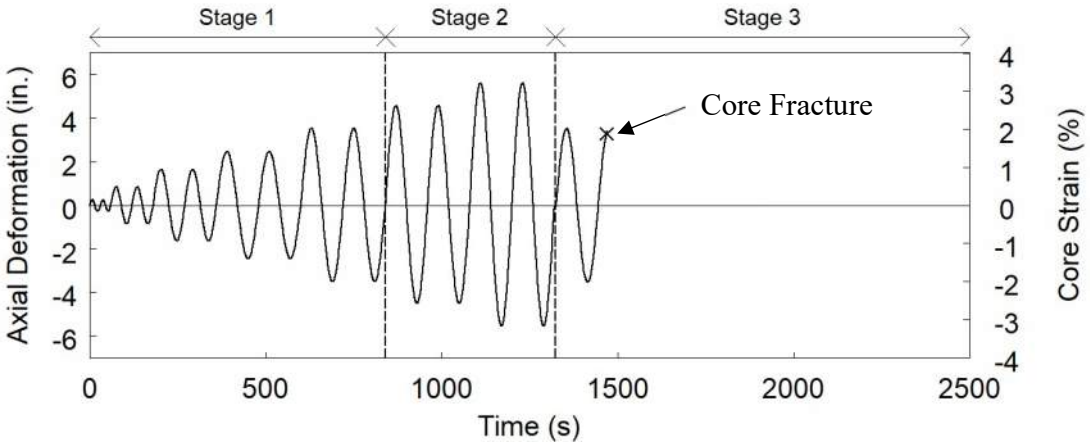


(b) β vs. Axial Deformation

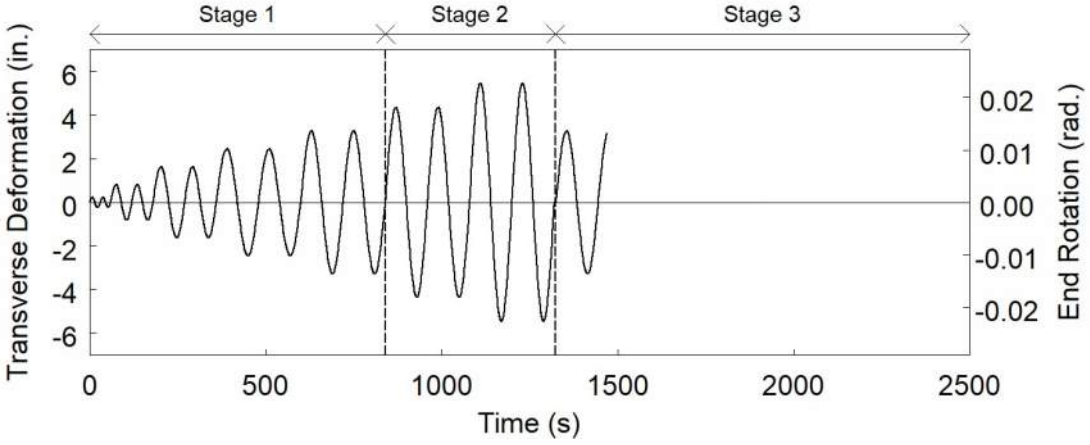


(c) βω vs. Axial Deformation

Figure 3.10 Specimen 9P: Strength Adjustment Factors

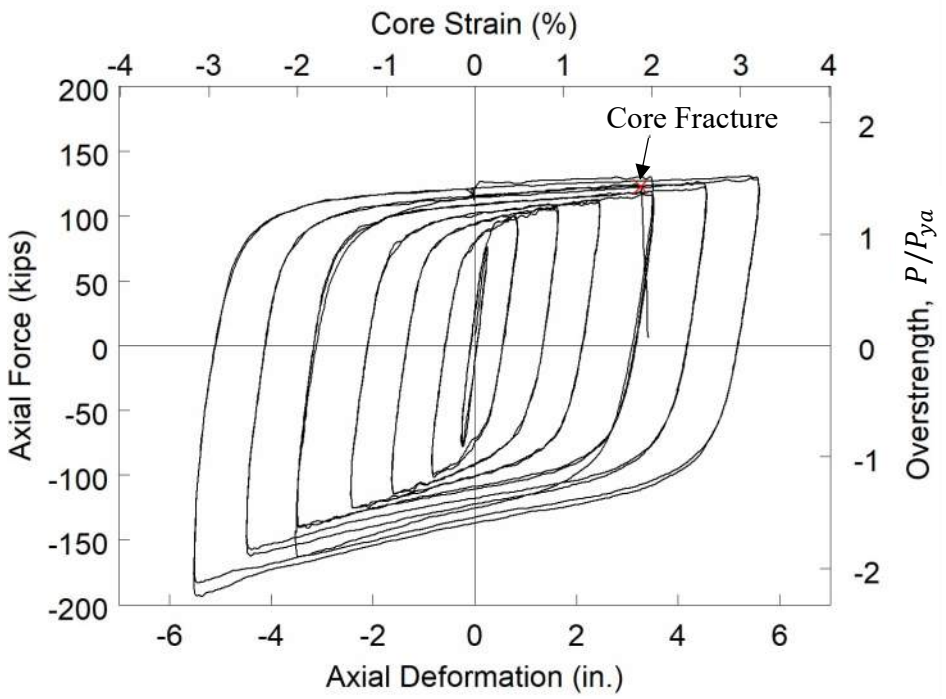


(c) Longitudinal Direction

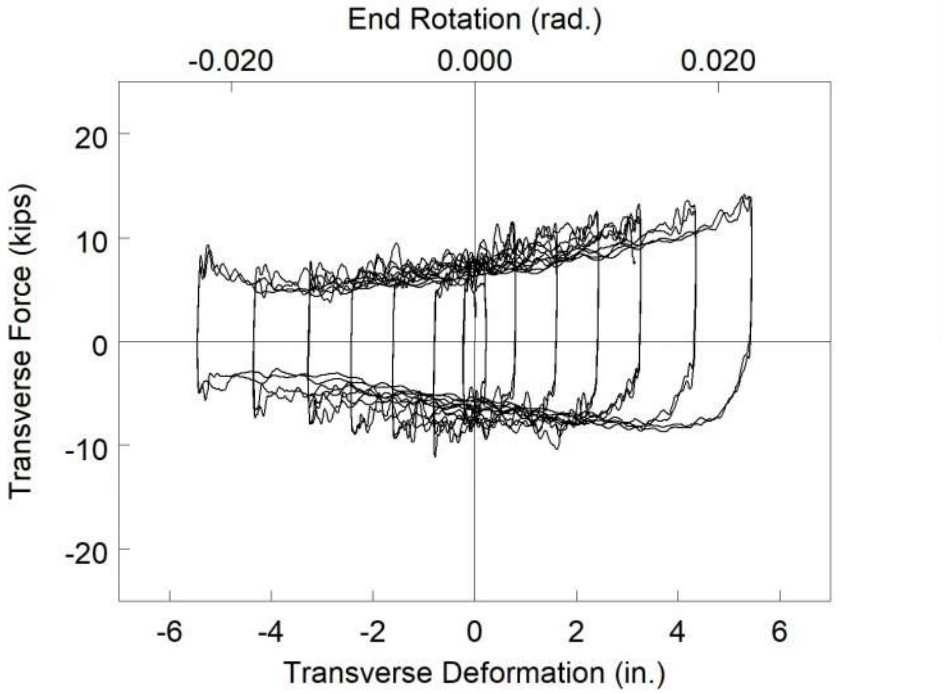


(d) Transverse Direction

Figure 3.11 Specimen 10P: Brace Deformation Time Histories



(c) Axial Force vs. Axial Deformation



(d) Transverse Force vs. Transverse Deformation

Figure 3.12 Specimen 10P: Hysteretic Response

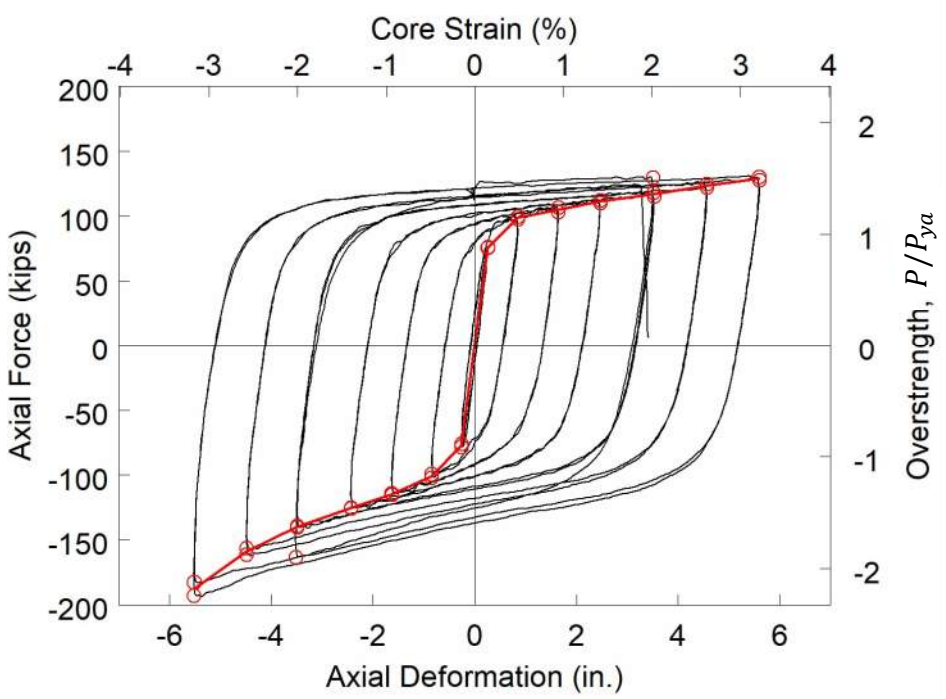


Figure 3.13 Specimen 10P: Hysteretic Response Envelope

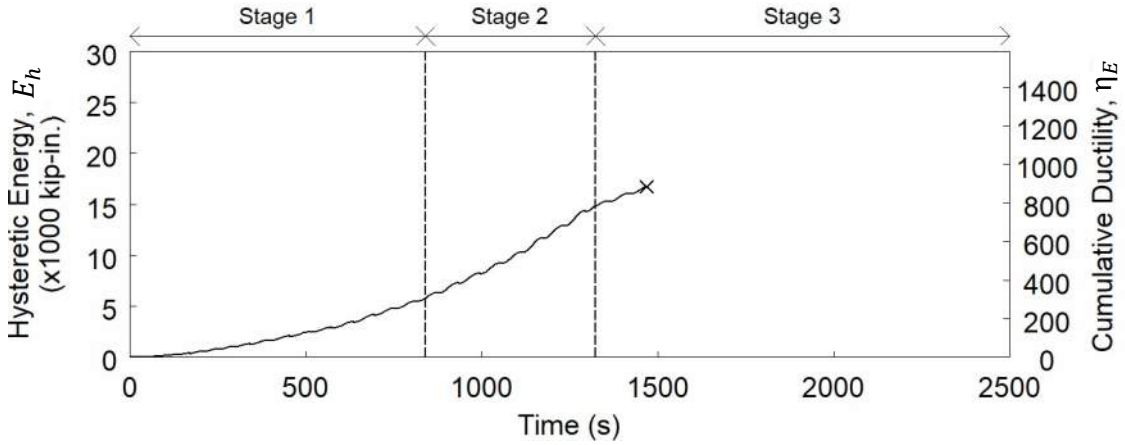
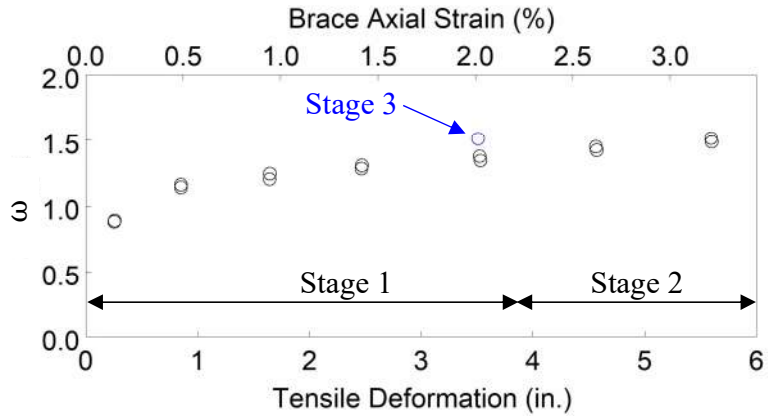
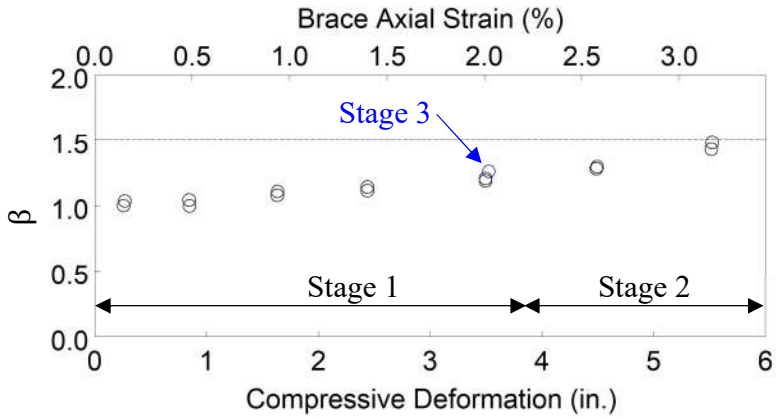


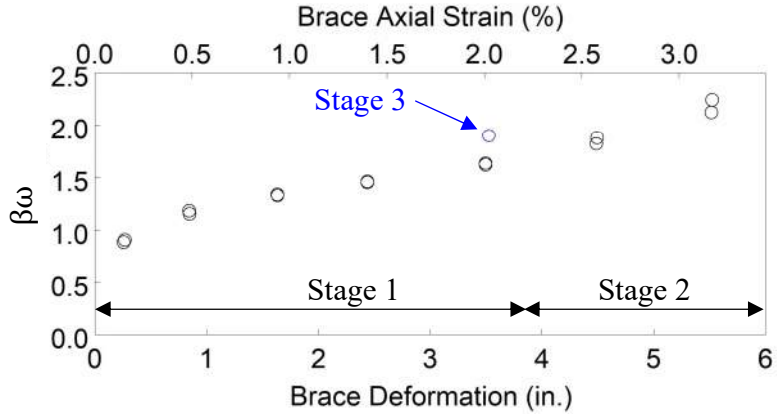
Figure 3.14 Specimen 10P: Cumulative Hysteretic Energy



(d) ω vs. Axial Deformation



(e) β vs. Axial Deformation



(f) βω vs. Axial Deformation

Figure 3.15 Specimen 10P: Strength Adjustment Factors

4 COMPARISON OF TEST RESULTS

4.1 Overall Performance

All three specimens were subjected to the pseudo-static loading protocol, they all performed well during the AISC loading protocol. Specimen 8P fractured in the beginning of the 1st cycle of Stage 3 loading, following the peak compressive force which occurred at $-21\Delta_{by}$. Specimen 9P complete Stages 1 and 2 loadings. After the brace reached the peak deformations of $\pm 20\Delta_{by}$ in Stage 2 loading, it fractured in the beginning of the 9th cycle of Stage 3 loading protocol as it was approaching the peak tensile force which occurred at $12\Delta_{by}$. Specimen 10P brace completed Stages 1 and 2 loadings. After the brace achieved the peak deformations of $\pm 23\Delta_{by}$ in Stage 2 loading, it fractured during the 2nd cycle of Stage 3 loading. The failure occurred just before the brace reached the peak tensile force which occurred at $14\Delta_{by}$. Table 4.1(a) provides key peak response quantities based on all loading protocols. All compression strength adjustment factors are below the AISC limiting value of 1.5.

4.2 Hysteretic Energy, E_h, and Cumulative Inelastic Deformation, η

The hysteretic energy and cumulative inelastic deformation achieved by each specimen are summarized in Figure 4.1 and Table 4.1(b). The cumulative inelastic axial deformations achieved by all specimens were significantly greater than $200\Delta_{by}$, an AISC acceptance criterion for BRBs. Table 4.1(b) shows the cumulative hysteretic energy achieved during each stage of loading protocol and the corresponding cumulative ductility at the end of testing altogether. All specimens exhibited larger cumulative inelastic deformation derived from the normalized cumulative dissipated energy, η_E, than that derived from the summation of the normalized inelastic axial deformation, η_D.

4.3 Acceptance Criteria

Section K3.8 of the 2016 AISC Seismic Provisions provides the following four acceptance criteria for buckling-restrained brace testing:

(1) *The plot showing the applied load versus displacement history shall exhibit stable, repeated behavior with positive incremental stiffness.*

Test results (see Figure 3.3 through Figure 3.13) show that all the specimens exhibit stable repeatable behavior with positive incremental stiffness.

(2) *There shall be no fracture, brace instability, or brace end connection failure.*

None of the specimens fractured during stage 1 of the loading protocols. All the specimens eventually failed during Stage 3 of the loading protocol, after the required cumulative inelastic ductility of 200 was achieved.

(3) *For brace tests, each cycle to a deformation greater than Δ_{by}, the maximum tension and compression forces shall not be less than the nominal strength of the core.*

Test results (see Figure 3.3 through Figure 3.13) show that no specimens experienced a degradation in resisting force.

(4) *For brace tests, each cycle to a deformation greater than Δ_{by}, the ratio of the maximum compression force to the maximum tension force shall not exceed 1.5.*

The maximum β values reported in Table 4.1 were less than 1.5 for all the specimens.

4.4 Cyclic Behavior of Low-Toughness BRB

Note that the core plate of Specimen 10P was intentionally selected to have a CVN toughness lower than the New Zealand code requirement (see Table 2.7). The ambient temperature in the SRMD laboratory during the testing for Specimen 10P was 63.7ºF. Test results showed that this low-toughness BRB still performed satisfactorily. The hysteretic responses of Specimen 8P [Figure 3.2(a)] and 9P [Figure 3.7(a)] show that the second cycle usually achieved a higher tensile force than the first cycle at each deformation level. By contrast, the increase in tensile force from the first to second cycles at each deformation level for Specimen 10P [see Figure 3.12(a)] was usually smaller than those in the other two specimens. Figure 4.2 shows the tensile peak force increment ratio versus core strain relationships for all specimens. Note that the tensile peak force increment ratio from the first to second cycles is defined as $\Delta T_{max}/T_{max1}$, where $\Delta T_{max} =$

$T_{max2} - T_{max1}$. Also, T_{max1} and T_{max2} are the forces at the tensile displacement peaks of the first and second cycles, respectively. It is observed that the tensile peak force increment ratio for Specimen 10P remained around 2% across all deformation levels. By contrast, the tensile peak force increment ratio varied with the core strain for Specimens 8P and 9P. For these two specimens, at a core strain of about 0.5%, the tensile peak force increment ratio did not exceed 2%. As the core strain reached about 1%, the increment ratio increased to 7% to 10%. After that, the increment ratio decreased with the core strain and approached 2% after the core strain reached 2.5%. It is apparent that, within a core strain range from 1% to 2.5%, the tensile peak force increment for Specimen 10P was noticeably smaller than those in the other two specimens. This suggests that the hysteretic responses of low-toughness Specimen 10P exhibited a smaller isotropic hardening than the other two specimens in that core strain range.

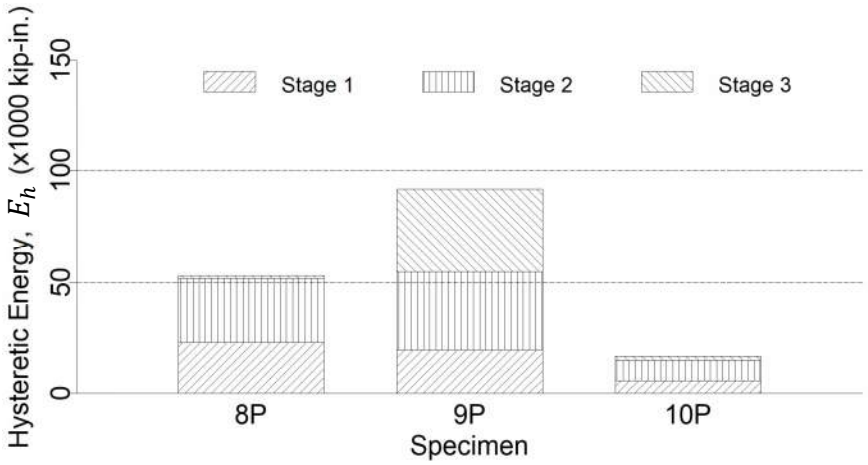
Table 4.1 Summary of Specimen Performances

(a) Maximum Response Quantities

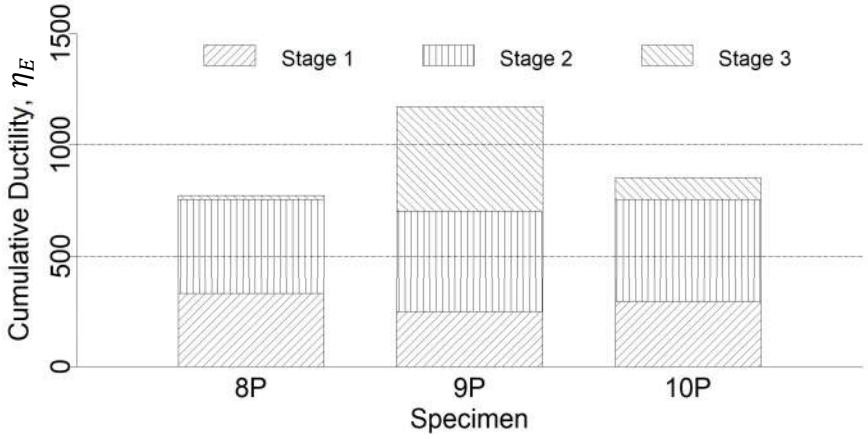
Specimen	ω	β	βω	Max. Core Strain (%)	Min. Core Strain (%)
8P	1.49	1.24	1.84	3.21	−3.14
9P	1.37	1.27	1.72	3.00	−2.98
10P	1.52	1.48	2.24	3.21	−3.17

(b) Hysteric Energy and Cumulative Inelastic Deformation

Specimen	E_h (×1000 kip-in.)				η_D	η_E
	Stage 1	Stage 2	Stage 3	Total		
8P	22.72	29.25	1.21	53.18	605	772
9P	19.40	35.47	36.84	91.71	999	1173
10P	5.77	9.07	1.90	16.73	658	851



(a) Hysteretic Energy



(b) Cumulative Ductility

Figure 4.1 Comparison of Hysteretic Energy and Cumulative Ductility

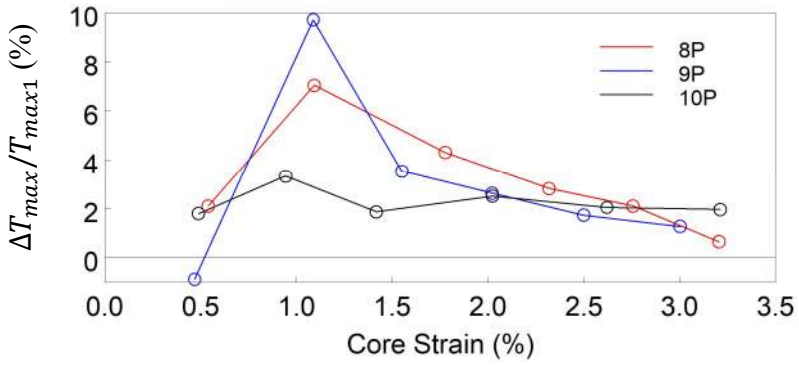


Figure 4.2 Tensile Peak Force Increment Ratio versus Core Strain Relationship

5 SUMMARY AND CONCLUSIONS

5.1 Summary

Three buckling-restrained braces (BRBs) of different design strengths were tested in the SRMD Test Facility at the University of California, San Diego. Specimens 8P and 9P were tested in July 2019, while Specimen 10P was tested in April 2020. All specimens consisted of A36 steel core plates encased in grout-filled A500 Gr. B square HSS casings. Bolted end connections were implemented on both ends of the brace in this P Series to connect each brace end to a bracket with a gusset plate. Specimens 8P, 9P, and 10P were connected to gusset plates with a thickness of 1-in., 1¼-in., and 1-in., respectively. The west end of the brace was fastened to the strong wall and the east end was fastened to the SRMD shake table platen.

The cyclic loading protocol used for this test program was composed of three stages. The first stage loading was the same as that specified in the AISC *Seismic Provisions*. The second stage loading was developed to impose a greater deformation demand to the brace to demonstrate that each specimen could achieve a cumulative inelastic axial deformation of at least $200\Delta_{by}$. The third stage loading had larger numbers of low-cycle inelastic deformation until core failure. Axial and transverse displacements were imposed to the specimens in the horizontal plane to simulate the in-plane frame action effect at the gusset connection.

All three specimens performed well during the AISC loading protocol (Stage 1), fracturing during Stage 3 testing. For all specimens, the maximum values of compression strength adjustment factor, β, were less than the AISC limiting value of 1.5. The computed cumulative inelastic deformation for all specimens were greater than $200\Delta_{by}$. Note that Specimen 9P dropped during construction before it was shipped back for testing, the brace performed well throughout the testing protocol and did not show any degradation in strength. In addition, steel core of Specimen 10P was intentionally made from a plate with a low CVN toughness. This was lower than the New Zealand code requirement but above the AISC requirement. Test results showed that this low-toughness BRB still exhibited a satisfactory cyclic performance.

5.2 Conclusions

Based on the test results, the following conclusions can be made.

(1) All three specimens performed well during the AISC loading protocol; no brace instability or brace end connection failures were observed. The braces fractured during Stage 3 loading protocol, whereby it incorporated greater deformation demands.

(2) The brace axial force versus deformation response showed stable and repeatable behavior with positive incremental stiffness.

(3) For all the cycles with an axial deformation greater than the yield deformation, Δ_{by}, the ratio of the maximum compression force to the maximum tension force, β, was under 1.5 for all stages of the loading protocol.

(4) For all the cycles with an axial deformation greater than the yield deformation, Δ_{by}, the maximum compression and tension forces were not less than 1.0 times the nominal brace yield force for all stages of the loading protocol.

(5) The cumulative inelastic deformation achieved by all the specimens were significantly greater than the minimum $200\Delta_{by}$ that is required by AISC *Seismic Provisions* for uniaxial brace test specimens.

(6) Specimen 9P had been dropped from a height of multiple stories during construction before it was shipped back for testing, the brace performed well throughout the testing protocol and did not show any degradation in strength.

(7) Specimen 10P was made from a core plate with a CVN toughness lower than the New Zealand code requirement. Tests results showed that this low-toughness BRB still exhibited satisfactory cyclic performance.

REFERENCES

AISC 341 (2016). "Seismic Provisions for Structural Steel Buildings." *AISC 341-16*, American Institute of Steel Construction, Chicago, IL.

Mansing, R., Reynolds, M., Uang, C.M. (2019). "Qualification Tests of CoreBrace Pinned, Welded, and Bolted Buckling-Restrained Braces." *Report No. TR-19/05*, University of California, San Diego, La Jolla, CA.

Standards New Zealand (2009). "Steel structures Standard Part 1: Materials, fabrication and construction." *NZS 3404.1:2009*, Standards New Zealand, Wellington, New Zealand.

APPENDIX SRMD Command Signal Input

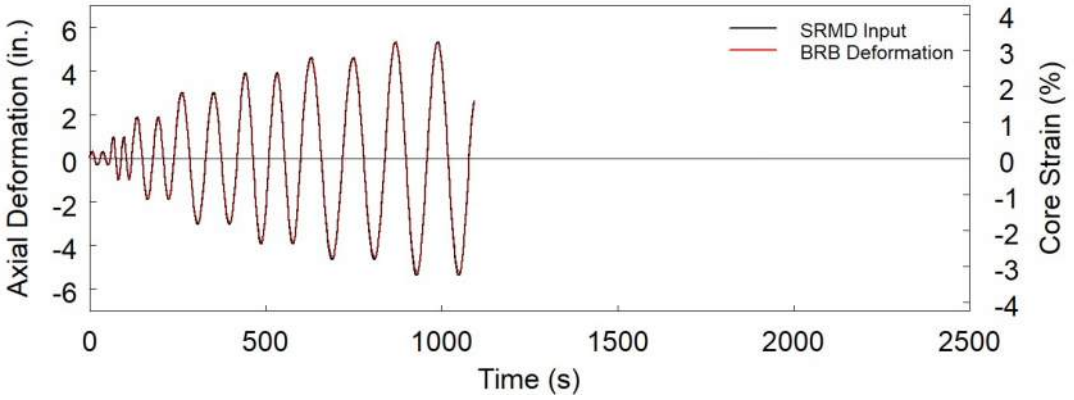


Figure A.1 Specimen 8P

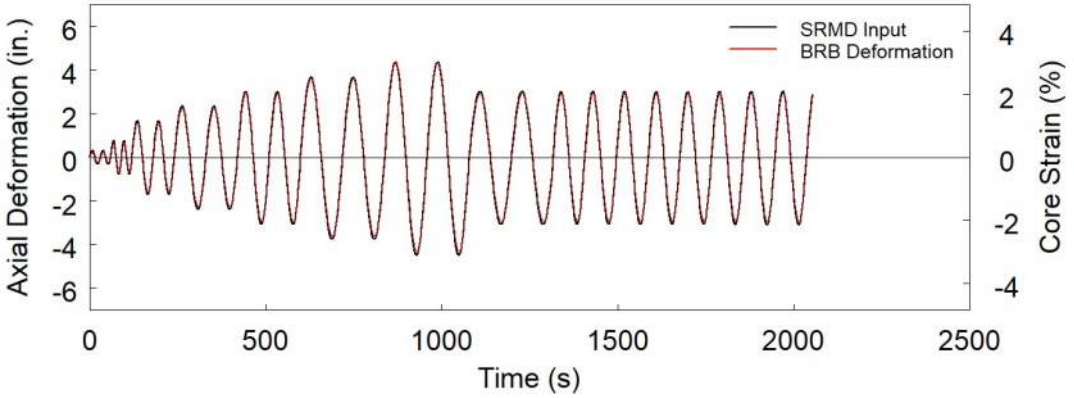


Figure A.2 Specimen 9P

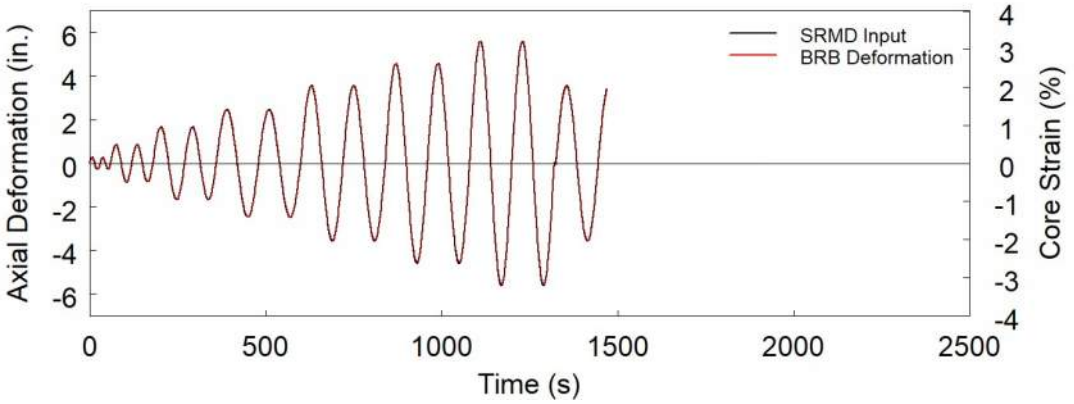


Figure A.3 Specimen 10P

AMERICAN INSTITUTE OF STEEL CONSTRUCTION CERTIFICATION PROGRAMS

PROUDLY RECOGNIZE THAT

Corebrace, LLC

MAINTAINS OPERATIONS LOCATED AT

669 West Quinn Rd. Building 28
Pocatello, ID 83201 USA

THAT SUCCESSFULLY MEET THE QUALITY CERTIFICATION REQUIREMENTS FOR

Building Fabricator
Complex Coating Endorsement 2 - Covered

PRESIDENT



CERTIFICATION NUMBER	ISSUED	VALID THROUGH
C-00024630	May 22, 2024	July 31, 2025

American Welding Society

Certifies that

Corebrace LLC

has complied with the requirements of the AWS B5.17 and QC17 Standards for the Qualification and Certification of AWS Welding Fabricators.

210702F
Certificate Number

July 1, 2024
Expiration Date

AMERICAN WELDING SOCIETY INCORPORATED 1932 NEW YORK

AWS President

Chair, Certification Programs

AWS CWF CERTIFIED WELDING FABRICATOR®

American Welding Society®

www.aws.org

August 28, 2023

Troy Carsey
C/o **Corebrace LLC**
669 West Quinn Road, Building 28
Pocatello, ID 93201

SUBJECT: **AISC-AWS CWF Certificate**

Dear Mr. Carsey:

Thank you for submitting your annual **AISC/AWS** renewal application. Your support of this program and AWS services is truly appreciated

Your facility's Fabricator certificate number is ***210702F***. Please note the expiration date is ***July 1, 2024*** one year from the date of issuance.

We appreciate your continued support of AWS and the AISC/AWS welding fabricator program.

If you have any comments or questions, please feel free to contact me directly at 786 937 9643or email me at Email: accreditation@aws.org.

Sincerely,

Grethel G Siezar Moreno
Program Administrator, Accreditation
Certification Department
American Welding Society
786-937-9643

FAST DRY 4190

DESCRIPTION

One-component, quick dry shop coat primer

PRINCIPAL CHARACTERISTICS

- Ideal for structural steel, tank exteriors, and equipment
- Fast drying properties
- Corrosion resistant in normal atmospheric conditions
- Interior or Exterior Usage
- Easy application

COLOR AND GLOSS LEVEL

- Gray, White, Red
- Flat

BASIC DATA AT 68°F (20°C)

Data for product	
Number of components	One
Volume solids	56 ± 2%
VOC (Supplied)	max. 2.8 lb/US gal (approx. 338 g/l)
Recommended dry film thickness	2.0 - 3.0 mils (50 - 75 µm) depending on system
Theoretical spreading rate	449 ft²/US gal for 2.0 mils (11.2 m²/l for 50 µm)
Shelf life	At least 36 months when stored cool and dry

Notes:
- See ADDITIONAL DATA – Overcoating intervals
- See ADDITIONAL DATA – Curing time

RECOMMENDED SUBSTRATE CONDITIONS AND TEMPERATURES

- Coating performance is, in general, proportional to the degree of surface preparation

Steel

- Remove all rust, dirt, moisture, grease or other contaminants from the surface
- Abrasive blast cleaning to SSPC SP-6 standards will give optimum performance
- Where abrasive blasting is not practical, power tool cleaning in accordance with SSPC SP-3 or hand tool cleaning to SSPC SP-2 requirements is acceptable

FAST DRY 4190

Previously painted surfaces

- Wash to remove contaminants
- Rinse thoroughly with water and allow to dry
- Sanidng is not required if the surface is properly and thoroughly cleaned (scuff sanding is required only on glossy, hard, slick, or dense surfaces which are subject to high levels of moisture)
- Remove loose paint
- Scrub heavily chalked exterior areas and overhead areas such as eaves with soap and water
- All existing mildew must be removed by washing with a solution of 16 oz (473 mil) liquid household bleach and 2 oz (59 ml) non-ammoniated liquid detergent per gallon (3.785 L) of water. Rinse surfaces clean with water and allow to dry for 24 hours
- Spot prime bare areas with this product

Substrate temperature and application conditions

- Surface temperature during application should be between 50°F (10°C) and 120°F (49°C)
- Surface temperature during application should be at least 5°F (3°C) above dew point
- Ambient temperature during application and curing should be between 45°F (7°C) and 100°F (38°C)
- Relative humidity during application should be above 0% and below 85%

Warning

Removal of old paint by sanding, scraping or other means may generate dust or fumes which contain lead. EXPOSURE TO LEAD DUST OR FUMES MAY CAUSE ADVERSE HEALTH EFFECTS, ESPECIALLY IN CHILDREN OR PREGNANT WOMEN. Controlling exposure to lead or other hazardous substances requires the use of proper protective equipment, such as a properly fitted and approved (e.g., NIOSHapproved) respirator and proper containment and cleanup. For additional information, contact the USEPA/Lead Information Hotline at 1-800-424-LEAD or the regional Health Canada office

SYSTEM SPECIFICATION

- Primers: Direct to metal
- Topcoats: conventional alkyd or latex coatings

INSTRUCTIONS FOR USE

- Inspect the top surface and remove any “skins” that may have formed on top
- Agitate with a power mixer for 1 – 2 minutes until completely dispersed. Ensure good off-bottom mixing

Application

- Area should be sheltered from airborne particulates and pollutants
- Ensure good ventilation during application and curing
- Provide shelter to prevent wind from affecting spray patterns

Material temperature

Material temperature during application should be between 50°F (10°C) and 90°F (32°C)

FAST DRY 4190

Air spray

- Separate air and fluid pressure regulators and a moisture and oil trap in the main air supply line are recommended.

Recommended thinner
No thinner should be added

Nozzle orifice
Approx. 0.070 in (1.8 mm)

Airless spray

- 30:1 pump or larger
- Adjust pump pressure as needed

Recommended thinner
No thinner should be added

Nozzle orifice
0.015 – 0.017 in (approx. 0.38 – 0.43 mm)

Brush/roller

- Use a high quality natural bristle brush and/or solvent resistant, 3/8" nap roller. Ensure brush/roller is well loaded to avoid air entrainment. Multiple coats may be necessary to achieve adequate film-build

Recommended thinner
No thinner should be added

Cleaning solvent
Paint thinner (lacquer thinner or mineral spirits)

FAST DRY 4190

ADDITIONAL DATA

Overcoating interval for DFT up to 2.0 mils (51 µm)		
Overcoating with...	**Interval**	**77°F (25°C)**
itself	Minimum	30 minutes
	Maximum	Extended
alkyds	Minimum	4 hours
	Maximum	Extended
Latexes	Minimum	16 hours
	Maximum	Extended

Notes:
- Overcoating times valid for a relative humidity of 50%
- Drying times may vary depending on temperature, humidity, and air movement

Curing time for DFT up to 2.0 mils (51 µm)		
Substrate temperature	**Dry to touch**	**Dry hard**
77°F (25°C)	20 minutes	1 hour

Note: Curing times valid for a relative humidity of 50%

Product Qualifications

- Meets MPI category #173, Shop Coat, Quick Dry, for Interior Steel
- Meets MPI category #275, Primer, Quick Dry, for Shop Application to Interior Steel

DISCLAIMER

SAFETY PRECAUTIONS

- For paint and recommended thinners see INFORMATION SHEETS 1430, 1431 and relevant Material Safety Data Sheets

Danger

Rags, steel wool or waste soaked with this product may spontaneously catch fire if improperly discarded. Immediately after use, place rags, steel wool or waste in a sealed water-filled metal container. Refer to www.pittsburghpaints.com, Spontaneous Combustion Advisory for additional information

WORLDWIDE AVAILABILITY

It is always the aim of PPG Protective and Marine Coatings to supply the same product on a worldwide basis. However, slight modification of the product is sometimes necessary to comply with local or national rules/circumstances. Under these circumstances an alternative product data sheet is used.

FAST DRY 4190

REFERENCES

• CONVERSION TABLES	INFORMATION SHEET	1410
• EXPLANATION TO PRODUCT DATA SHEETS	INFORMATION SHEET	1411
• SAFETY INDICATIONS	INFORMATION SHEET	1430
• SAFETY IN CONFINED SPACES AND HEALTH SAFETY, EXPLOSION HAZARD – TOXIC HAZARD	INFORMATION SHEET	1431

WARRANTY

PPG warrants (i) its title to the product, (ii) that the quality of the product conforms to PPG's specifications for such product in effect at the time of manufacture and (iii) that the product shall be delivered free of the rightful claim of any third person for infringement of any U.S. patent covering the product. THESE ARE THE ONLY WARRANTIES THAT PPG MAKES AND ALL OTHER EXPRESS OR IMPLIED WARRANTIES, UNDER STATUTE OR ARISING OTHERWISE IN LAW, FROM A COURSE OF DEALING OR USAGE OF TRADE, INCLUDING WITHOUT LIMITATION, ANY OTHER WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE OR USE, ARE DISCLAIMED BY PPG. Any claim under this warranty must be made by Buyer to PPG in writing within five (5) days of Buyer's discovery of the claimed defect, but in no event later than the expiration of the applicable shelf life of the product, or one year from the date of the delivery of the product to the Buyer, whichever is earlier. Buyer's failure to notify PPG of such non-conformance as required herein shall bar Buyer from recovery under this warranty.

LIMITATIONS OF LIABILITY

IN NO EVENT WILL PPG BE LIABLE UNDER ANY THEORY OF RECOVERY (WHETHER BASED ON NEGLIGENCE OF ANY KIND, STRICT LIABILITY OR TORT) FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES IN ANY WAY RELATED TO, ARISING FROM, OR RESULTING FROM ANY USE MADE OF THE PRODUCT. The information in this sheet is intended for guidance only and is based upon laboratory tests that PPG believes to be reliable. PPG may modify the information contained herein at any time as a result of practical experience and continuous product development. All recommendations or suggestions relating to the use of the PPG product, whether in technical documentation, or in response to a specific inquiry, or otherwise, are based on data, which to the best of PPG's knowledge, is reliable. The product and related information is designed for users having the requisite knowledge and industrial skills in the industry and it is the end-user's responsibility to determine the suitability of the product for its own particular use and it shall be deemed that Buyer has done so, as its sole discretion and risk. PPG has no control over either the quality or condition of the substrate, or the many factors affecting the use and application of the product. Therefore, PPG does not accept any liability arising from any loss, injury or damage resulting from such use or the contents of this information (unless there are written agreements stating otherwise). Variations in the application environment, changes in procedures of use, or extrapolation of data may cause unsatisfactory results. This sheet supersedes all previous versions and it is the Buyer's responsibility to ensure that this information is current prior to using the product. Current sheets for all PPG Protective & Marine Coatings Products are maintained at www.ppgpmc.com. The English text of this sheet shall prevail over any translation thereof.

AVAILABILITY

Packaging

1-gallon and 5-gallon kits

The PPG logo, and all other PPG marks are property of the PPG group of companies. All other third-party marks are property of their respective owners.

PPG Protective & Marine Coatings

PERFORMANCE TEST RESULTS
FAST DRY 4190

One Component, Quick Dry Shop Coat Primer

TEST	METHOD	TYPICAL RESULTS
Salt fog	ASTM B117, 168 hours (on carbon steel blasted per SSPC-SP10)	No panel face blistering
Humidity resistance	ASTM D4585; 1680 hours (on carbon steel blasted per SSPC-SP10)	No panel face rusting or blistering
Humidity resistance	ASTM D4585; 1680 hours (on CRS)	No panel face rusting or blistering
Prohesion	ASTM G85, 744 hours (on carbon steel blasted per SSPC-SP10)	No blistering on the panel face or creepage at the scribe
Prohesion	ASTM G85, 744 hours (on CRS)	No blistering on the panel face or creepage at the scribe
Pencil hardness	ASTM D3363	HB
Pendulum hardness	Koenig	30

5789 West Wells Park Road
West Jordan, UT 84088
(801)280-0701

Site Specific
Quality Assurance Procedures

For the

Buckling-Restrained Brace

Revision 7.4
16 November 2023

Proprietary & Confidential
DO NOT DUPLICATE

Controlled Copy _____ **Number _____**
Uncontrolled Copy _____

Table of Contents

Corporate Quality Policy Statement **1**

Project Specific Requirements **2**

Introduction **3**

Quality Assurance **6**

Plate Material Receiving **8**

Coupon Testing **11**

Welding Material Control **12**

Core Plate Fabrication **15**

Core Plate Assembly **17**

Bolt Hole Drilling (When Required) **19**

Welding and Nondestructive Examination **20**

Proprietary Interface Material (PIM) Assembly **24**

Buckling-Restrained Brace (BRB) Assembly **26**

Proprietary Fill Material (PFM) Placement **28**

Final Finish System **30**

Shipping and Final Inspection **32**

Site Quality Control **33**

Erection **33**

Attachments **34**

List of Flow Charts

Product Acceptance Plan……..……4

Plate Receiving……...7

Coupon Testing……10

Core Plate Fabrication……....14

Core Plate Assembly……....16

Bolt Hole Drilling……18

PIM Fabrication……..….22

PIM Assembly……..23

BRB Assembly…….…….25

PFM Placement……..……..27

Final Finish System…….….29

Shipping and Final Inspection……....31

List of Check Charts

QA Plan Hold Point Check Table..... 35
Lug Cut Check Chart..... 36
Core Cut Check Chart..... 36
Core & Lug Edge Check..... 36
Lug Bolt Hole Layout Check Chart..... 36
Core Assembly Check Chart..... 37
CB Assembly Check..... 38
Casing Check Chart..... 38

Corporate Quality Policy Statement

It is the intent of CoreBrace to produce steel products that are in compliance with all applicable codes, standards and job specifications. CoreBrace further certifies that they intend to manufacture Buckling Restrained Braces utilizing materials and processes that are essentially identical to test specimens in accordance with the CoreBrace Quality Assurance Procedures and Manuals. All fabrication will be produced using **Engineer approved drawings and specifications**. At no time will modifications to the approved designs, or substitution of materials be made without the explicit approval of the Design Engineer. **Only approved materials shall be used**. All materials requiring traceability will be monitored with the appropriate documentation being maintained on file for review to verify compliance with material specifications. All departments shall comply with this policy.

CoreBrace has an independent **Quality Assurance Department** to monitor the production of Buckling Restrained Braces for compliance with code and job specifications. The department is **Independent** of the Production Departments and has final authority on all matters relating to quality and acceptance of the final product. The **Quality Assurance Manager** reports to the **President.**

It is the further goal of CoreBrace to provide a product that meets all of the customers' specifications and delivers it on time. All company policies and procedures will be initiated from West Jordan, Utah, including material trace-ability records and Quality Control Documentation. This Manual shall be reviewed as a minimum annually for revisions.

Approved: 

Contact: Dieter Klohn
President
801.280.0701

Project Specific Requirements

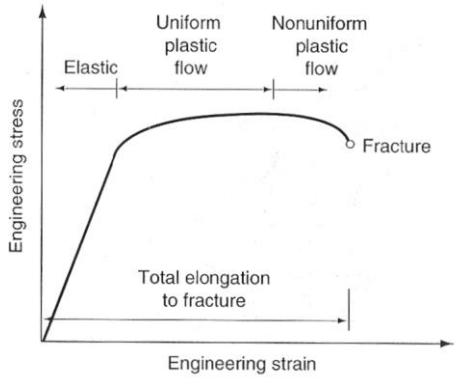
If any, see **Attachment A**

Introduction

Steel used in structural design affords unique properties to the engineer. It is both strong and flexible. It's excellent elastic properties permit columns and beams to deflect under load and return to their original position. This elastic region, however, is only a small piece of steel's capabilities. As loads exceed the yield point of the steel alloy, the material can stretch or compress plastically. Permanent deformations in steel structures after a traumatic event, are evidence of steel's ability to deform without failure. The steel has "failed" in terms of allowable stress design, but the structure has not. The unanticipated stress has been effectively and safely removed due to the normal plastic deformation of the steel. Steel's ability to deform without fracture can be used by the designer to effectively absorb atypical stresses placed upon a structure by seismic activities.

One only needs to look at a stress-strain diagram of common structural steel to see why steel can safely plastically deform without catastrophic failure. The elastic region of the curve is only a small portion of steel's response during tensile stress. The area of uniform plastic flow represents a comparably large area of safe deformation for steel that is not normally utilized by the Engineer. The toughness of the steel permits the material to absorb the strain energy imposed by the particular load without cracking or failure. Utilizing the region of uniform plastic flow increases the engineering potential of this economical material. The CoreBrace Buckling-Restrained Brace effectively harnesses this potential.

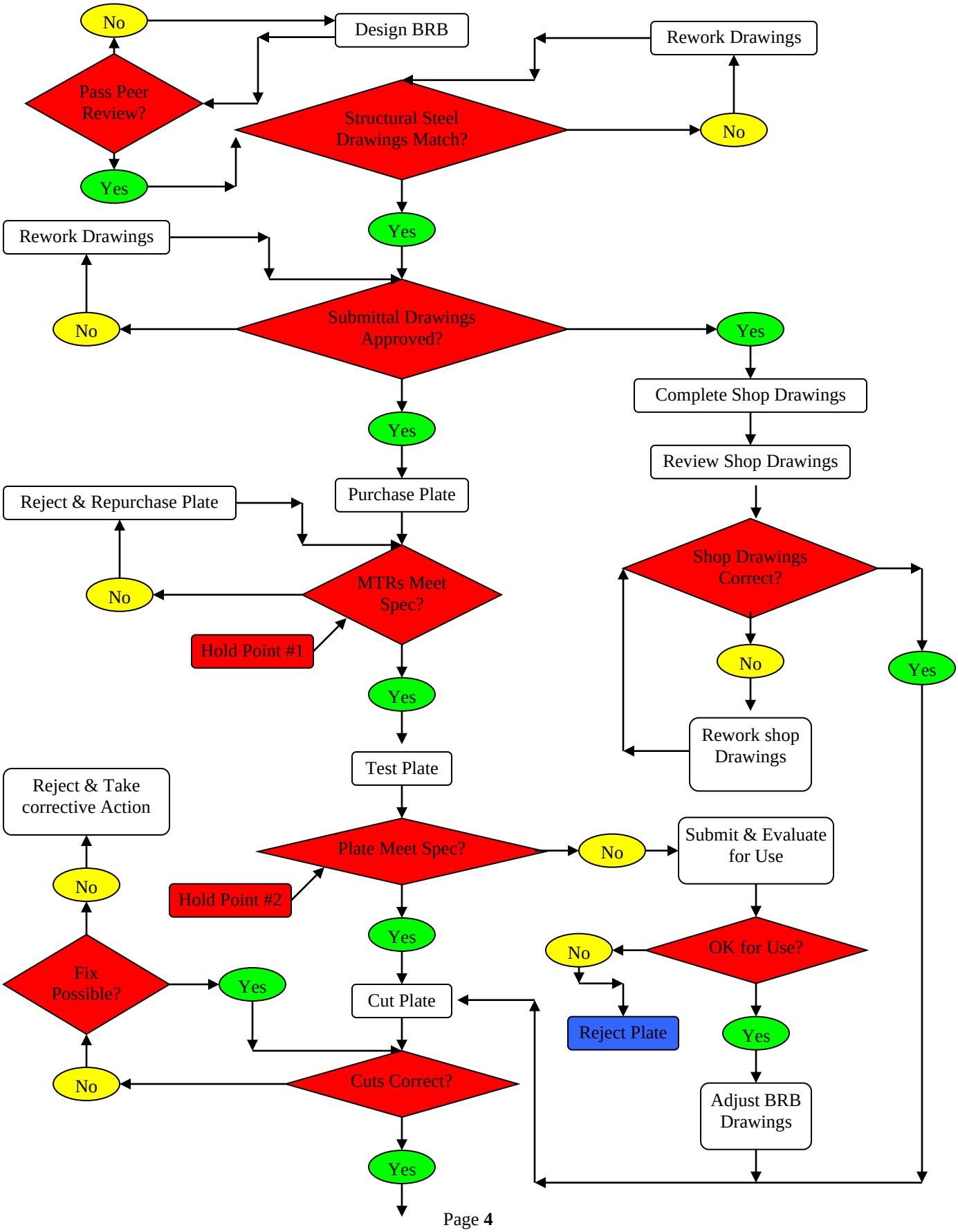
CoreBrace has developed the Buckling-Restrained Brace and characterized its properties through extensive testing of full-scale brace mock-ups. The repeatability of the tests and the quality of the actual product is assured through the company quality program.



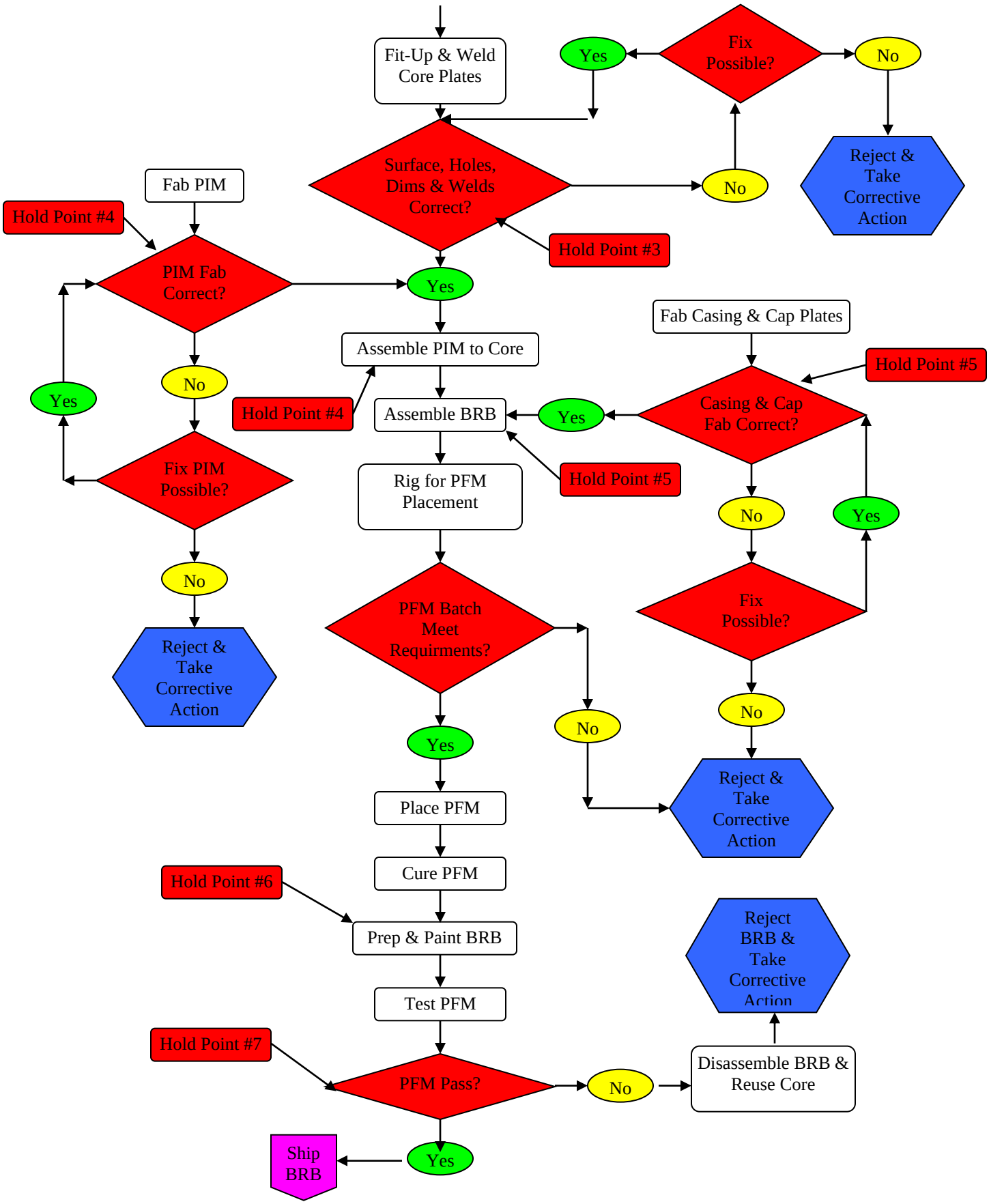
The designed plastic flow of the steel must be controlled and remain in plane to adequately support a given structure. The unique CoreBrace design surrounds the load carrying steel core in a Proprietary Fill Material (PFM) filled HSS casing. The strength and stiffness of the PFM and casing keeps the steel core from buckling out of plane while absorbing the stretching and compressing loads encountered during seismic activity. Special proprietary interface materials (PIM) isolate the steel from the PFM to permit the steel to slide within the casing elements without binding and thus optimizing uniform plastic flow.

The toughness is built into each heat of steel purchased. Properties are verified for each piece incorporated into the core of a Buckling-Restrained Brace. Welding is controlled following the requirements of the American Welding Society as modified by CoreBrace. PFM mix designs and placement are carefully controlled to assure uniform mechanical properties and repeatability. Every effort is taken to assure that each Buckling-Restrained Brace performs as designed.

PRODUCT ACCEPTANCE PLAN



PRODUCT ACCEPTANCE



Quality Assurance

The successful completion of the **Product Acceptance Plan** and Testing verify that the fabrication processes used to build the Buckling-Restrained Brace meet the designed performance specifications. By controlling certain critical fabrication operations, CoreBrace assures they will repeatedly provide a product that will perform as originally tested. Purchasing, material preparation, assembly and special processes are closely monitored, and the data recorded for examination. The data verifies company fabrication operations are within the tolerance limits needed to maintain product reliability.

The steel core component of the brace requires the most monitoring and in-process testing by CoreBrace. The materials are tailored into the Buckling-Restrained Brace by testing and heat number traceability. Certifications and qualifications are checked before any fabrication begins. Fabrication methods are modified to conform to the parameters established by testing in the **Product Acceptance Plan**. Only after complete acceptance of the steel core by CoreBrace inspectors, are these welded assemblies cast into their PFM sleeves.

The outer casing of the brace is made of three parts: an outer steel casing, a PFM matrix, and a proprietary interface material (PIM) between the PFM and assembled steel core. The steel core is carefully wrapped with the PIM. Precision assembly is required to provide the desired plastic deformation performance of the steel core. PFM is placed using the same techniques proven in the **Product Acceptance Plan**. Destructive tests are performed on samples taken from each batch of PFM used while casting the Buckling-Restrained Brace.

Verification of product quality is performed at various stages of CoreBrace fabrication. It is important to document acceptance of all fabrication activities critical to the performance of the Buckling-Restrained Brace before proceeding with subsequent operations that could make rework or repair more costly or difficult to perform. Inspection results are recorded on CoreBrace inspection report forms and stored in company archives as required by the Quality Assurance Procedures and Manuals. A documentation package is assembled for each individual Buckling-Restrained Brace to record the tests and inspections performed on each brace assembly. Braces and component pieces are tagged in accordance with the CoreBrace Steel Tagging Procedure. Red tags signify that a hold point has not yet been accepted or that other rework operations must be performed. If discontinuities or process discrepancies are found during inspection, the inspector documenting the situation for management review and corrective action writes nonconformance reports.

This manual designates procedures that are imposed on CoreBrace operations to assure quality. The supplemental Quality Assurance Manual specifies technical requirements for quality assurance. The Quality Assurance Procedures govern over the Quality Assurance Manual.

PLATE RECEIVING

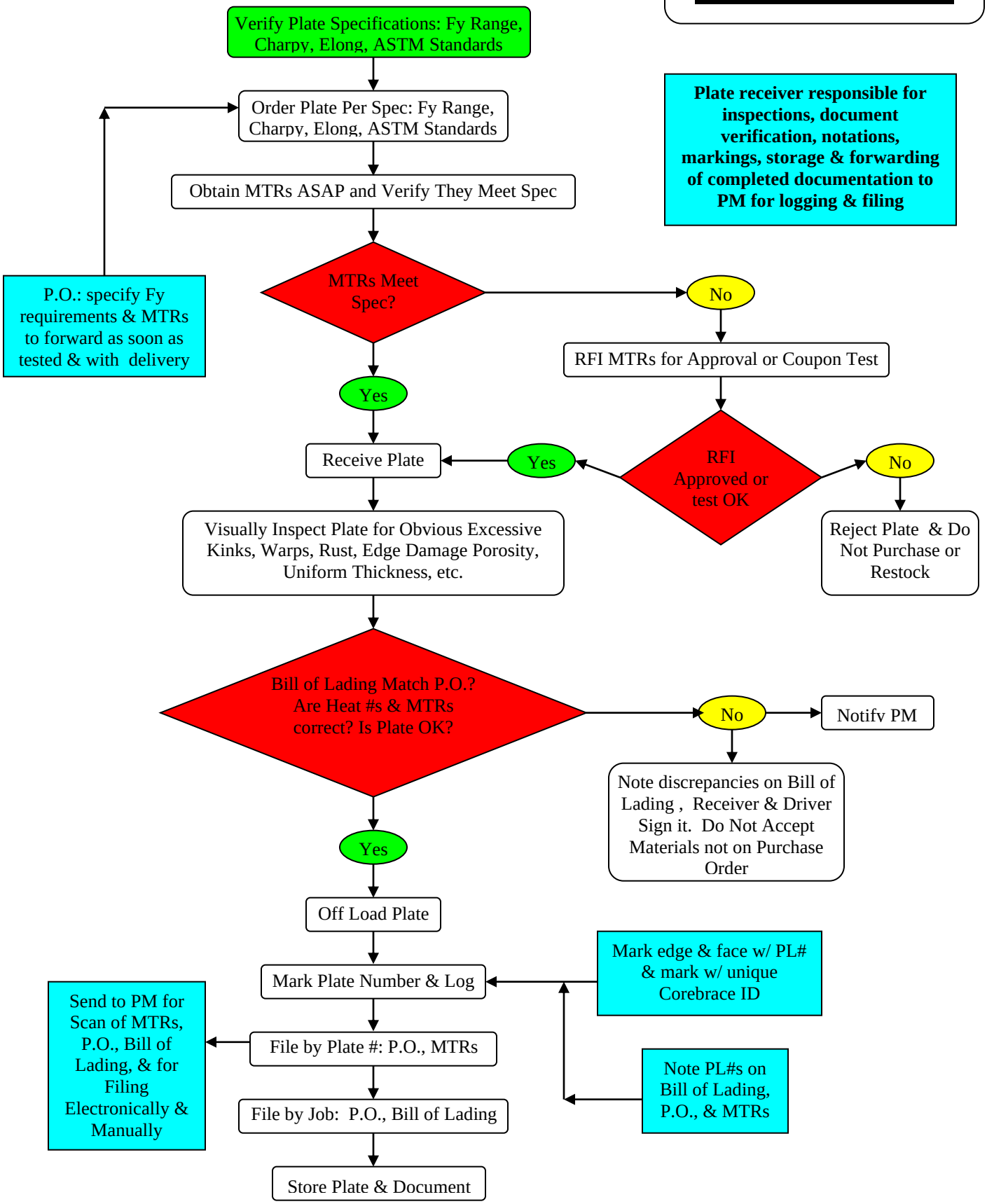


Plate Material Receiving

The steel plate used in the fabrication of the Buckling-Restrained Brace steel cores is purchased and controlled in accordance with The American Institute of Steel Construction Code of Standard Practice and the CoreBrace Quality Assurance Manual. The Code of Standard Practice requires that all structural material received by CoreBrace be traceable to its certifying documents. The CoreBrace Quality Assurance Manual further requires that the material used for the Buckling-Restrained Braces be readily traceable to its certifying documents during all phases of fabrication.

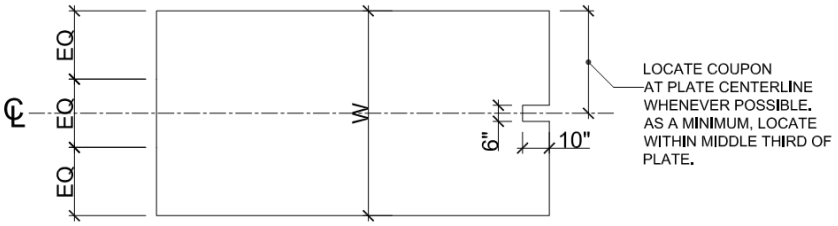
Once submittal drawings have been reviewed and the structural steel layout drawings match, the steel plate can be ordered. Material standards for the plate are verified for the order. The thickness and quantities of plate are verified for the order. Plate is ordered with issuance of Purchase Order (PO) agreement only. Purchase Order must specify the plate acceptable range for Fy as per specification and ASTM standards it must meet. The results of the Mill Test Reports (MTRs) shall be forwarded as soon as test results are recorded. Copies of the MTRs are also sent with the plate shipment. MTRs are verified that they meet material specifications for project and are data based, logged, scanned, and filed both electronically & manually in the Plate # folders by the Project Manager (PM). Then Project Manager shall submit MTRs for review. If MTRs do not meet material requirements, either perform coupon test, reject plate or write Request for Information (RFI) for acceptance of use and coreplate dimension adjustments. Additional coupon tests are performed as required on project specifications.

The received plate is inspected for obvious kinks, warps, excessive rust, damaged edges, contaminates, deformities, surface porosity, uniform thickness, etc. If any unacceptable traits are observed, they are reported to the QC inspector. Plate with noted problems is subject to rejection and may not be offloaded. Prior to offloading, the Bill of Lading is checked against original PO. Also, the Heat #s and MTRs are verified. Any discrepancies shall be noted on the bill of lading and signed both by the driver and receiver and the PM shall be notified of such ASAP. Non-conformity between Bill of Lading and PO may be cause for rejection of part or all of shipment and rejected material shall not be offloaded. Receiver shall notify Project Management (PM) of any such discrepancies. The plate is off-loaded from the delivery trucks and stored in protective areas. It is verified that Heat numbers have been printed on these plates by the producing mill. The heat number is a unique identification code established by the producing mill to positively distinguish the plates received at CoreBrace from other plates produced by the mill. The heat number on the material corresponds with an identical heat number recorded on the material test reports (MTR) provided by the mill for documentation. The MTR records the results of the testing performed by the mill as they verify their materials meet the requirements of the controlling ASTM material specification and the CoreBrace purchase order. Each received plate is marked with next sequential and unique plate number (PL#). CoreBrace marks all of the components as they are cut from these plates with the corresponding PL#. All cut parts may then be traced back to the specific MTR as they are processed through company fabrication operations.

Receiver is responsible for all duties associated with receiving plate as noted here-in, including all inspections, markings, document verification, noting any dispositions, documenting stored location, and forwarding all such documentation to PM for records & filing. PM is responsible

for resolution of all dispositions and recording and filing of information both electronically and manually.

COUPON TESTING



Cut Coupon

Mark coupon with PL#

Use paint marker

Ship to Lab

Receive Results From Lab

Results Meet Spec?

No

Retest or Write RFI for Approval

Retest or RFI Approved?

No

Yes

Yes

Plate Approved for Production

File Results by Plate# & Log

No

Reject Plate for Project

Restock or Transfer

File Results by Plate# & Log

Coupon Testing

The governing ASTM specifications permit the producing mill to determine compliance of all plates rolled in one heat based upon tensile tests run on a representative sample of the heat. The mill test reports (MTRs) will be used to determine plate material compliance with specified requirements. If MTRs are not in compliance, or if required by the project specifications, CoreBrace may elect to perform additional tensile tests on at least one plate of steel in a heat in conformance with ASTM A370 and ASTM E8. The actual tensile and yield strength values obtained from these additional tests will be used to determine compliance with the specified requirements.

Test coupons are cut from the end of the plates at typically the midpoint in from the edge of the plates. From this coupon, two samples are milled by the testing lab, to be tested in the longitudinal direction. Specimens are marked with the CoreBrace plate # and then shipped to the lab.

Test results are received from the lab and the average of the two tests is compared to the project specifications. If test results meet specification the plate is approved for production. If test results do not meet specification resampling and testing may be performed. If test results still do not meet specification, the plate may be rejected or an RFI may be written to adjust BRB design per test results. If design adjustment is deemed acceptable the plate will be released for production and the shop drawings will be revised accordingly. Otherwise plate shall be rejected for the project. Rejected plate shall be restocked for future projects with different specifications or transferred out of inventory. All actions will be logged in the data base plate log and filed to the plate corresponding plate # file.

Welding Material Control

Welding materials are similarly controlled. Filler metals are purchased to conform to the requirements of the latest edition of American Welding Society (AWS) and CoreBrace welding procedures. Shielded metal arc welding electrodes conform to AWS A5.1/5.1M, flux-cored arc welding electrodes conform to AWS A5.20/5.20M, and electrodes used for gas metal arc or submerged arc conform to the requirements of AWS A5.18/5.18M and A5.17/5.17M respectively. Each container is printed with the manufacturer's statement of conformance to the appropriate AWS specification. Welding filler metals are produced in a continuous process, not subject to distinguishing identification that characterizes discreet batch runs common to structural steel members. The manufacturer, to comply with AWS specifications, tests the filler metal forming process regularly. The minimum tensile strength of the E70 class electrodes used in production is 70,000 psi [470 MPa]. The welding materials are also selected for toughness. These materials provide production welds with minimum Charpy V Notch (CVN) properties of 20 ft-lbs [27 J] @ -20°F [-30 C]. All filler materials used in joining are certified as "low-hydrogen" by the manufacturer. They meet H16 requirements of the filler metal specifications and are tested by the manufacturer to verify diffusible hydrogen levels are below 16mL per 100 g of deposited weld metal.

Production welds using low-hydrogen welding materials and techniques provide superior mechanical properties in the finished weld. Moisture contamination of the welding filler materials and submerged arc welding flux must be prevented and is controlled throughout all phases of fabrication. Welding materials are off-loaded and stored in a protected area in the manufacturer's original packaging to prevent atmospheric contamination. Welding materials are used and stored in accordance with the manufacturer's requirements to maintain the low-hydrogen condition of the materials.

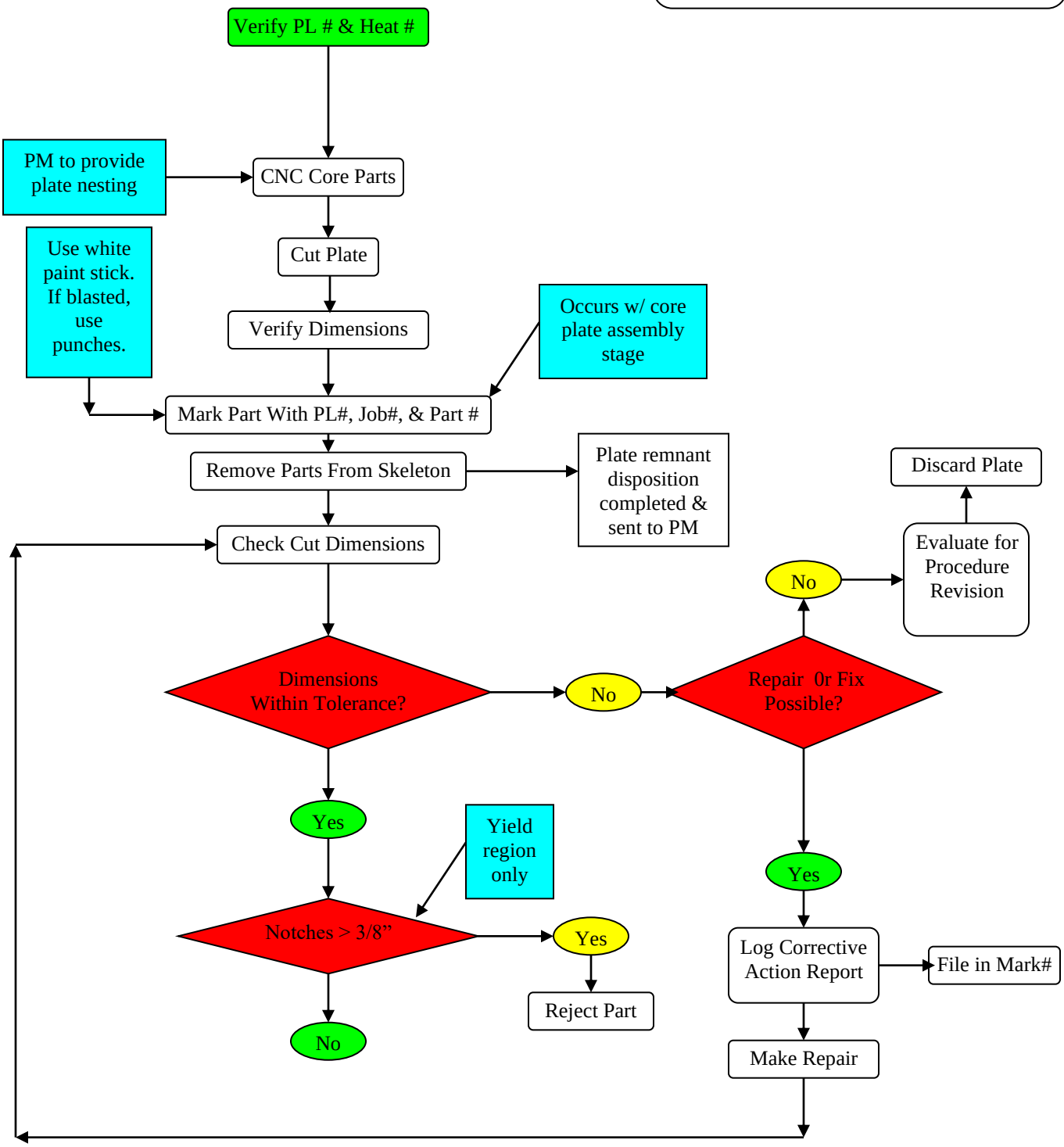
Welding electrodes used for shielded metal arc welding are stored in heated rod ovens after they have been removed from their original containers. They are held at a minimum holding temperature of 250°F [121 C] until they are released for use by the company leadman or quality control inspector. Typical shielded metal arc welding electrodes used to fabricate the steel brace are permitted to be exposed to atmospheric contamination for no more than 4 hours, though specially formulated "moisture resistant" electrodes are available that may be exposed for up to 9 hours without degrading the mechanical properties of the weld. Electrodes that have not been used within the allowable exposure time are reconditioned by baking a maximum of one time in a separate rebake oven held at a minimum of 500° F [260 C] for at least 2 hours or discarded. The bare ends of the electrodes are painted to identify them as reconditioned. The reconditioned electrodes are placed back into the holding ovens for production use. Electrodes may only be reconditioned in this manner once. They are scrapped after being exposed to the atmosphere a second time.

Spooled welding electrodes used for flux-cored, gas-metal, and submerged arc welding will be protected from atmospheric contamination during use. Condensation of moisture on the surface of the electrode must be minimized to maintain the low hydrogen properties of the filler metal. Spools of filler metal remaining on the wire feeding equipment will be covered when not in use to prevent moisture condensation on the wire overnight. Equivalent methods may also be

employed to prevent moisture condensation, such as spool covers furnished with some wire feeding equipment. All covers should permit some airflow within the cover to prevent moisture condensation under the preventative cover. Ideally, spooled welding electrodes should be consumed within the exposure limitations specified by the manufacturer after removal from the original container.

Fluxes used for submerged arc welding must be dry and free of contamination from dirt and other foreign material. The flux is stored in covered containers that properly identify the type and brand of stored flux. Flux may be stored in the manufacturer's original hermetically sealed container for up to six months without degradation. Open bags of flux may remain in the work area while submerged arc welding operations are being performed. If flux is used from an open bag, the top one-inch of flux shall be discarded before use.

CORE PLATE FABRICATION



Core Plate Fabrication

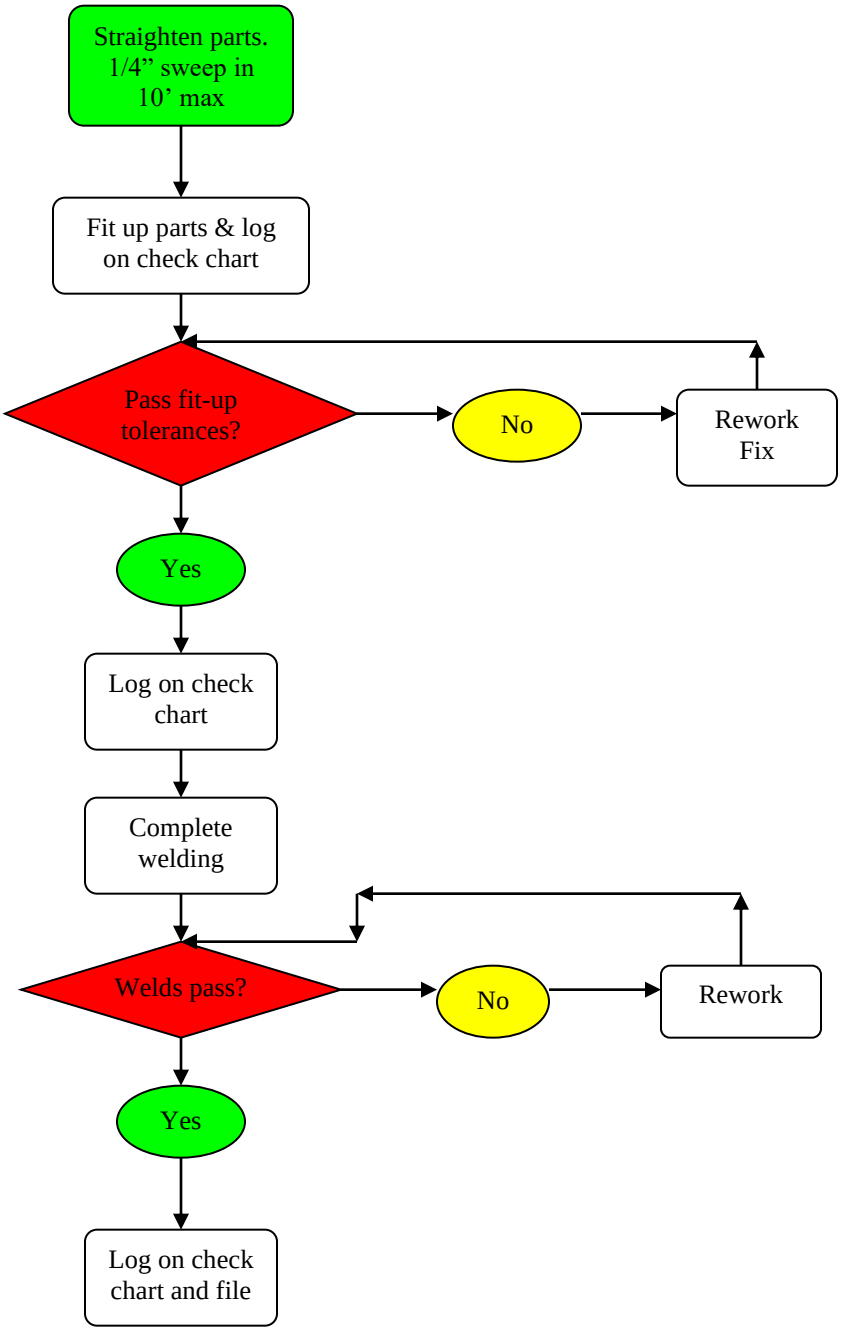
Steel brace components are laid out and "nested" on the plates before CNC cutting. The identifying material heat number is recorded onto each component piece in a location and manner that will not be obliterated or hidden by subsequent fabrication operations. CoreBrace operators verify the correct transfer of heat numbers to the components and release the plate for cutting.

The components are cut by oxy-fuel CNC cutting techniques. Plate # are verified. The oxy-fuel cutting process provides excellent dimensional accuracy with square cuts. The general roughness of the cut in the yielding length and elsewhere cannot exceed CoreBrace standard. The roughness is compared to base samples for acceptance. The cut edges are dressed by grinding to remove occasional notches and carburized metal. Notches are repaired by grinding or welding in accordance with CoreBrace repair procedures. The repairs in the yielding region are examined using Magnetic Particle Testing (MT) procedures in conformance with AWS D1.1/ASTM E709. Notches greater than 3/8” in the yield length may be cause for rejection of the piece.

The cut edges of the components are also visually inspected for laminar discontinuities. If there is any evidence of such discontinuities the piece will be examined via UT process. Discontinuities are evaluated and repaired in conformance with the requirements of AWS D1.1 section 5.14, Preparation of Base Metal.

Dimensional tolerances are checked at fit-up. Parts are marked with Plate # and Part # and okayed for dimensional check. If parts are not acceptable, repair, fix or other use is considered. If so, a corrective action is logged. Repairs, fixes or reallocations are made and the parts are rechecked. Tolerance checks are recorded in the inspection reports. Inspection reports require indication of inspection and initial of inspector prior to BRB parts proceeding to next operation

CORE PLATE ASSEMBLY



Core Plate Assembly

Fabrication of the Buckling-Restrained Brace begins after CoreBrace has accepted material preparation. After acceptance, material is released for further processing. CoreBrace QC inspector checks the piece mark numbers and plate numbers against the assembly list to verify the particular brace is assembled with the correct material.

The component pieces are assembled according to the shop detail drawings. Gaps between pieces are as required by AWS D1.1. Alignment, squareness and sweep checks shall be as per CoreBrace's proprietary standard.

The only welds permitted on the Buckling-Restrained Brace are shown on the shop detail drawings. No unauthorized welds are allowed. Temporary attachments to facilitate fit-up and welding are permitted outside of the yielding segment. All tacks used to assemble the braces must be incorporated in the final weld. All temporary attachment welds must be completely removed by grinding and the area visually checked by the fitter for excessive reduction in component thickness or cracking in the material. All final welds and reworked temporary attachment areas will be inspected in accordance with AWS D1.1 as modified by CoreBrace .

After assembly, the welder checks the tack welds before final welding to ensure the tack welds are clean and free of slag or foreign material that could prevent quality welding. The tack welds are also checked for cracks or other welding discontinuities at this time. Tack welds are performed to the same acceptance criteria as the final weld. Welding of the steel brace begins after the welder has determined the tack welds are acceptable.

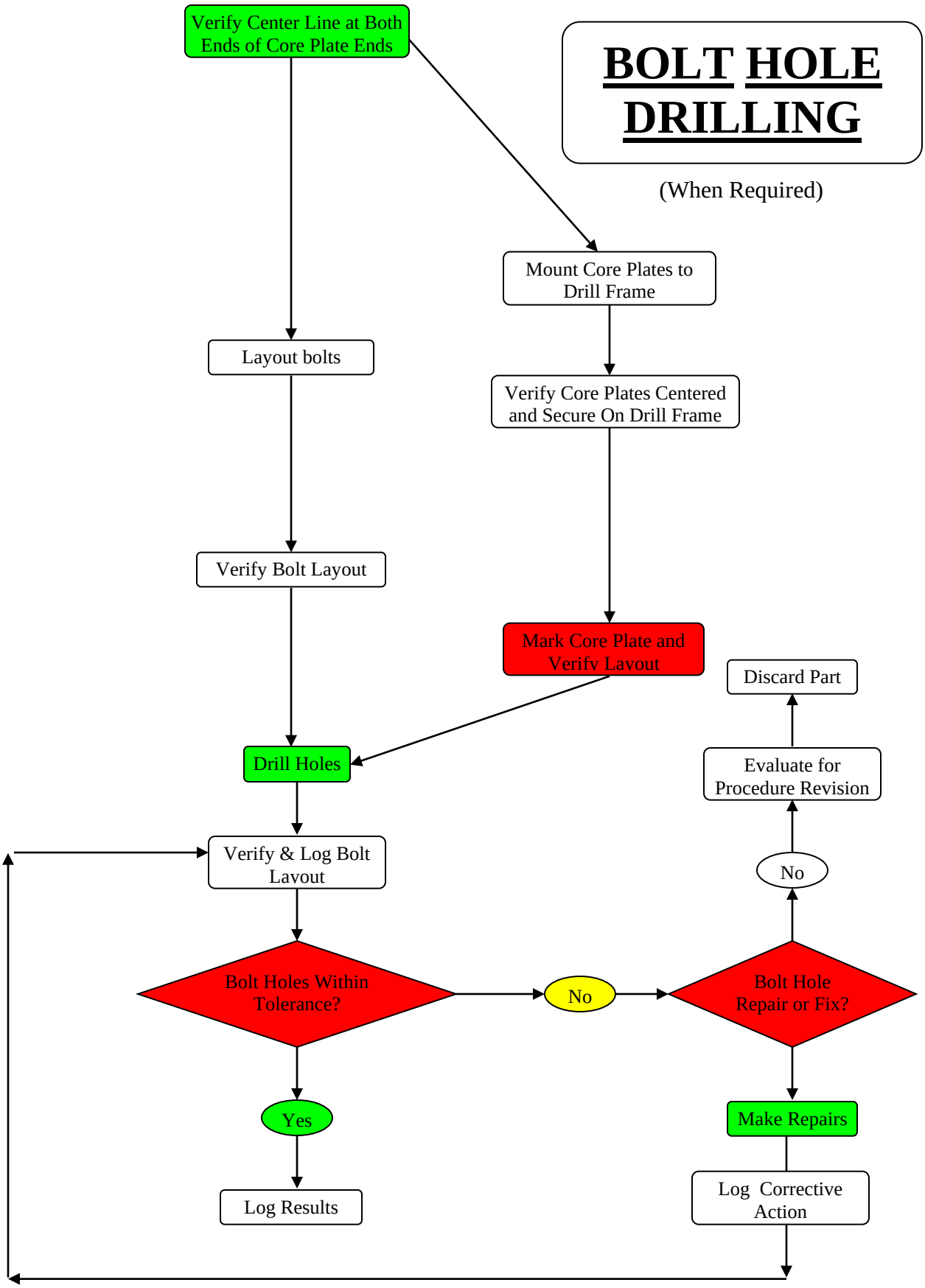
Final welding is performed in accordance with CoreBrace welding requirements. The necessary preheat and interpass temperatures, wire feed speed (wfs), voltage values, and other welding requirements are detailed on the applicable welding procedure specification (WPS). Monitoring and random verification by CoreBrace QC will be performed.

CoreBrace inspectors visually examine all welds after final welding has been completed, prior to assembly in the supporting PFM sleeve. The acceptance criteria for production welds are detailed in Table 6.1 of AWS D1.1 as modified by CoreBrace. Welds are measured to verify the correct weld size has been achieved. They are checked for welding discontinuities such as porosity, undercut, overlap, slag inclusions, and cracks. These discontinuities are repaired by the welder as permitted by AWS D1.1 as modified by CoreBrace.

Upon acceptance of the structural welding of the Buckling-Restrained Brace, fit-up is rechecked. If acceptable, the piece is tagged tag and released for PIM material assembly.

BOLT HOLE DRILLING

(When Required)



Bolt Hole Drilling (When Required)

Bolt hole drilling is performed on a high-speed Drill Line utilizing special drilling frame rig or other drilling tools. Centerlines of core parts are verified at each end of the core part or lug assembly. Then the parts are mounted into the drill frame rig and secured. Verification of alignment and clamping of assembly is made. If lug assembly is drilled separate from core plate, centerline verification is made when lug assembly is attached to core.

Parts are input into the program. And core parts are loaded to drill line. Hole locations are verified then holes are drilled. Alternatively holes are manually laid out and verified and drilled with other tools.

Bolthole tolerances are checked and recorded. If parts are acceptable, initial of inspector shall be recorded on the check chart. If parts are not acceptable fixes, such as plug weld and redrill or connector adjustments, will be assessed. If repairable, log corrective action and make repairs.

Welding and Nondestructive Examination

Welding and nondestructive examination are considered special processes by various quality disciplines. Properly trained technicians, qualified to perform their special process by testing, work in conformance with CoreBrace procedures to repeatedly provide welds and testing that meet the requirements of the governing code.

Company welders are required to pass initial qualification tests to weld the components together. The welders test (QW) assures the welder has the ability to produce welds that meet the visual and testing requirements of AWS D1.1 within the process, position, and thickness limitations. They are requalified as required by the welding code every six months by either verifying the welder's use of the process within the six-month period or by qualification testing.

Company nondestructive testing technicians are initially qualified in accordance with ASNT. The tests include evaluation of general nondestructive testing concepts, concepts specific to the testing process and a practical examination to evaluate the ability to use the testing method correctly on a test piece with known discontinuities. Technicians are recertified every three years as recommended by SNT-TC.1A on the basis of continuing satisfactory performance or retesting. They have their eyesight tested every year. Technicians must be capable of reading Jaeger #2 test charts at a distance not less than 12 inches and be capable of differentiating and distinguishing contrast among colors.

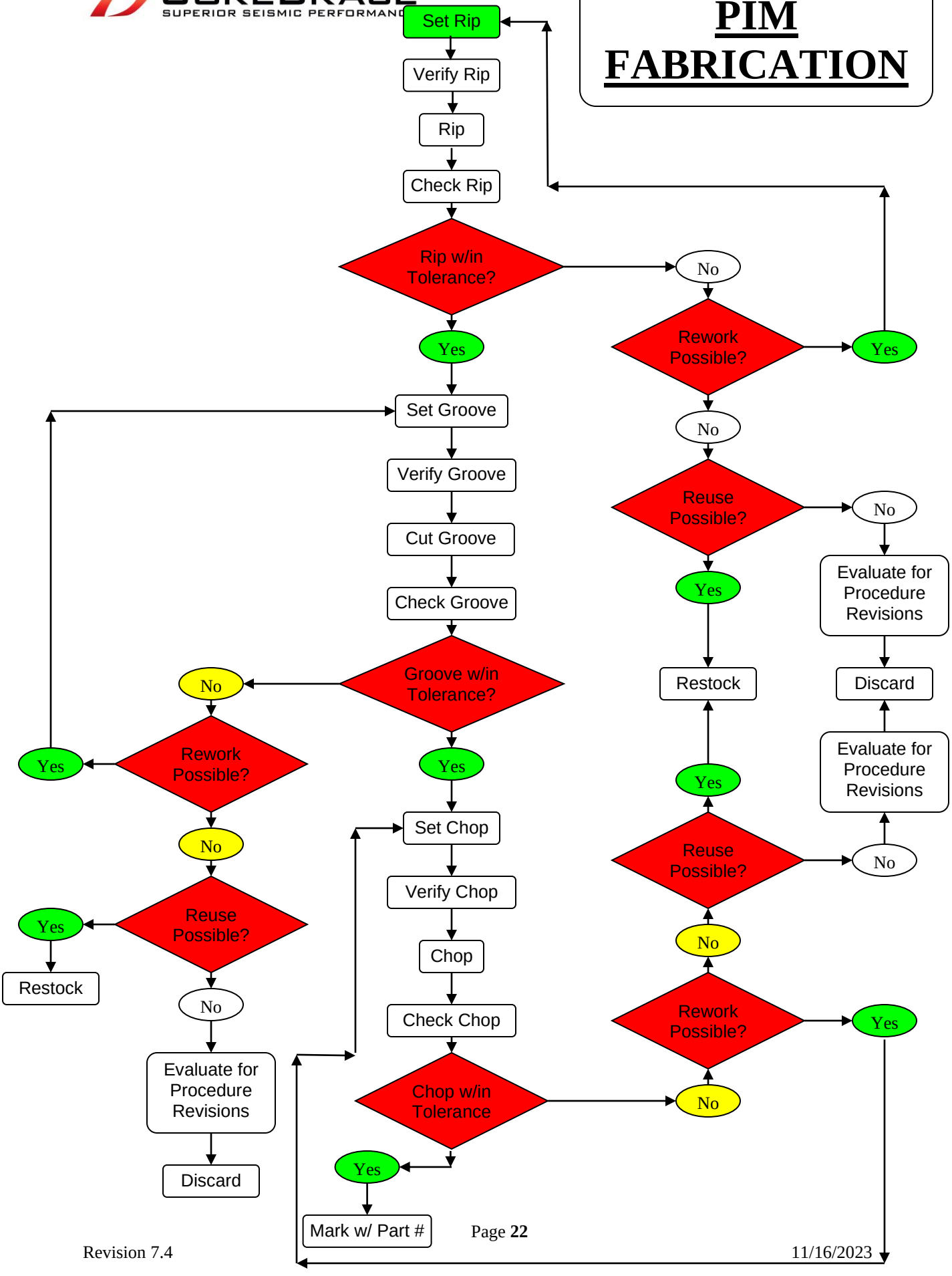
CoreBrace inspectors are responsible for final acceptance of the welded assemblies. They have sound experience in quality welding operations and shop manufacturing techniques. They have been trained in the visual acceptance criteria of AWS D1.1 and methods of performing visual examination of welds. AWS D1.1, Section 6.1.4(3), Inspector Qualification Requirements, recognizes the qualification of the CoreBrace inspectors to perform welding inspection in accordance with the AWS Structural Steel Codes. CoreBrace also accepts national certifying agencies' qualifications, such as the AWS certified weld inspector program.

The CoreBrace welding procedures are developed to document the essential welding variables used when making the successful weld. They are written to conform to the requirements of AWS D1.1, Section 3, Prequalification of WPSs, or Section 4, Qualification, as applicable as modified by CoreBrace. The CoreBrace nondestructive examination procedures, like the welding procedures, also document the essential variables of the examination process for the qualified technician. The procedures are written to conform to AWS D1.1 and the appropriate ASTM specifications as modified by CoreBrace. All of the procedures establish the sequences and parameters the qualified welder or nondestructive testing technician must follow to produce repeatedly acceptable welds and valid examinations.

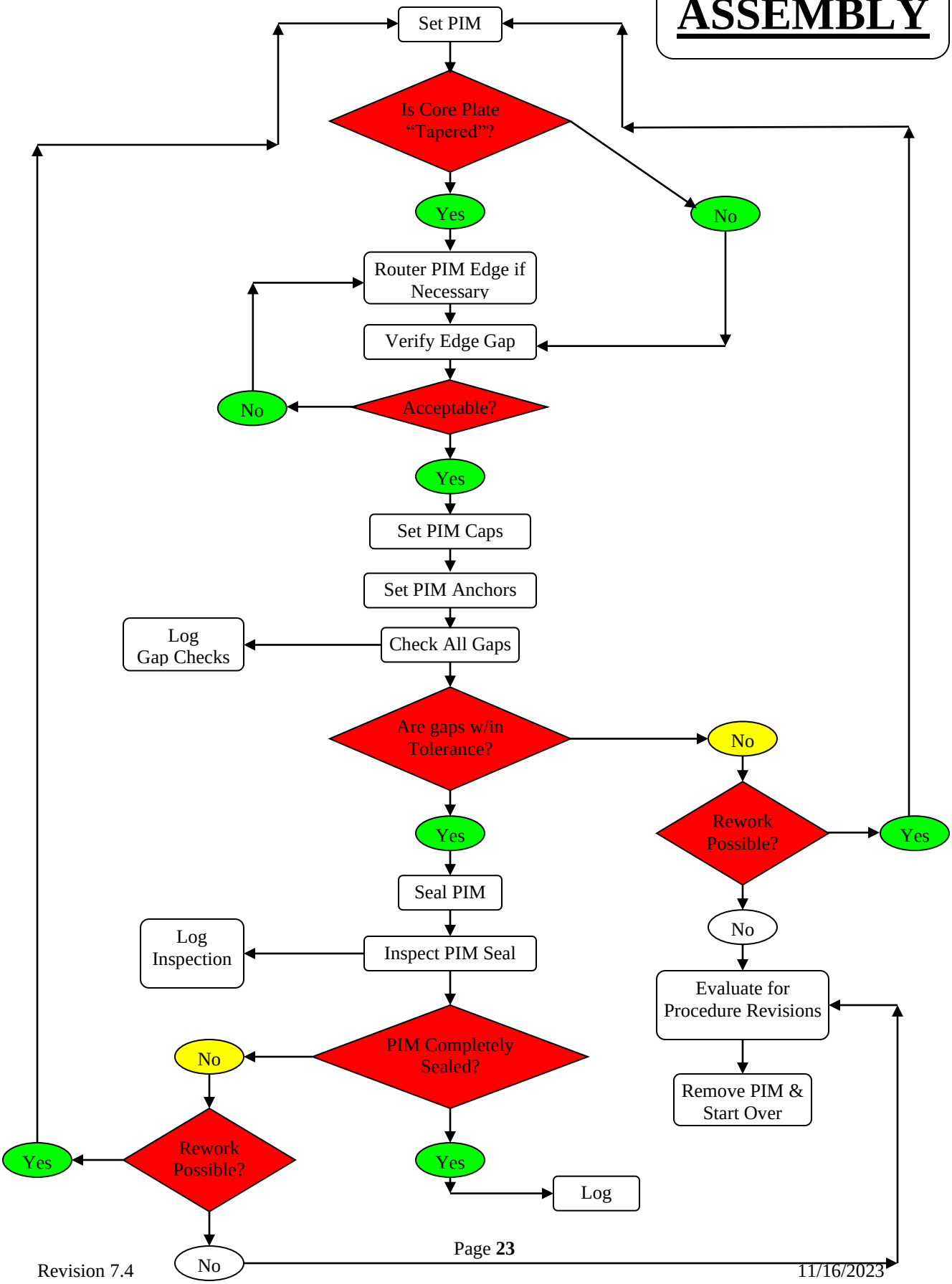
The steel components of the Buckling-Restrained Brace are joined together by welds. Destructive tests of numerous assemblies were performed in accordance with the Product Acceptance Plan for the BRB. The data collected and visual examinations of the braces after destructive testing have shown the welds perform well and meet product design requirements. Repair welds were also introduced into the test assemblies for evaluation. Welding repair had no noticeable effect on the performance of the Buckling-Restrained Braces. Repair welds are

permitted after evaluation of the discontinuity by CoreBrace inspectors in accordance with the requirements of AISC, ASTM A6, AWS D1.1, as modified by CoreBrace. These Codes and procedures specify the extent of nondestructive testing to be performed on weld repairs. Methods and acceptance criteria will vary according to the severity of the permissible weld repair. The essential variable parameters for all company welds are documented in CoreBrace welding procedures.

PIM FABRICATION



PIM ASSEMBLY

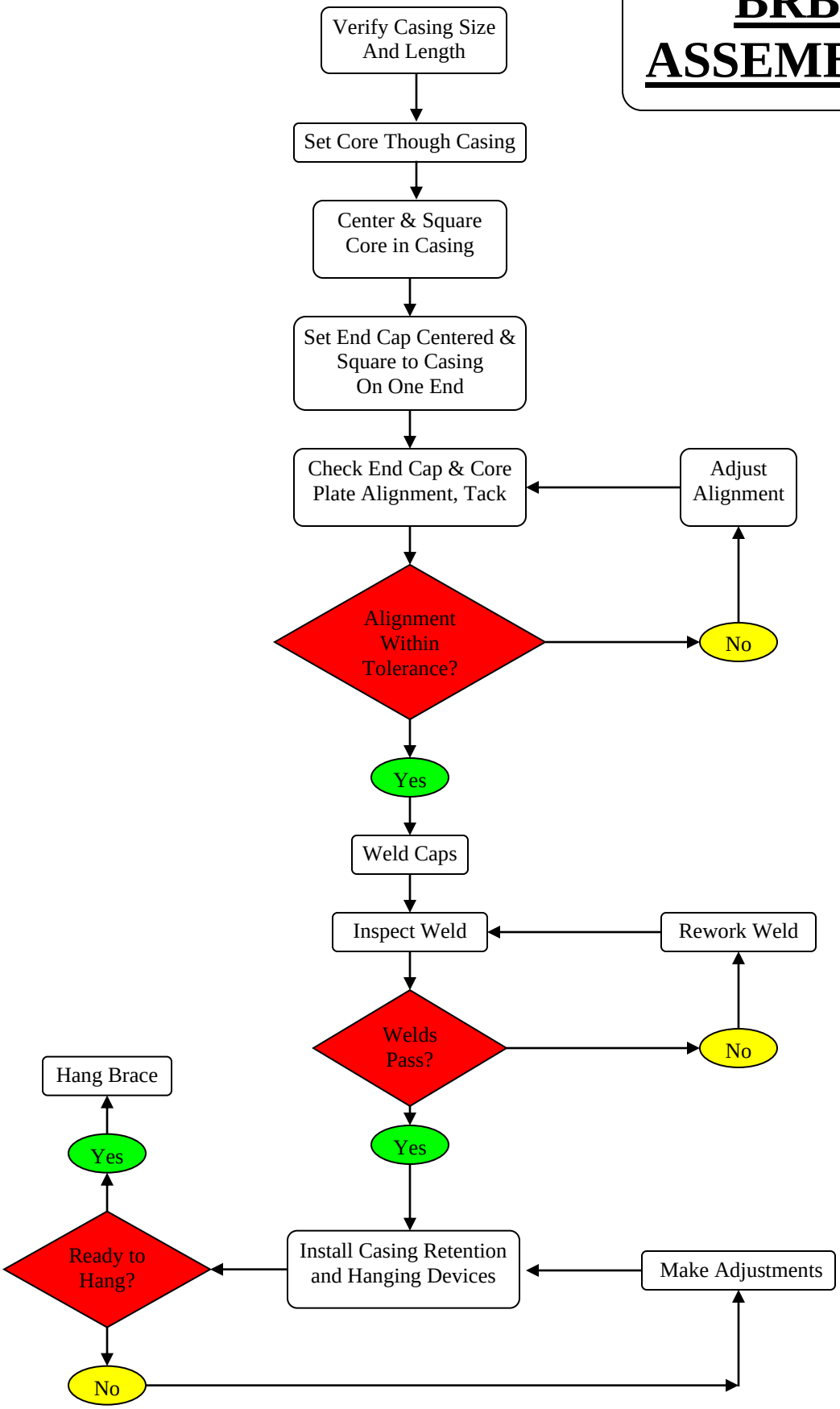


Proprietary Interface Material (PIM) Assembly

The PIM material is the same type of material used in CoreBrace testing. Parts are marked with Brace # and Part # and okayed for final dimensional check. PIM is dimensionally checked during the cutting process to conform with the individual part drawings including lengths, width, and thickness and that the proprietary fabrication tolerance for air gap will be maintained to within CoreBrace standards. If parts are not acceptable, fix or re-cutting is performed and a corrective action is logged. Repairs, fixes or re-cuts are made and the parts are rechecked. Tolerance checks are recorded in the PIM section of the inspection reports. Inspection reports require indication of inspection and initial of inspector prior to assembly. These reports are proprietary and can be viewed at the CoreBrace office or fabrication facility.

The PIM is then assembled to the core element of the brace. Upon completion the PIM is verified by qualified personnel to be within CoreBrace standards. Nonconformance assemblies are repaired or replaced. CoreBrace QA inspector performs random audits.

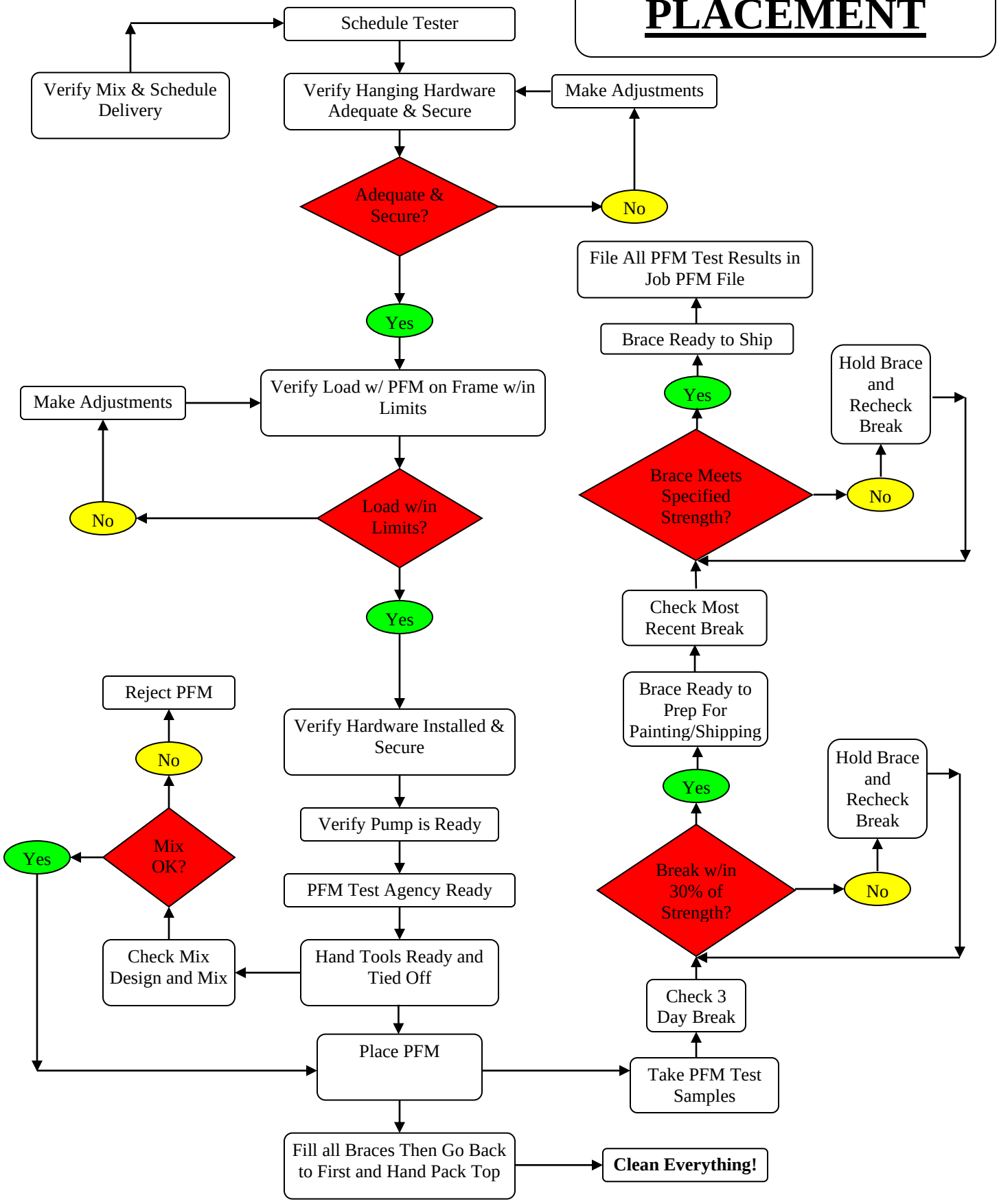
BRB ASSEMBLY



Buckling-Restrained Brace (BRB) Assembly

The casing element of the brace is checked for length. The brace core element is passed through the casing and centered via the end closure plate at one end of the casing and fit-up aids at the other end. The core element is checked for center of the casing at the casing ends. Also the end cap gap tolerance is checked.

PFM PLACEMENT



Proprietary Fill Material (PFM) Placement

Additional PFM placing aids are added to the brace assembly. Then the assembled core and casing unit is hung vertically for PFM placement via pump through the top end of the casing. Special proprietary mechanisms are utilized to insure the brace core does not deflect during PFM placement.

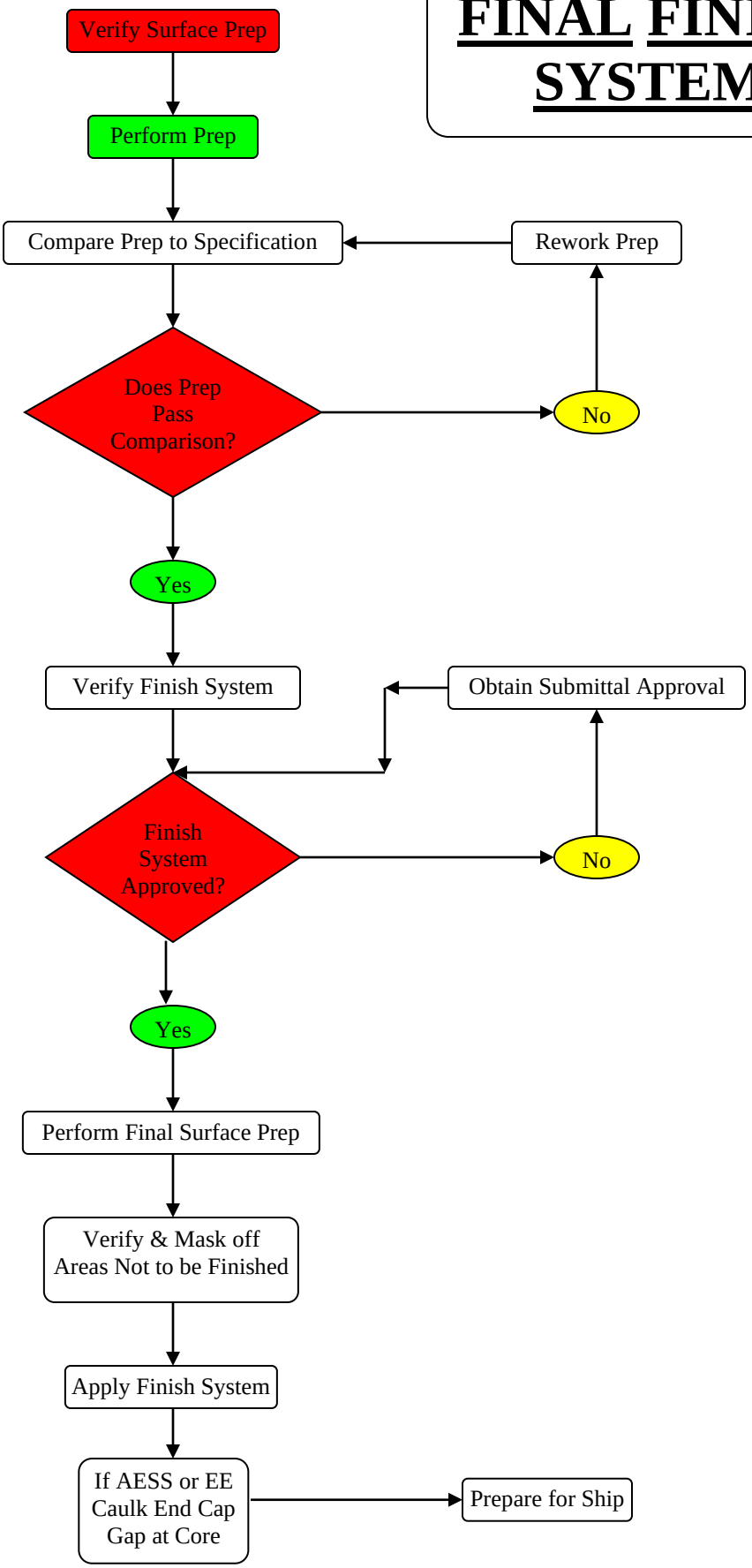
The required quantity of PFM is calculated and ordered from the supplier. Prior to placing PFM the batch ticket for each delivery truck is checked for conformance with mix design. The mix is checked visually and any necessary adjustments are made. A Spread test (ASTM C1611) is performed and Temperature (ASTM C1064) and Air Content (ASTM C231) measurements are taken by an independent testing agency qualified to perform the testing. Once these measurements are confirmed to be within acceptable limits PFM placement commences. A non-conforming batch of PFM is rejected and the delivery truck dismissed.

All personnel performing any fill material testing shall be qualified and all equipment used shall be calibrated in accordance with the applicable standards and code. If requested, independent agencies performing testing shall provide evidence of qualification and certification satisfying the code and Jurisdictional requirements. Reports and records of testing shall be submitted to CoreBrace on completion of the testing, for project submittal.

After PFM has been placed, a check is made for any minor PFM settlement and is topped off as necessary. Due to the natural “self-consolidating” properties of the PFM no extraneous consolidation procedures are necessary. Four test cylinders (ASTM C31) are made for every batch of PFM for future testing to verify the PFM compressive strength (ASTM C39). These cylinders are typically tested at 3-day, 7-day, and 28-day intervals as required to verify that the compressive strength is per standard. If the PFM does not come up to the requisite strength then the BRBs containing that batch of PFM are rejected and re-fabricated.

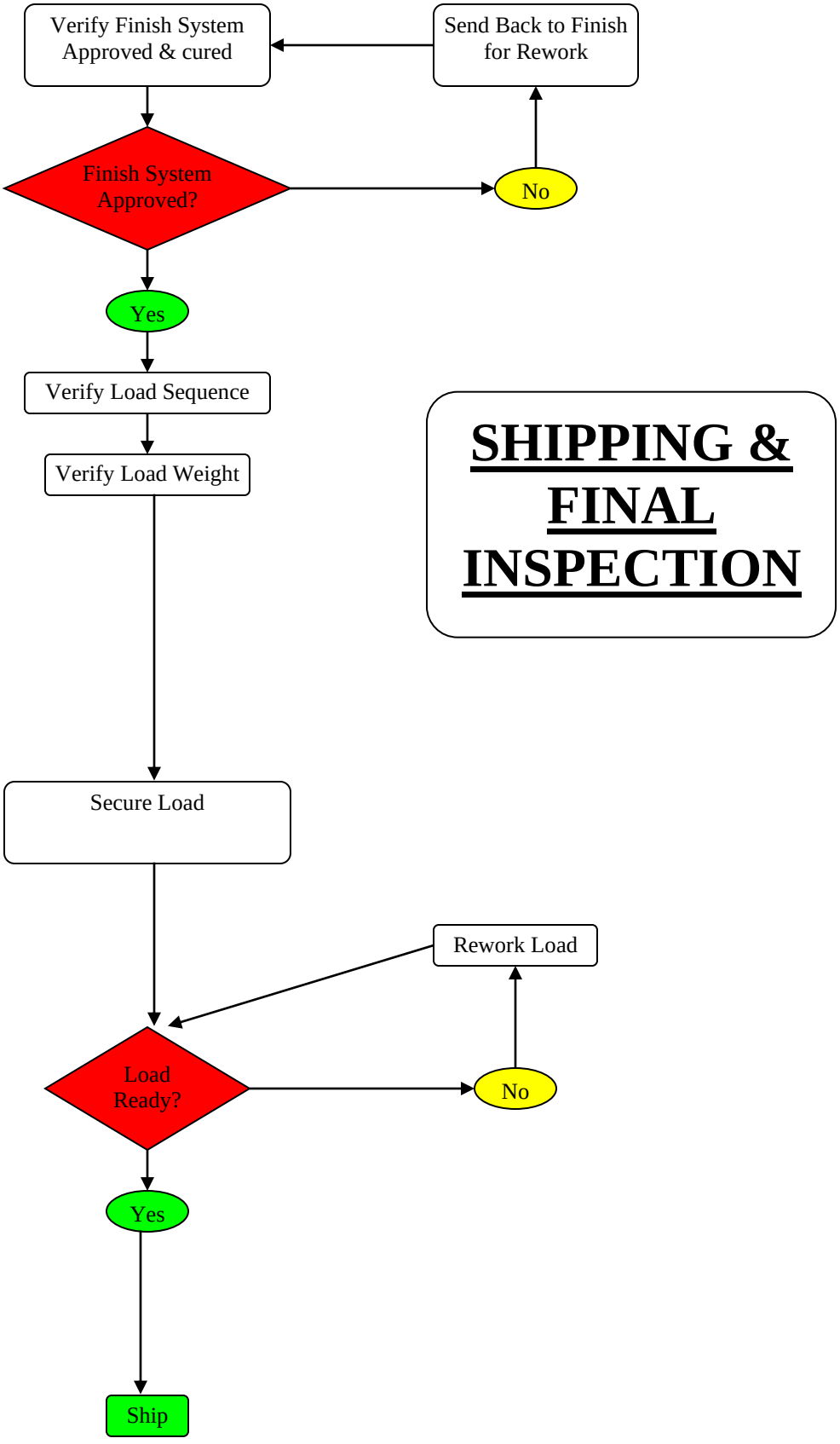
The CoreBraces are allowed to cure for a minimum of 1/2 day prior to removing from pour racks.

FINAL FINISH SYSTEM



Final Finish System

Prior to surface prep the end plate at the top end of the brace is placed and sealed and sealant is allowed to cure, if required. Then the brace is cleaned as per project specifications. At this time both the casing and the ends of the core that protrude beyond the casing are prepared. After surface preparation is visually inspected the brace is sent to paint with appropriate areas masked off.


Verify Finish System Approved & cured
Send Back to Finish for Rework
Finish System Approved?
No
Yes
Verify Load Sequence
Verify Load Weight
SHIPPING & FINAL INSPECTION
Secure Load
Rework Load
Load Ready?
No
Yes
Ship

Shipping and Final Inspection

One last visual check of the brace is made. Any objections are repaired, and the brace is prepared for shipment.

Site Quality Control

CoreBraces shall be stored on dunnage keeping them free from contacting site surfaces in order to protect finishes. Soft material between the dunnage and the CoreBrace is recommended to protect finishes. CoreBraces may be stacked with dunnage between levels. It is recommended that the stacks be covered with tarps to protect them from damage to finishes.

CoreBraces shall be handled in a manner to prevent impact loading to the brace. If CoreBraces are subjected to impact loading causing gouging or deformation to any of the steel components, CoreBrace shall be notified immediately for further evaluation.

Erection

Each CoreBrace will be provided with a piece mark identification that correlates to the erection drawings for determination of brace location in the field.

If requested, CoreBrace will provide lifting lugs on the braces. Removal of such lugs, if required, is not by CoreBrace. Remove lugs by torch cutting to within 1/16" of face of casing, then grind smooth. Do not gouge the casing or remove more material than the original casing had. In lieu of lugs Corebraces may be choked with slings. Soft non-metal straps are recommended for choking braces to minimize damage to finishes. The method of erection remains the responsibility of the erector.

During erection, CoreBraces shall be handled in a manner to prevent impact loading to the brace. If CoreBraces are subjected to impact loading causing gouging or deformation to any of the steel components, CoreBrace shall be notified immediately for further evaluation.

Any field modification to the CoreBraces shall not be permitted without written consent of Corebrace. Attachment of any items to the Corebraces shall not be permitted without written consent of CoreBrace. Utilize standard RFI procedures for the project if such conditions are necessary.

CoreBrace excludes touch up paint requirements due to handling and erection after delivery of braces.

Attachments

QA Plan Hold Point Check Tables

Sample Inspection Reports

- Core & Lug Cut Check Chart
- Core & Lug Edge Check Chart
- Bolt Hole Layout Check Chart
- Core Assembly Check Chart
- PIM Assembly Check Chart (Proprietary not included)
- CB Assembly Check Chart
- Casing Check Chart

Core Brace, LLC.
QA Plan Hold Point Check Table

#	Description	Standards	Tolerance
1	Verify Plate MTR	ASTM	As specified
2	Coupon tension test	ASTM A370 ASTM E8	As specified
3	Cut dimensions of brace core parts	CoreBrace	+/- 1/4" longitudinally +/- 1/8" transversely
3	Cut edge roughness		
	Yielding length	AISC LRFD 3rd Ed. Code of Standard Practice	≦ 1000 μinches
	Remainder	AWS D1.1 Section 5.14	≦ 1000 μinches
	Notches yielding length	AWS D1.1 Section 5.14 & CoreBrace	≦ 3/16" flare grind or weld ＞ 3/16" repair ＞3/8" may reject
	Notches elsewhere	AWS D1.1 Section 5.14 & CoreBrace	≦ 3/16" flare grind or weld ＞3/16" repair
3	Laminar discontinuities	See cut edge roughness, UT examination if observed	See cut edge roughness
3	Holes spacing & alignment	CoreBrace	+/- 1/16"
3	Core Assembly	CoreBrace	See check chart
3	Welds and Weld Repair of core	AWS D1.1 Sections 3, 5 & 6 as modified by CoreBrace	Pass visual by qualified inspector
4	Special fabrication of PIM	CoreBrace	Proprietary
4	Seal PIM	CoreBrace	Visual, no gaps
4	PIM & Fit-Up	CoreBrace	Proprietary
5	Casing length	CoreBrace	+/- ¼"
5	Center of core in casing	CoreBrace	+/- ¼ "
6	Surface preparation casing and ends	Specification Standard	As specified
6	Inspect paint	Specification standard	As specified
7	PFM strength	Proprietary	Proprietary

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Job#:	
Mark#:	
Plate# Main Core:	
Part# Main Core:	
Date:	

Check at Fit-Up
Travels with Mark#

Lug Cut Check Chart

Checker Initials:

Dim		Tolerance	Pass	Fail
L_L	Overall length	+/-1/4"		
L_{SL}	End of lug to transition	+/-1/4"		
L_{ugg}	Length along lug	+/-1/4"		
a	Transition length	+/-1/4"		
L_{Cpl}	Length of hairpin to start of radius	+/- 1/8"		
W_L	Width of lug at bolt group	+/-1/8"		
Wi_{se}	Width of lug at end in casing	+/-1/8"		
W_{hole}	Width of hairpin	+/-1/16"		
W_1	Width of lug at hairpin	+/-1/8"		
	Verify correct surface preparation (i.e. Class A or B)	NA		

Core Cut Check Chart

Checker Initials:

Dim		Tolerance	Pass	Fail
L_b	Overall length	+/-1/4"		
L_{ap}; L_t	Slot Length-end of core to radius; transition length	+/-1/8"		
S_c, W_t	Width along entire length of steel core	+/-1/8"		
W_{ag}	Hairpin width	0"~+1/16"		
W_{ag}	Centered	+/-1/16"		

Core & Lug Edge Check

Checker Initials:

Dim	Description	Tolerance	Pass	Fail
L_b , L_L	Gouges from QC/QA manual	<= 3/8"		
L_y , L_L	Laminar discontinuities in yield section UT if observed	<= 3/8"		
Gouge	Gouge <=3/16" flare 1:10 or weld, >3/16" & <=3/8 weld	as stated		
Laminar	Laminar <=3/16" flare 1:10 or weld, >3/16" & <=3/8 weld	as stated		
Roughness	Repair as needed by grinding	1000μ"		

Lug Part#:

Lug Bolt Hole Layout Check Chart

Checker Initials:

Dim	Description	Tolerance	Pass	Fail
g_1 , g_2	Gauge between bolt rows, check 1st and last bolts of row	+/-1/16"		
Align	Bolt row alignment, check all bolts in row	+/-1/16"		
s	Bolt spacing, check all bolts	+/-1/16"		
s/2	Bolt spacing between inner and outer line	+/-1/16"		
Hole	Size, Burs, Elongation	AISC		

# of failures if any:

Potential Cause?:	
Disposition (Repair, Fix or Loss):	

cc: Project Manager

Travels with Mark #

Job #:

PL # (main):

Mark #: **Date:**

Checker Initials:

Core Assembly Check Chart

Dim	Description	Tolerance	Pass	Fail
Ca_{lyx}	Centering of lug plates. Check at both ends.	+/-1/16"		
Sq_{uee}	Square of lugs. Set square to plates and measure maximum gap. Check at both ends of brace.	+/-1/16"		
Sweep Brace	Any 10' along plate edge, check both directions	+/-1/4"/10'		
Bolt Align	Alignment of bolt rows end to end of brace. Check with string along edge of holes	+/-1/8"		
Bolt Centers	Alignment of holes through both lug plates. Test bolts shall easily slide through both plies of each hole.	+/-1/16"		
Lha	Out to out dimension of outermost holes	+/-1/16"		
Lug Gap	At root of lug plates at center of lug	+1/32"		
	At end of brace, (6) bolts total or less: 3/8", otherwise ½"	-1/8", +1/4"		
Ws	Yield: Visual per AWS/AISC as modified by CoreBrace			
W_L	Lug: Visual per AWS/AISC & 1:1 taper at start & termination			
Gee	Yield gouge <= 3/16" flare 1:10 or weld, > 3/16" & <= 3/8" weld	Repair		
Ge	Elsewhere gouge <= 3/16" flare 1:10 or weld, >3/16" weld	Repair		
Ly	Yield: Laminar <= 3/16" flare 1:10 or weld, >3/16" & <= 3/8" weld	Repair		
Le	Elsewhere: Laminar <= 3/16" flare 1:10 or weld, >3/16" weld	Repair		
Ry	Yield: Roughness repair as needed by grinding	1000µ"		
Re	Elsewhere: Roughness repair as needed by grinding	1000µ"		
Center Stiffener Location	ONLY REQUIRED FOR BRACES WITH CENTER STIFFS: Verify stiffener is at center of yield section and center of brace longitudinal axis	+/-1/8"		

# of failures if any:

Potential Cause?:	
Disposition (Repair, Fix, Loss):	

cc: Project Manger

SAMPLE

Travels with Mark #

Job #:

Mark #: **Date:**

Checker Initials:

CB Assembly Check

Dim	Description	Tolerance	Pass	Fail
CL HSS	Center HSS casing on core length wise	+/-1/4"		
Cap Weld	Continuous at flat faces, seal weld corners & seams if exposed	Visual		
Temp Cap Caulk Seal	Fill bottom joint completely with caulk	Visual		
	Place 12 hours prior to pour	Visual		
AESS?	Welds ground, sharp edges, fit-up	Visual		

Part # :

Checker Initials:

Casing Check Chart

Dim	Description	Tolerance	Pass	Fail
L_c	Overall length	+/- 1/4"		
$W_{k.}$	Out to out width	Correct		
t_c	Wall thickness	Correct		
Gap	Gap between end cap and core, check all sides	0-3/8”		

Checker Initials:

Primer

Dim	Description	Tolerance	Pass	Fail
Primer	Correct primer applied?			
Primer	Applied to manufacturer/specification requirements?			

# of failures if any:

Potential Cause?:	
Disposition (Repair, Fix, Loss):	

cc: Project Manager

SAMPLE

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

5789 West Wells Park Road, West Jordan, Utah 84081

DATE: 6/10/2024

PSE Operational Training Center
Blue Star Welding

CoreBrace Job#: 5872

Subject: ***Certificate of Compliance - Weld Consumables***

This letter is to certify that all welding consumables supplied by CoreBrace for use on the referenced project, were and will be purchased, maintained, and used in strict accordance with the applicable contract documents, specifications, codes (AISC, ASTM and AWS), approved plans, and the Material Manufactures recommendations. The Manufacturers data sheets, certifications and product information sheets have been reviewed and those variables, requirements and instructions have been included within the CB Welding Procedure Specifications (WPS) within the appropriate tolerances allowed by code. Each WPS is written to comply with the AWS D1.1 and D1.8 requirements for seismic use and is prequalified for Demand Critical welds of the SFRS.

Each WPS indicates the approved ranges and code application of the specific wire listed therein. Each WPS provides for the additional requirements found in the AISC and AWS Seismic provisions for Heat Input for the given consumable specified therein.

CoreBrace certifies the above is true and all records pertaining to the above are on file at CoreBrace and are available for review upon request.

If you have any questions, please call.

Sincerely,

Daniel Christensen
CoreBrace QA/QC Director Manager
Phone 801-280-4947, Cell 801-819-8423

AWS
Daniel S. Christensen
CWI 16010023
QC1 EXP. 1/1/2025

CoreBrace
SUPERIOR SEISMIC PERFORMANCE

Welder qualification summary and continuity log

Welder Continuity Record		Shift and Date Qualified		FCAW-G	GMAW-S	GMAW	POSITION																	
LASTUPDATED2/15/2024		2		Qualified in	Qualified in	Qualified in	Qualified	In	Position	Welder Continuity Log 2024													
ID#	Employee Name	Shift	Date	Process	Process	Process	FCAW-G	GMAW	GMAW-S	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		
C1	ADRIAN ANGULO	1st	2/6/2017	X		X	2G 3G	1G		RD	RD												
C2	ALLAN LOVE	2nd	10/30/2018	X	X	X	1G	2F 1G	2F	RD	RD												
C4	BERNIE GERDES	1st	10/26/2015	X		X	2G 3G	1G		RD	RD												
C6	BRADLEE HELLIKSON	1st	5/6/2019		X	X		2F 1G	2F	RD	RD												
C7	Brandon Renfro	1st	3/7/2022	X	X	X	1G	1G	2F	RD	RD												
C13	CODY RASMUSSEN	1st	1/11/2019	X	X	X	1G	1G	2F	RD	RD												
C17	DALE TAYLOR	1st	5/31/2019	X	X	X	1G	1G 2F	2F	RD	RD												
C19	DAVE MADSEN	1st	12/17/2014	X			2G 3G			RD	RD												
C21	DON GREEN	1st	10/30/2018	X	X		1G		2F	RD	RD												
C22	DOUGLAS LUKER	1ST	10/26/2015	X		X	2G 3G	2F		RD	RD												
C23	DUSTY RUPE	1st	5/23/2019	X	X		1G		2F	RD	RD												
C24	ELEUTERIO MANCILLA	1st	11/21/2014	X	X	X	2G 3G	1G	2F	RD	RD												
C30	JERRY COOK	1st	6/30/2016	X		X	2G 3G	1G		RD	RD												
C32	JESSE MOORE	2nd	8/14/2017	X	X	X	1G	2F 1G	2F	RD	RD												
C34	JULIO JIMENEZ	1st	3/1/2016	X	X	X	1G	1G 2F	2F	RD	RD												
C38	KENNETH CHAPLIN	1st	2/25/2015	X			2G 3G 6G			RD	RD												
C39	KENNETH HOPKINS	1st	6/21/2017	X			1G			RD	RD												
C41	KIM BEEBE	2nd	10/26/2011	X	X	X	2G 3G	1G	2F	RD	RD												
C44	MARIO ASTUHUAMAN	1st	2/9/2017	X	X	X	1G	1G	2F	RD	RD												
C45	MIGUEL HERNANDEZ	1st	3/21/2019		X		2G		2F	RD	RD												
C47	NICK POPPLETON	1st	11/17/2016	X		X	1G 2G 6G	1G		RD	RD												
C50	Peter Mitchell	1st	4/3/2017	X	X	X	1G 2G 6G	1G	2F	RD	RD												
C51	RANDY PHILLIPS	1st	9/2/2015	X		X	2G 3G 6G	1G		RD	RD												
C54	RONY LOPEZ	1st	1/16/2018	X		X	1G	1G		RD	RD												
C57	SEAN COOK	1st	10/7/2015	X			2G 3G			RD	RD												
C68	Trevor Valladolid	1st	7/5/2019	X		X		2F	2F	RD	RD												
C74	Dalton Lee	1st	5/1/2019	X		X	1G 2G	1G		RD	RD												
C75	Spencer Henrickson	1st	6/26/2018	X		X	2G 3G	1G		RD	RD												
C86	Jose Varela	1st	9/1/2020	X		X	2G 3G	1G		RD	RD												
C88	Austin Garcia	1ST	9/1/2020	X	X	X	1G	1G 2F	2F	RD	RD												
C92	Roger Davis	1st	10/8/2020	X	X	X	1G	1G 2F	2F	RD	RD												
C95	Kyle Jones	1ST	10/12/2020	X		X	2G 3G	1G		RD	RD												
C98	Darrick Lycklama	1ST	11/10/2020	X		X	2G 3G	1G		RD	RD												
C103	Levi Running Eagle	1st	1/5/2021		X	X		2F	2F	RD	RD												
C105	Armando Pena	1st	1/20/2021	X		X	1G	1G		RD	RD												
C110	Chris Maldonado	1st	2/17/2021		X	X		2F	2F	RD	RD												
C111	Ward Anderson JR	1st	2/17/2021	X	X	X	1G	1G	2F	RD	RD												
C114	Dee Crane	2ND	4/20/2021		X				2F	RD	RD												
C116	Bridger Sharp	1ST	6/20/2021	X	X	X	1G	1G	2F	RD	RD												
C124	Andrew Cox	1st	8/31/2021	X	X	X	2G	1G		RD	RD												
C128	Sam Munk	1st	10/15/2021	X		X	1G	1G		RD	RD												
C129	Santiago Resendiz Munoz	1st	10/15/2021		X	X		1G2F	2F	RD	RD												
C132	Jake Rossen	1st	11/9/2021	X	X	X	1G	2F 1G	2F	RD	RD												
C141	Nathan Standley	2nd	4/20/2022		X				2F	RD	RD												
C155	Brandon Smith	1st	6/30/2022	X	X	X	1G	1G	2F	RD	RD												
C156	Doug Johnson	1st	9/15/2022	X			1G			RD	RD												
C160	Elliot Parsons	1st	10/7/2022		X			1G2F		RD	RD												
C162	David Cuahutzihua Zopiyactle	1st	10/26/2022			X	1G	1G 2F		RD	RD												
C164	Jaren Larson	2nd	12/16/2023	X		X	1G	1G 2F		RD	RD												

Welder qualification summary and continuity log

Welder Continuity Record		Shift and Date Qualified		FCAW-G	GMAW-S	GMAW	POSITION																
LASTUPDATED2/15/2024		2		Qualified in	Qualified in	Qualified in	Qualified	In	Position	Welder Continuity Log 2024													
ID#	Employee Name	Shift	Date	Process	Process	Process	FCAW-G	GMAW	GMAW-S	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		
C166	Tyler Rowe	1ST	12/1/2022	X		X	1G	1G		RD	RD												
C171	Cristian Hernandez	1st	1/25/2023			X		2F		RD	RD												
C172	Gabe Inzurriaga	1st	2/9/2023			X		2F		RD	RD												
C173	Miguel Gonzales	1st	2/14/2023			X		2F		RD	RD												
C176	Rigoberto Navamete	1st	3/30/2023			X		2F		RD	RD												
C178	Donyvon Hamilton	2nd	4/24/2023			X		1G		RD	RD												
C179	Brayden Nalder	2nd	5/23/2023			X		2F		RD	RD												
C180	Jesse Converse	1st	5/24/2023			X		2F		RD	RD												
C181	Garrick Atencio	2nd	6/23/2023			X		1G		RD	RD												
C183	Feliciano Astuaman	1st	7/3/2023			X		2F		RD	RD												
C184	John Vanderlieth	2nd	7/8/2023			X		2F 1G		RD	RD												
C185	Jeff Jenkins	2nd	8/3/2023			X		2F		RD	RD												
C186	A.J. Neary	1st	8/25/2023			X		1G		RD	RD												
C187	Braelynn Teeples	1st	1/31/2024			X		1G 2F		RD	RD												
C188	Zach Chacon	2nd	1/24/2024			X		1G		RD	RD												
C189	Rogelio Bravo	2nd	2/6/2024			X		1G			RD												
I134	Sheldon Umphenour	1st	7/6/2023			X		1G		RD	RD												
I 184	Shawn Hollingsworth	1st	8/14/2023			X		1G		RD	RD												

Verification of continuous service from inception of the original certification through update period noted. A review of records has shown continuous service within the process for each welder. The given records included, personal witness, inspector logs, payroll and / or production records. Original certification and portions of the documents reviewed are available for review at the CoreBrace QA Office, note some documents are sensitive and are not for general distribution.

This document shall serve as an affidavit of this review. To the best of my knowledge this document is accurate and true. This document serves as certification of continued service through each six month period documented here-in.

Q.A. Manager - Roger Davis

Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Structual Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Attach Joint Configurations

Welding Procedure Specification (WPS)	FabCOR Edge XP	Supporting P.Q.R #	Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)		
Welding Process:	MCAW - Spray transfer		
Manual or Machine:	Semi-Automatic		
Position of Weld	Flat and Horizontal		
Filler Metal: Specification, Classification, Trade Name:	AWS A5.18, A5.28; SFA 5.18, 5.28 / E70C-6M H4, E80C-G H4, Hobart FabCOR Edge XP		
Flux:	N/A		
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	75 - 95% Argon/ 5 - 25% $Co_{2,}$ 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others		
Welding Current:	DCEP (CV Output)		
Root Treatment:	Clean to remove all contaminants (see QC plan)		
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)		
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)		
Heat Input Limits 0.045" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 24.3 kj/in Maximum HI - 81.1 kj/in		
Heat Input Limits 0.052"	Minimum HI - 28.2 kj/in Maximum HI - 81.2 kj/in		
Heat Input Limits 1/16"	Minimum HI - 29.8 kj/in Maximum HI - 81.4 kj/in		
Joint Geometry	**See joint configurations, attached pages**		

Electrical Characteristics

Pass No.	Weld Position	Electrode Diameter / CTWD	Welding Current		WFS	Travel Speed
			Volts	Amps	IPM	IPM
Flat and Horizontal Positions						
All	Groove or Fillet	0.045" Dia. CTWD 3/4"	20 -(23)- 26	180 -(200)- 220	216 -(240)- 264	5 (6.6) 8.25
All	Groove or Fillet	0.045" Dia. CTWD 3/4"	21 -(25)-28	225 -(250)- 275	306 -(340)-374	6.7 (8.9) 11
All	Groove or Fillet	0.045" Dia. CTWD 3/4"	22 -(26)-30	270 -(300)- 330	378 -(420)- 462	8.6 (11.5) 14.4
All	Groove or Fillet	0.045" Dia. CTWD 7/8"	24 -(28)-32	315 -(350)- 385	513 -(570)-627	12.1 (16.1) 20.1
All	Groove or Fillet	0.045" Dia. CTWD 7/8"	26 -(30)-34	360 -(400)- 440	653 -(725)- 797	16.9 (20.1) 23.3
All	Groove or Fillet	0.052" Dia. CTWD 3/4"	20 -(23)- 26	180 -(200)- 220	171 -(190)- 209	5.2 (6.9) 8.6
All	Groove or Fillet	0.052" Dia. CTWD 3/4"	20 -(24)- 27	225 -(250)- 275	216 -(240)- 264	6.8 (9.1) 11.4
All	Groove or Fillet	0.052" Dia. CTWD 3/4"	22 -(26)- 29	270 -(300)- 330	288 -(320)- 352	8.5 (11.4) 14.2
All	Groove or Fillet	0.052" Dia. CTWD 7/8"	24 -(28)- 32	315 -(350)- 385	364 -(405)- 445.5	11 (14.6) 18.3
All	Groove or Fillet	0.052" Dia. CTWD 7/8"	26 -(30)- 34	360 -(400)- 440	463 -(515)-566.5	14.4 (19.1) 24
All	Groove or Fillet	1/16" Dia. CTWD 7/8"	21 -(24)- 27	225 -(250)-275	139 -(155)-170	5.7 (7.6) 9.9
All	Groove or Fillet	1/16" Dia. CTWD 7/8"	22 -(25)- 28	270 -(300)- 330	184 -(205)- 225	7.8 (10.4) 13
All	Groove or Fillet	1/16" Dia. CTWD 7/8"	23 -(27)- 31	315 -(350)- 385	238 -(265)- 291	9.1 (12.1) 15.1
All	Groove or Fillet	1/16" Dia. CTWD 1"	25 -(29)- 33	360 -(400)- 440	292 -(325)- 357	11.7 (15.6) 19.5
All	Groove or Fillet	1/16" Dia. CTWD 1"	27 -(31)- 35	450 -(500)- 550	450 -(500)- 550	18.5 (24.7) 30.9

NOTES

1	For Fillets, where root separation is greater than 1/16" ≤ 3/16", the size of the fillet weld may be increased by the amount of the actual gap. Fillet and Groove welds may have excessive root openings "buttered up"/ repaired, up to a 1/4", to close a gap to within acceptable limits.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal 1" Vertical
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	"As Fit" tolerance, where applicable - Angle +10°, -5°, root opening +1/4", 1/16" (W/backing), +1/16", -1/8" (W/O backing), f not limited
7	Backing may be steel, copper, ceramic or backing weld. Non-fusible backing shall be removed and backgouged to sound metal, then back welded.
8	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
9	This WPS may be used for any prequalified joint configuration not shown, without inclusion herein with QC verification.
10	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
11	Weave (vertical only) or stringers may be used. Stringers is preferred for control of heat input where applicable.
12	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included.

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
0	initial Issue	8/4/2023	Approved
1	format revised	2/14/2024	Approved

Approved by: Roger Davis

Signed:

Roger R. Davis
CWI 24011831
QC1 EXP. 1/1/2027

Daniel S. Christensen
CWI 16010023
QC1 EXP. 1/1/2025

Date: 2/19/2024

Structual Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Attach Joint Configurations

Welding Procedure Specification (WPS)	FabCO TR-70	Supporting P.Q.R #	Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)		
Welding Process:	FCAW-G		
Manual or Machine:	Semi-Automatic		
Position of Weld	Flat and Horizontal		
Filler Metal: Specification, Classification, Trade Name:	AWS A5.20/A5.20M - E70T-1C H8,E70T-9C H8, Hobart FabCO TR-70		
Flux:	N/A		
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	100% Co_2, 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others		
Welding Current:	DCEP (CV Output)		
Root Treatment:	Clean to remove all contaminants (see QC plan)		
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)		
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)		
Heat Input Limits 1/16" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 28.5 kj/in Maximum HI - 75.5 kj/in		
Heat Input Limits 5/64"	Minimum HI - 31.0 kj/in Maximum HI - 84.3 kj/in		
Joint Geometry	**See joint configurations, attached pages**		

Electrical Characteristics

Pass No.	Weld Position	Electrode Diameter / CTWD	Welding Current		WFS	Travel Speed
			Volts	Amps	IPM	IPM
Flat and Horizontal Positions						
All	Groove or Fillet	1/16" Dia. CTWD 1"	22 -(25)- 28	153 -(170)- 187	126 -(140)- 154	3.97 (5.3) 6.62
All	Groove or Fillet	1/16" Dia. CTWD 1"	23 -(26)-30	180 -(200)- 220	153 -(170)-187	4.80 (6.4) 8.00
All	Groove or Fillet	1/16" Dia. CTWD 1"	23 -(27)-31	234 -(260)- 286	189 -(210)- 231	5.85 (7.8) 9.75
All	Groove or Fillet	1/16" Dia. CTWD 1"	27 -(32)-36	315 -(350)- 385	311 -(345)-379	9.67 (12.9) 16.12
All	Groove or Fillet	5/64" Dia. CTWD 1"	22 -(26)- 30	225 -(250)- 275	99 -(110)- 121	4.87 (6.50) 8.12
All	Groove or Fillet	5/64" Dia. CTWD 1"	22 -(26)- 30	270 -(300)- 330	126 -(140)- 154	6.22 (8.30) 10.4
All	Groove or Fillet	5/64" Dia. CTWD 1"	23 -(27)- 31	315 -(350)- 385	153 -(170)- 187	7.50 (10.0) 12.5
All	Groove or Fillet	5/64" Dia. CTWD 1"	23 -(27)- 31	378 -(420)- 462	202 -(225)- 247	10.1 (13.50) 16.8
All	Groove or Fillet	5/64" Dia. CTWD 1"	27 -(32)- 36	495 -(550)- 605	310 -(345)-379	15.6 (20.80) 26.0

NOTES

1	For Fillets, where root separation is greater than 1/16" ≤ 3/16", the size of the fillet weld may be increased by the amount of the actual gap. Fillet and Groove welds may have excessive root openings "buttered up"/ repaired, up to a 1/4", to close a gap to within acceptable limits.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal 1" Vertical
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	"As Fit" tolerance, where applicable - Angle +10°, -5°, root opening +1/4", 1/16" (W/backing), +1/16", -1/8" (W/O backing), f not limited
7	Backing may be steel, copper, ceramic or backing weld. Non-fusible backing shall be removed and backgouged to sound metal, then back welded.
8	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
9	This WPS may be used for any prequalified joint configuration not shown, without inclusion herein with QC verification.
10	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
11	Weave (vertical only) or stringers may be used. Stringers is preferred for control of heat input where applicable.
12	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included.

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
0	initial Issue	8/4/2023	Approved
1	format revised	2/14/2024	Approved

Approved by: Roger Davis

Signed: Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027

Daniel S. Christensen CWI 16010023 QC1 EXP. 1/1/2025

Date: 2/19/2024

Structual Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Attach Joint Configurations

Welding Procedure Specification (WPS)	FabCO 811N1	Supporting P.Q.R #	Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)		
Welding Process:	FCAW-G		
Manual or Machine:	Semi-Automatic		
Position of Weld	All		
Filler Metal: Specification, Classification, Trade Name:	AWS A5.29/A5.29M - E81T1-Ni1 MJ H4, Hobart FabCO 811N1		
Flux:	N/A		
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	100% Co_2, 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others		
Welding Current:	DCEP (CV Output)		
Root Treatment:	Clean to remove all contaminants (see QC plan)		
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)		
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)		
Heat Input Limits 1/16" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 28.9 kj/in Maximum HI - 80.5 kj/in		
Joint Geometry	**See joint configurations, attached pages**		

Electrical Characteristics

Pass No.	Weld Position	Electrode Diameter / CTWD	Welding Current		WFS	Travel Speed
			Volts	Amps	IPM	IPM
All Positions						
All	Groove or Fillet	1/16" Dia. CTWD 3/4"	21 -(24)- 27	135 -(150)- 165	108 -(120)- 132	3.0 (4.0) 5.0
All	Groove or Fillet	1/16" Dia. CTWD 3/4"	22 -(25)- 28	180 -(200)- 220	140 -(155)- 170	4.3 (5.7) 7.1
All	Groove or Fillet	1/16" Dia. CTWD 1"	22 -(26)- 30	225 -(250)- 275	198 -(220)- 242	5.7 (7.6) 9.5
All	Flat & Hoirizontal	1/16" Dia. CTWD 1"	23 -(27)- 31	270 -(300)- 330	252 -(280)- 308	7.6 (10.2) 12.7

NOTES

1	For Fillets, where root separation is greater than 1/16" ≤ 3/16", the size of the fillet weld may be increased by the amount of the actual gap. Fillet and Groove welds may have excessive root openings "buttered up"/ repaired, up to a 1/4", to close a gap to within acceptable limits.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal 1" Vertical
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	"As Fit" tolerance, where applicable - Angle +10°, -5°, root opening +1/4", 1/16" (W/backing), +1/16", -1/8" (W/O backing), f not limited
7	Backing may be steel, copper, ceramic or backing weld. Non-fusible backing shall be removed and backgouged to sound metal, then back welded.
8	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
9	This WPS may be used for any prequalified joint configuration not shown, without inclusion herein with QC verification.
10	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
11	Weave (vertical only) or stringers may be used. Stringers is preferred for control of heat input where applicable.
12	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included.

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
0	initial Issue	8/4/2023	Approved
1	format revised	2/14/2024	Approved

Approved by: Roger Davis

Signed: Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027

Daniel S. Christensen CWI 16010023 QC1 EXP. 1/1/2025

Date: 2/19/2024

Structual Steel AWS D1.1 / D1.8
Welding Procedure Specification (WPS)

Attach Joint Configurations

Welding Procedure Specification (WPS)	FabCo Excel-Arc 71	Supporting P.Q.R #	Prequalified
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I & II)		
Welding Process:	FCAW-G		
Manual or Machine:	Semi-Automatic		
Position of Weld	All		
Filler Metal: Specification, Classification, Trade Name:	AWS A5.20/A5.20M, E71T-1 C/M E71T-9 C/M H8, Hobart FabCO Excel-Arc 71		
Flux:	N/A		
Shielding Gas: Mix, Type, Flow Rate, Wind Velocity	100% Co_2, 35 - 50 CFH, Wind Velocity ≤ 3 MPH DCW, ≤ 5 MPH all others		
Welding Current:	DCEP (CV Output)		
Root Treatment:	Clean to remove all contaminants (see QC plan)		
Preheat and Interpass Temperature:	Min Preheat 32°F, Max interpass 550° F (See table below)		
Post-Weld Heat Treatment:	Not required, UNO Written procedure required (see QC plan)		
Heat Input Limits 1/16" (A x V x .06 / Travel Speed = KJ/in.)	Minimum HI - 31.0 kj/in Maximum HI - 82.5 kj/in		
Joint Geometry	**See joint configurations, attached pages**		

Electrical Characteristics

Pass No.	Weld Position	Electrode Diameter / CTWD	Welding Current		WFS	Travel Speed
			Volts	Amps	IPM	IPM
All Positions						
All	Groove or Fillet	1/16" Dia. CTWD 3/4"	20 -(23)- 26	162 -(180)- 198	117 -(130)- 143	3.5 (4.6) 5.8
All	Groove or Fillet	1/16" Dia. CTWD 1"	22 -(25)-27	221 -(245)- 269	171 -(190)- 209	4.9 (6.5) 8.1
All	Groove or Fillet	1/16" Dia. CTWD 1"	22 -(26)-28	248 -(275)- 302	203 -(225)- 247	5.2 (7.8) 8.7
All	Flat & Hoirizontal	1/16" Dia. CTWD 1"	23 -(27)-31	252 -(280)- 308	216 -(240)- 264	5.9 (9.3) 11.6
All	Flat & Hoirizontal	1/16" Dia. CTWD 1"	24 -(28)-32	324 -(360)- 396	297 -(330)- 363	9.0 (12.0) 15.0
All	Flat & Hoirizontal	1/16" Dia. CTWD 1"	26 -(30)- 34	360 -(400)- 440	387 -(430)- 473	12.4 (16.5) 20.6

NOTES

1	For Fillets, where root separation is greater than 1/16" ≤ 3/16", the size of the fillet weld may be increased by the amount of the actual gap. Fillet and Groove welds may have excessive root openings "buttered up"/ repaired, up to a 1/4", to close a gap to within acceptable limits.
2	Electrode exposure limit - 7 days (per CoC), spools removed, bagged, and stored or stored in an oven, do not count as exposure time.
3	This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limits of all mandatory variables given in AWS D1.1.
4	Weld layer thickness - root 5/16" max, fill passes 1/4" max, Single pass fillet 3/8" max. Max layer width 5/8" flat/horizontal 1" Vertical
5	Peening and caulking are not allowed, the use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
6	"As Fit" tolerance, where applicable - Angle +10°, -5°, root opening +1/4", 1/16" (W/backing), +1/16", -1/8" (W/O backing), f not limited
7	Backing may be steel, copper, ceramic or backing weld. Non-fusible backing shall be removed and backgouged to sound metal, then back welded.
8	Grind, chip, wire brush between passes and layers. Remove all slag and spatter. Remove noted discontinuities, do not weld over them.
9	This WPS may be used for any prequalified joint configuration not shown, without inclusion herein with QC verification.
10	CB QCM PR12.1 Shall be used in conjunction with this WPS for all other notes, instructions and foot note legend.
11	Weave (vertical only) or stringers may be used. Stringers is preferred for control of heat input where applicable.
12	Voltage +/- 15%, Amperage & WFS +/- 10%, travel speed +/- 25% included in value range given. The number in parenthesis () is manufacturer's recommendation, to the right and left are with D1.1 variables included.

Minimum Preheat/inter-pass Temperature for Material (refer to D1.1 Table 5.8 category and Grade of material)
When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

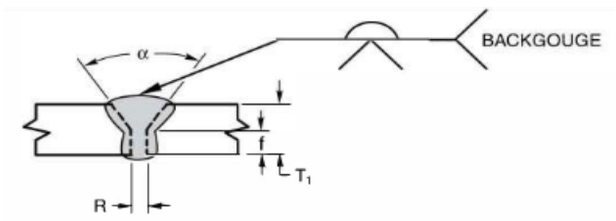
Category B	Category C
≤ 3/4" is 32° F	≤ 3/4" is 50° F
over 3/4" to 1 1/2" is 50° F	over 3/4" to 1 1/2" is 150° F
over 1 1/2" to 2 1/2" is 150° F	over 1 1/2" to 2 1/2" is 225° F
over 2 1/2" is 225° F	over 2 1/2" 300° F

Revision #	Description	Date	Status:
0	initial Issue	8/4/2023	Approved
1	format revised	2/14/2024	Approved

Approved by: Roger Davis **Signed:** Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027 **Date: 2/19/2024**

Daniel S. Christensen CWI 16010023 QC1 EXP. 1/1/2025

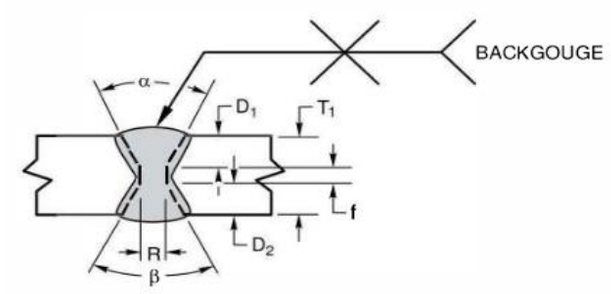
Single-V-groove weld (2) - Butt joint (B)



Welding Process		
GMAW FCAW		
Base Metal Thickness		
T_1 = U	T_2 = --	
Root opening Root Face Groove angle	Tolerances	
	As detailed	As Fit-up
R = 0 to 1/8	+1/16, -0	.+1/16, -1/8
f = 0 to 1/8	.+1/16, -0	Not limited
α = 60°	.+10°, -0	.+10°, -5°
Allowed Welding Positions = ALL		
Gas shielding for FCAW - Not required		
Notes: a, d, j		

B-U2-GF

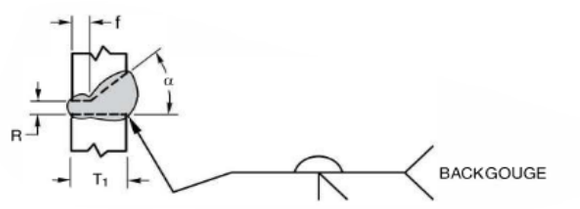
Double-V-groove weld (3) - Butt joint (B)



Welding Process		
GMAW FCAW		
Base Metal Thickness		
T_1 = U	T_2 = --	
Root opening Root Face Groove angle	Tolerances	
	As detailed	As Fit-up
R = 0 to 1/8	+1/16, -0	.+1/16, -1/8
f = 0 to 1/8	.+1/16, -0	Not limited
α = β = 60°	.+10°, -0	.+10°, -5°
Allowed Welding Positions = ALL		
Gas shielding for FCAW - Not required		
Notes: a, d, h, j		

B-U3-GF

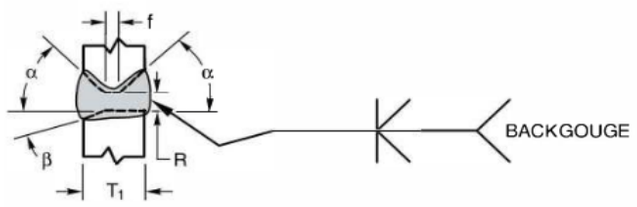
Single-bevel-groove weld (4) - Butt joint (B)



Welding Process		
GMAW FCAW		
Base Metal Thickness		
T_1 = U	T_2 = --	
Root opening Root Face Groove angle	Tolerances	
	As detailed	As Fit-up
R = 0 to 1/8	+1/16, -0	.+1/16, -1/8
f = 0 to 1/8	.+1/16, -0	Not limited
α = 45°	.+10°, -0	.+10°, -5°
Allowed Welding Positions = ALL		
Gas shielding for FCAW - Not required		
Notes: a, c, d, j		

B-U4b-GF

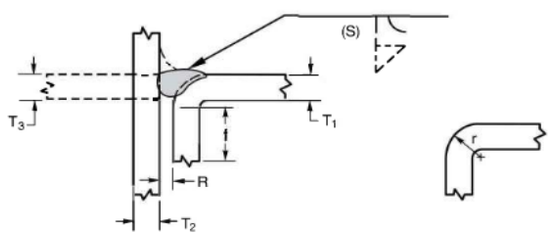
Double-bevel-groove weld (5) - Butt joint (B)



Welding Process		
GMAW FCAW		
Base Metal Thickness		
T_1 = U	T_2 = --	
Root opening Root Face Groove angle	Tolerances	
	As detailed	As Fit-up
R = 0 to 1/8	+1/16, -0	.+1/16, -1/8
f = 0 to 1/8	.+1/16, -0	Not limited
α = 45° β = 0° to 15°	α + β = +10°, -0°	α + β = +10°, -0°
Allowed Welding Positions = ALL		
Gas shielding for FCAW - Not required		
Notes: a, c, d, h, j		

B-U5-GF

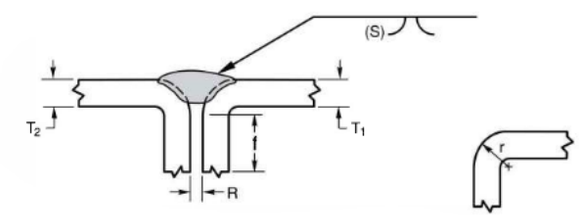
Flare-bevel-groove weld (10) - Butt joint (B) - T-joint (T) Corner joint (C)



GMAW FCAW-G		
Base Metal Thickness		
T_1 = 3/16 min. T_2 = U T_3 = T_1 min.		
Root opening Root Face Bend Radius	Tolerances	
	As detailed	As Fit-up
R = 0	+1/16, -0	.+1/8, -1/16
f = 3/16 min.	.+U, -0	.+U, -1/16
r = $3T_1/2$ min.	.+U, -0	.+U, -0
Allowed Welding Positions = ALL		
Weld size (S) - 5/8 r		
Notes: a, g, j, l, m		

BTC-P10-GF

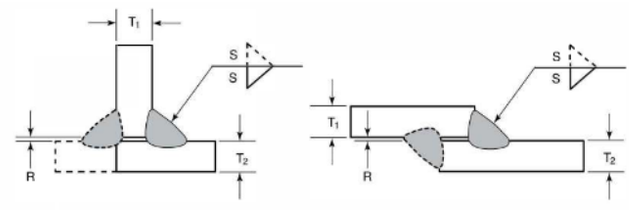
Flare-V-groove weld (11) - Butt joint (B)



GMAW FCAW-G		
Base Metal Thickness		
T_1 = 3/16 min.	T_2 = T_1 min.	
Root opening Root Face Bend Radius	Tolerances	
	As detailed	As Fit-up
R = 0	+1/16, -0	.+1/8, -1/16
f = 3/16 min.	.+U, -0	.+U, -1/16
r = $3T_1/2$ min.	.+U, -0	.+U, -0
Allowed Welding Positions = ALL		
Weld size (S) - 3/4 r		
Notes: e, g, l, m, n		

B-P11-GF

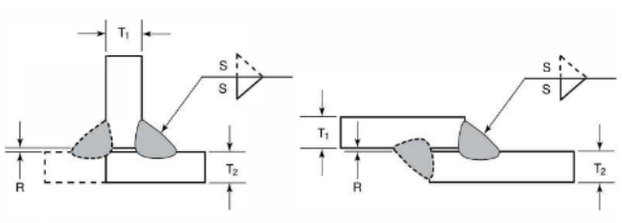
Fillet weld (12) - T-joint (T) - Corner joint (C) - Lap joint (L)



GMAW FCAW		
Base Metal Thickness		
T_1 or T_2 = < 3		
	Tolerances	
Root opening	As detailed	As Fit-up
R = 0	.+1/16, -0	3/16 max.
Allowed Welding Positions = ALL		
TC-F12-GF Notes: a, b, d		
L-F12-GF Notes: a, b, c		

TC-F12-GF - L-F12-GF

Fillet weld (12) - T-joint (T) - Corner joint (C) - Lap joint (L)



GMAW FCAW		
Base Metal Thickness		
T_1 or T_2 = ≥ 3		
	Tolerances	
Root opening	As detailed	As Fit-up
R = 0	.+1/16, -0	5/16 max.
Allowed Welding Positions = ALL		
Notes: a, b, c		

L-F12a-GF

STRUCTURAL STEEL AWS D1.1 & D1.8
WELDING PROCEDURE MANUAL

Title: Welding Procedure Specification (WPS) No.	**FabCOR Edge Xp Hole Repair**	Supporting P.Q.R. #	**Prequalified**

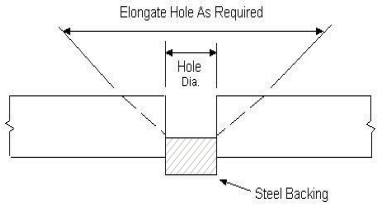
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I or II)
Welding Process:	GMAW Spray Transfer
Manual or Machine:	Semi-Automatic
Position of Weld:	Flat and Horizontal
Filler Metal:	AWS A5.18, AWS A5.28M E70C-6M-H4 / E80C-6M-H4, Hobart FabCOR Edge Xp
Flux:	N/A
Shielding Gas:	75%-95% Argon / 25%-5% CO2, 35 – 50 CFH/Wind Velocity < 5 mph, DC < 3 mph
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants – Grind, chip and wire brush
Preheat and Interpass Temperature:	Min Preheat 32º F, Max Interpass 550º F
Postweld Heat Treatment	Not required
Heat Input Limits 1/16" DIA.	Minimum HI – 29.8 kJ/in Maximum HI – 81.4 kJ/in
Heat Input Limits .045" DIA.	Minimum HI – 24.3 kJ/in Maximum HI – 82.5 kJ/in

Joint Geometry

Welded Restoration of Mislocated Hole

1. This WPS is for use only on mislocated bolt holes that have been approved by an engineer for repair welding.
2. Elongate the first side of the hole enough to allow good fusion throughout the full length and cross-section of the repair weld.
3. Insert steel backing of the same material as the base metal into the hole on the second side.
4. Weld the first side of the hole using longitudinal stringer passes.
5. Gouge the second side to sound metal and weld it complete.
6. Grind both surfaces flush with the base metal.
7. Perform Ultrasonic or Radiographic Testing as specified.

Joint Geometry



Pass No.	Weld Type	Electrode Diameter / CTWD	Welding Current		WFS (in/min)	Travel Speed IPM
			Volts	Amperes		
		Flat and Horizontal				
All	Groove	1/16" DIA. CTWD 7/8"	21 - 27	225 - 275	139 - 170	5.7 – 9.9
All	Groove	1/16" DIA. CTWD 7/8"	22 - 28	270 - 330	184 - 225	7.8 - 13
All	Groove	1/16" DIA. CTWD 7/8"	23 - 31	315 - 385	238 - 291	9.1 – 15.1
All	Groove	1/16" DIA. CTWD 1"	25 - 33	360 - 440	292 - 357	11.7 – 19.5
All	Groove	1/16" DIA. CTWD 1"	27 - 35	450 - 550	450 - 550	18.5 – 30.9
All	Groove	.045" DIA. CTWD 3/4"	20 - 26	180 - 220	216 - 264	5 – 8.25
All	Groove	.045" DIA. CTWD 3/4"	21 – 28	225 - 275	306 - 374	6.7 - 11
All	Groove	.045" DIA. CTWD 3/4"	22 - 30	270 - 330	378 - 462	8.6 – 14.4
All	Groove	.045" DIA. CTWD 7/8"	24 - 32	315 - 385	513 - 627	12.1 – 20.1
All	Groove	.045" DIA. CTWD 7/8"	26 - 34	360 - 440	653 - 797	16.9 – 23.3

Notes -

1 If the root separation is greater than 1/16" between the backing and base metal correction is required.
2 Contact tube to work distance = 3/4" to 1".
3 This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limitation of all mandatory variables given in AWS D1.1.
4 Peening and Caulking is prohibited. The use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
5 Weld Layer thickness, root 5/16" max., fill passes 1/4" max., Single pass fillet 3/8" max./Max. layer width 5/8", 1" for vertical.
6 Plus and Minus variables added per D1.1 Table5.2

Minimum Preheat for Material

Category B	**Category B & C**
≤ 3/4" is 32º F over 3/4" to 1 1/2" is 50º F over 1 1/2" to 2 1/2" is 150º F over 2 1/2" is 225º F	≤ 3/4" is 50º F over 3/4" to 1 1/2" is 150º F over 1 1/2" to 2 1/2" is 225º F over 2 1/2" is 300º F

When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

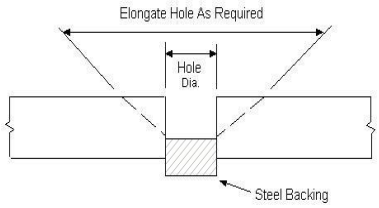
Rev. No.	Date	Description	Status
3	2/19/24	Updated for WPS consolidation	Approved

APPROVED BY:		SIGNED:		Date: 2/19/2024
	Roger R. Davis		Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027 / Daniel S. Christensen CWI 16010023 QC1 EXP. 1/1/2025	

STRUCTURAL STEEL AWS D1.1 & D1.8
WELDING PROCEDURE MANUAL

Title: Welding Procedure Specification (WPS) No.	**FabCO Excel-Arc 71 Hole Repair**	Supporting P.Q.R. #	**Prequalified**

Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I or II)
Welding Process:	FCAW-G
Manual or Machine:	Semi-Automatic
Position of Weld:	All
Filler Metal:	AWS A5.20, AWS A5.20M E71T-1C/M-H8 / E71T-9C/M-H8, Hobart FabCO Excel-Arc 71
Flux:	N/A
Shielding Gas:	100% CO2 35 - 50 CFH - Wind Velocity < 5 mph, DC < 3 mph
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants - Grind, chip and wire brush
Preheat and Interpass Temperature:	Min Preheat 32º F, Max Interpass 550º F
Postweld Heat Treatment	Not required
Heat Input Limits 1/16" DIA.	Minimum HI – 31 kJ/in Maximum HI – 82.5 kJ/in

Joint Geometry	Joint Geometry
Welded Restoration of Mislocated Hole 1. This WPS is for use only on mislocated bolt holes that have been approved by an engineer for repair welding. 2. Elongate the first side of the hole enough to allow good fusion throughout the full length and cross-section of the repair weld. 3. Insert steel backing of the same material as the base metal into the hole on the second side. 4. Weld the first side of the hole using longitudinal stringer passes. 5. Gouge the second side to sound metal and weld it complete. 6. Grind both surfaces flush with the base metal. 7. Perform Ultrasonic or Radiographic Testing as specified.	

Pass No.	Weld Type	Electrode Diameter / CTWD	Welding Current		WFS (in/min)	Travel Speed IPM
			Volts	Amperes		
		All Positions				
All	Groove	1/16" DIA. CTWD 3/4"	20 - 26	162 - 198	117 - 143	3.5 – 5.8
All	Groove	1/16" DIA. CTWD 1"	22 - 27	221 - 269	171 - 209	4.9 – 8.1
All	Groove	1/16" DIA. CTWD 1"	22 - 28	248 - 302	203 - 247	5.2 – 8.7
		Flat & Horizontal				
All	Groove	1/16" DIA. CTWD 1"	23 - 31	252 - 308	216 - 264	5.9 – 11.6
All	Groove	1/16" DIA. CTWD 1"	24 - 32	324 - 396	297 - 363	9 – 15
All	Groove	1/16" DIA. CTWD 1"	26 - 34	360 - 440	387 - 473	12.4 – 20.6

Notes -

1 If the root separation is greater than 1/16" between the backing and base metal correction is required.
2 Contact tube to work distance = 3/4" to 1".
3 This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limitation of all mandatory variables given in AWS D1.1.
4 Peening and Caulking is prohibited. The use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
5 Weld Layer thickness, root 5/16" max., fill passes 1/4" max., Single pass fillet 3/8" max./Max. layer width 5/8", 1" for vertical.
6 Plus and Minus variables added per D1.1 Table5.2

Minimum Preheat for Material

Category B	**Category B & C**
≤ 3/4" is 32º F over 3/4" to 1 1/2" is 50º F over 1 1/2" to 2 1/2" is 150º F over 2 1/2" is 225º F	≤ 3/4" is 50º F over 3/4" to 1 1/2" is 150º F over 1 1/2" to 2 1/2" is 225º F over 2 1/2" is 300º F

When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Rev. No.	Date	Description	Status
3	2/19/24	Updated for WPS consolidation	Approved

APPROVED BY:	SIGNED:	
Roger R. Davis	Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027	Daniel S. Christensen CWI 16010023 QC1 EXP. 1/1/2025
		Date: 2/19/2024

STRUCTURAL STEEL AWS D1.1 & D1.8
WELDING PROCEDURE MANUAL

Title: Welding Procedure Specification (WPS) No.	**FabCO TR-70 Hole Repair**	Supporting P.Q.R. #	**Prequalified**

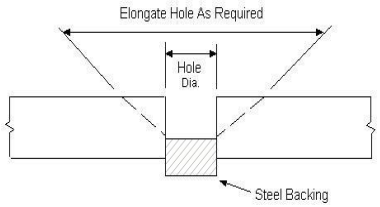
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I or II)
Welding Process:	FCAW-G
Manual or Machine:	Semi-Automatic
Position of Weld:	Flat and Horizontal
Filler Metal:	AWS A5.20, AWS A5.20M E70T-1C H8 / E70T-9C H8, Hobart FabCO TR-70
Flux:	N/A
Shielding Gas:	100% CO2, 35 – 50 CFH/Wind Velocity < 5 mph, DC < 3 mph
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants – Grind, chip and wire brush
Preheat and Interpass Temperature:	Min Preheat 32º F, Max Interpass 550º F
Postweld Heat Treatment	Not required
Heat Input Limits 1/16" DIA.	Minimum HI – 28.5 kJ/in Maximum HI – 75.5 kJ/in
Heat Input Limits 5/64" DIA.	Minimum HI – 31.0 kJ/in Maximum HI – 84.3 kJ/in

Joint Geometry

Welded Restoration of Mislocated Hole

1. This WPS is for use only on mislocated bolt holes that have been approved by an engineer for repairwelding.
2. Elongate the first side of the hole enough to allow good fusion throughout the full length and cross-section of the repair weld.
3. Insert steel backing of the same material as the base metal into the hole on the second side.
4. Weld the first side of the hole using longitudinal stringer passes.
5. Gouge the second side to sound metal and weld it complete.
6. Grind both surfaces flush with the base metal.
7. Perform Ultrasonic or Radiographic Testing as specified.

Joint Geometry



Pass No.	Weld Type	Electrode Diameter / CTWD	Welding Current		WFS (in/min)	Travel Speed IPM
			Volts	Amperes		
		Flat and Horizontal				
All	Groove	1/16" DIA. CTWD 1"	22 - 28	153 - 187	126 - 154	3.97 – 6.62
All	Groove	1/16" DIA. CTWD 1"	23 - 30	180 - 220	153 - 187	4.8 - 8
All	Groove	1/16" DIA. CTWD 1"	23 - 31	234 - 286	189 - 231	5.85 – 9.75
All	Groove	1/16" DIA. CTWD 1"	27 - 36	315 - 385	311 - 379	9.67 – 16.12
All	Groove	5/64" DIA. CTWD 1"	22 - 30	225 - 275	99 - 121	4.87 – 8.12
All	Groove	5/64" DIA. CTWD 1"	22 - 30	270 - 330	126 - 154	6.22 – 10.4
All	Groove	5/64" DIA. CTWD 1"	23 - 31	315 - 385	153 - 187	7.5 – 12.5
All	Groove	5/64" DIA. CTWD 1"	23 - 31	378 - 462	202 - 247	10.1 – 16.8
All	Groove	5/64" DIA. CTWD 1"	27 - 36	495 - 605	310 - 379	15.6 – 26

Notes -

1 If the root separation is greater than 1/16" between the backing and base metal correction is required.
2 Contact tube to work distance = 1" to 1".
3 This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limitation of all mandatory variables given in AWS D1.1.
4 Peening and Caulking is prohibited. The use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
5 Weld Layer thickness, root 5/16" max., fill passes 1/4" max., Single pass fillet 3/8" max./Max. layer width 5/8", 1" for vertical.
6 Plus and Minus variables added per D1.1 Table5.2

Minimum Preheat for Material

Category B	**Category B & C**
≤ 3/4" is 32º F over 3/4" to 1 1/2" is 50º F over 1 1/2" to 2 1/2" is 150º F over 2 1/2" is 225º F	≤ 3/4" is 50º F over 3/4" to 1 1/2" is 150º F over 1 1/2" to 2 1/2" is 225º F over 2 1/2" is 300º F

When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Rev. No.	Date	Description	Status
3	2/19/24	Updated for WPS consolidation	Approved

Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027

Daniel S. Christensen CWI 16010023 QC1 EXP. 1/1/2025

APPROVED BY:	Roger R. Davis	SIGNED:	Date: 2/19/2024

STRUCTURAL STEEL AWS D1.1 & D1.8
WELDING PROCEDURE MANUAL

Title: Welding Procedure Specification (WPS) No.	**FabCO 811N1 Hole Repair**	Supporting P.Q.R. #	**Prequalified**

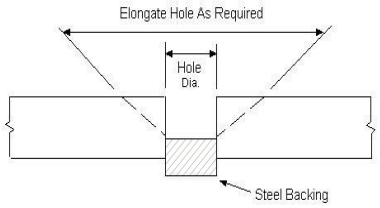
Material Specification:	Group I & II Material in Table 5.3 AWS D1.1 (also Group III to Group I or II)
Welding Process:	FCAW-G
Manual or Machine:	Semi-Automatic
Position of Weld:	All
Filler Metal:	AWS A5.29 - E81T1-Ni1 CJ H4, E81T1-Ni1 MJ H4 - Hobart FabCO 811N1
Flux:	N/A
Shielding Gas:	100% CO2 35 - 50 CFH - Wind Velocity < 5 mph, DC < 3 mph
Welding Current:	DCEP (CV Output)
Root Treatment:	Clean to remove all contaminants - Grind, chip and wire brush
Preheat and Interpass Temperature:	Min Preheat 32º F, Max Interpass 550º F
Postweld Heat Treatment	Not required
Heat Input Limits 1/16" DIA.	Minimum HI – 28.9 kJ/in Maximum HI – 80.5 kJ/in

Joint Geometry

Welded Restoration of Mislocated Hole

1. This WPS is for use only on mislocated bolt holes that have been approved by an engineer for repair welding.
2. Elongate the first side of the hole enough to allow good fusion throughout the full length and cross-section of the repair weld.
3. Insert steel backing of the same material as the base metal into the hole on the second side.
4. Weld the first side of the hole using longitudinal stringer passes.
5. Gouge the second side to sound metal and weld it complete.
6. Grind both surfaces flush with the base metal.
7. Perform Ultrasonic or Radiographic Testing as specified.

Joint Geometry



Pass No.	Weld Type	Electrode Diameter / CTWD	Welding Current		WFS (in/min)	Travel Speed IPM
			Volts	Amperes		
		All Positions				
All	Groove	1/16" DIA. CTWD 3/4"	21 – 27	135 - 165	108 – 132	3 – 5
All	Groove	1/16" DIA. CTWD 3/4"	22 – 28	180 - 220	140 – 170	4.3 – 7.1
All	Groove	1/16" DIA. CTWD 1"	22 – 30	225 – 275	198 – 242	5.7 – 9.5
		Flat and Horizontal Positions				
All	Groove	1/16" DIA. CTWD 1"	23 - 31	270 - 330	252 - 308	7.6 – 12.7

Notes -

1 If the root separation is greater than 1/16" between the backing and base metal correction is required.
2 Contact tube to work distance = 3/4" to 1".
3 This procedure may vary due to fabrication sequence, fit-up, pass size, etc… within the limitation of all mandatory variables given in AWS D1.1.
4 Peening and Caulking is prohibited. The use of pneumatic hand tools to remove slag and spatter shall not be considered peening.
5 Weld Layer thickness, root 5/16" max., fill passes 1/4" max., Single pass fillet 3/8" max./Max. layer width 5/8", 1" for vertical.
6 Plus and Minus variables added per D1.1 Table5.2

Minimum Preheat for Material

Category B	**Category B & C**
≤ 3/4" is 32º F over 3/4" to 1 1/2" is 50º F over 1 1/2" to 2 1/2" is 150º F over 2 1/2" is 225º F	≤ 3/4" is 50º F over 3/4" to 1 1/2" is 150º F over 1 1/2" to 2 1/2" is 225º F over 2 1/2" is 300º F

When the base metal temperature is below 32°F, the base metal shall be preheated to a minimum of 70°F and maintained.

Rev. No.	Date	Description	Status
3	2/19/24	Initial Issue	Approved

Roger R. Davis CWI 24011831 QC1 EXP. 1/1/2027

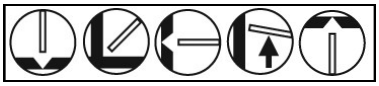
Daniel S. Christensen CWI 16010023 QC1 EXP. 1/1/2025

APPROVED BY:	Roger R. Davis	SIGNED:	Date: 2-19-2024

FabCO® 811N1

AWS A5.29: E81T1-Ni1CJ H4, E81T1-Ni1MJ H4

WELDING POSITIONS:



FEATURES:

- Fast-freezing slag
- Nominal 1% nickel deposit
- Excellent impact toughness
- Low-hydrogen deposit
- Low spatter and excellent slag removal

BENEFITS:

- Excellent out-of-position performance
- Suitable to replacement to E8018-C3 stick (SMAW) electrodes
- Resists cracking in severe applications
- Assists in minimizing the risk of hydrogen-induced cracking
- Improves operator appeal, reduces clean-up time

APPLICATIONS:

- High-strength low-alloy steels
- Single and multi-pass welding
- Weathering steels (ASTM A588, A709, etc.)
- Bridge fabrication
- Heavy equipment fabrication
- Structural fabrication
- Shipbuilding

SLAG SYSTEM: Fast-freezing, rutile-type, flux-cored wire

SHIELDING GAS: 100% Carbon Dioxide (CO_2), 75-80% Argon (Ar)/Balance Carbon Dioxide (CO_2), 35-50 cfh (17-24 l/min)

TYPE OF CURRENT: Direct Current Electrode Positive (DCEP)

STANDARD DIAMETERS: 0.045" (1.2 mm), 1/16" (1.6 mm)

RE-DRYING: Not recommended

STORAGE: Product should be stored in a dry, enclosed environment, and in its original intact packaging

TYPICAL WELD METAL CHEMISTRY* (Chem Pad):

Weld Metal Analysis (%)	100% CO_2	75% Ar/25% CO_2	AWS Spec
Carbon (C)	0.03	0.06	0.12
Manganese (Mn)	1.09	1.39	1.50
Phosphorus (P)	0.007	0.009	0.030
Sulphur (S)	0.005	0.008	0.030
Silicon (Si)	0.32	0.53	0.80
Nickel (Ni)	1.01	1.00	0.80-1.10

Note: AWS specification single values are maximums.

TYPICAL DIFFUSIBLE HYDROGEN*:

Hydrogen Equipment	100% CO_2	75% Ar/25% CO_2	AWS Spec
(GAS CHROMATOGRAPHY)	2.4 ml/100g	3.0 ml/100g	4.0 ml/100g Maximum

TYPICAL MECHANICAL PROPERTIES* (As Welded):

Mechanical Tests	100% CO_2	75% Ar/25% CO_2	AWS Spec
Tensile Strength	83,000 psi (572 MPa)	93,000 psi (641 MPa)	80,000-100,000 psi (552-689 MPa)
Yield Strength	73,000 psi (503 MPa)	85,000 psi (586 MPa)	68,000 psi (470 MPa) Minimum
Elongation % in 2" (50 mm)	26%	25%	19% Minimum

TYPICAL CHARPY V-NOTCH IMPACT VALUES* (As Welded):

CVN Temperatures	100% CO_2	75% Ar/25% CO_2	AWS Spec
CVN @-40°F (-40°C)	65 ft•lbs (88 Joules)	40 ft•lbs (54 Joules)	20 ft•lbs (27 Joules) Minimum "J" Requirement

*The information contained or otherwise referenced herein is presented only as "typical" without guarantee or warranty, and Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Typical data are those obtained when welded and tested in accordance with the AWS A5.29 specification. Other tests and procedures may produce different results. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers LLC.

Hobart Brothers LLC • 101 Trade Square East • Troy, OH 45373
PH: (800) 424-1543 • FX: 800-541-6607 • www.hobartbrothers.com

FabCO® 811N1

Diameter Inches	(mm)	Weld Position	Amps	Volts	Wire Feed Speed in/min	(m/min)	Deposition Rate lbs/hr	(kg/hr)	Contact Tip to Work Distance Inches	(mm)
0.045	(1.2)	All Position	100	17	120	(3.81)	1.6	(0.7)	5/8	(16)
0.045	(1.2)	All Position	125	24	200	(5.1)	2.0	(0.9)	5/8	(16)
0.045	(1.2)	All Position	200	26	390	(9.9)	7.0	(3.2)	5/8	(16)
0.045	(1.2)	All Position	225	27	455	(11.6)	8.8	(4.0)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	250	28	530	(13.5)	10.0	(4.5)	3/4	(19)
1/16	(1.6)	All Position	150	24	120	(3.0)	4.0	(1.8)	3/4	(19)
1/16	(1.6)	All Position	200	25	155	(3.9)	5.7	(2.6)	3/4	(19)
1/16	(1.6)	All Position	250	26	220	(5.6)	7.6	(3.4)	1	(25)
1/16	(1.6)	Flat & Horizontal	300	27	280	(7.1)	10.2	(4.6)	1	(25)

- **Maintaining a proper welding procedure - including pre-heat and interpass temperatures - may be critical depending on the type and thickness of steel being welded.**
- The above information was determined by welding using 100% CO_2 shielding gas with a flow rate between 35-50 cfh (17-24 l/min). When welding using 75% Argon (Ar)/25% Carbon Dioxide (CO_2) shielding gas, decrease voltage by 1-2 volts.
- All positions include: Flat, Horizontal, Vertical Up, and Overhead.
- 100 Amp parameters for 1/8” plate thickness and lower.

STANDARD DIAMETERS AND PACKAGES: For a complete list of diameters and packaging, please contact Hobart Brothers at (800) 424-1543 or (937) 332-5188 for International Customer Service.

Diameter Inches	(mm)	33-lb. (15kg) Spool	50-lb. (22.6kg) Spool	60-lb. (27.2kg) Coil
Net Pallet Weight		**2376-lb (1078kg)**	**1600-lb (726kg)**	**1920-lb (871kg)**
0.045	(1.2)	S283612-029	—	—
1/16	(1.6)	S283619-029	S283619-027	S283619-002

CONFORMANCE AND APPROVALS:
- **AWS A5.29,** E81T1-Ni1CJ H4, E81T1-Ni1MJ H4
- **AWS A5.29M,** E551T1-Ni1CJ H4, E551T1-Ni1MJ H4

TECHNICAL QUESTIONS? For technical support of Hobart Filler Metals products, contact the Applications Engineering department by phone toll-free at 1-800-532-2618 or by e-mail at Applications.Engineering@hobartbrothers.com

CAUTION:
Consumers should be thoroughly familiar with the safety precautions on the warning label posted in each shipment and in the American National Standard Z49.1, “Safety in Welding and Cutting,” published by the American Welding Society, 8669 NW 36th St., Miami, FL 33166 (can also be downloaded online at www.aws.org); OSHA Safety and Health Standards 29 CFR 1910 is available from the U.S. Department of Labor, Washington, D.C. 20210

Safety Data Sheets on any Hobart Brothers LLC product may be obtained from Hobart Customer Service or at www.hobartbrothers.com.

Because Hobart Brothers LLC is constantly improving products, Hobart reserves the right to change design and/or specifications without notice.

FabCO and Hobart are registered trademarks of Hobart Brothers LLC, Troy, Ohio.

Revision Date: 230222 (Replaces **220407**)

HOBART FILLER METALS

Product: FabCO 811N1
Diameter: 1/16”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E81T1-Ni1 MJ H4
Specification: AWS A5.29/A5.29M:2010
Test Completed: 12/19/2022

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot- # C003240601463	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.4 kJ/in	28.9 kJ/in	Mechanical Properties		78.4 kJ/in	28.9 kJ/in
Voltage	25	23	Test Reference #		PD7580	PD7734
Current (amps)	230	220				
WFS (ipm)	170	170				
Travel Speed (ipm)	4.4	10.5	Tensile Strength (psi)	80,000	90,000	104,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	68,000	78,000	97,000
# of passes	8	20	Elongation (%)	19	25	20
# of layers	5	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	117	92
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # Z026471824041	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.5 kJ/in	30.4 kJ/in	Mechanical Properties		80.5 kJ/in	30.4 kJ/in
Voltage	25	23	Test Reference #		PD2728	PD2727
Current (amps)	220	220				
WFS (ipm)	170	170				
Travel Speed (ipm)	4.1	10	Tensile Strength (psi)	80,000	100,000	113,000
Stick Out	3/4“	3/4”	Yield Strength (psi)	68,000	87,000	108,000
# of passes	9	21	Elongation (%)	19	24	21
# of layers	5	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	111	77
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # F05959	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.5 kJ/in	29.0 kJ/in	Mechanical Properties		79.5 kJ/in	29.0 kJ/in
Voltage	25	23	Test Reference #		PE4814	PE4813
Current (amps)	222	223				
WFS (ipm)	180	180				
Travel Speed (ipm)	4.18	10.7	Tensile Strength (psi)	80,000	91,100	108,000
Stick Out	1/2"-5/8“	3/4“	Yield Strength (psi)	68,000	73,500	103,000
# of passes	9	21	Elongation (%)	19	25	21
# of layers	5	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	134	93
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.29/A5.29M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	G02493	HB6005	3.7 (ml/100g)
7 Day Exposure	G02493	HB6403	7.3 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets ("SDS").



James Owens, Quality Assurance Specialist

HOBART FILLER METALS

Certificate of Conformance to Requirements for Welding Electrode

Product Type:	**FabCO 811N1**
Classification:	**E81T1-Ni1CJ H4; E81T1-Ni1MJ H4**
Specifications:	**AWS A5.29/A5.29M; ASME SFA 5.29**
Diameter Tested:	**1/16"**
Date Tested:	**1/12/2024**
Date Generated:	**1/29/2024**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001, ANSI/AWS A5.01, and other specification and Military requirements, as applicable. This document supplies actual test results of non-specific inspection in conformance with the requirements of EN 10204, type 2.2 certification.

THE STEEL USED IN THIS LOT OF MATERIAL WAS MELTED AND MANUFACTURED IN THE U.S.A.

Test Settings

Shielding Medium	Amps / Polarity	Volts	WFS in/min(m/min)	ESO in(mm)	Preheat F(C)	Interpass F(C)	Travel Speed in/min(cm/min)
M21-ArC-25	260-290 / DCEP	27	250 (6.4)	3/4 (19)	300(149)	300(149)	10.7 (27.2)
C1	260-290 / DCEP	27	250 (6.4)	3/4 (19)	300(149)	300(149)	10.8 (27.4)

Mechanical Properties - Tensile

Shielding Medium	Ref. No.	Testing Conditions	Ult. Tensile Strength psi (MPa)	Yield Strength psi (MPa)	Elong.% in 2"
C1	PE7390	Aged 48 Hrs 220F	86,000 (590)	78,000 (536)	27
M21-ArC-25	PE7414	Aged 48 Hrs 220F	98,000 (674)	87,000 (599)	24

Mechanical Properties - Impact

Shielding Medium	Ref. No.	Testing Conditions	Temp. F (C)	Individuals ft.lb.(J)	Avg. ft.lb.(J)	Type
M21-ArC-25	PE7387	As Welded	-40 (-40)	58,70,52 (79,95,70)	60 (81)	Charpy-V-Notch
C1	PE7390	As Welded	-40 (-40)	116,118,115 (157,160,156)	116 (158)	Charpy-V-Notch

Ref.No.	Radiographic Inspection	Fillet Weld Test					
PE7387	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms
PE7390	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms

Chemical Analysis

Shielding Medium / Ref. No	C	Mn	P	S	Si	Cu	Cr	V	Ni	Mo	Al	Ti	Nb	Co	B	W	Sn	Fe	Sb	N	Mg	Zn	Be	Sb	As
M21-ArC-25 / PE7387	0.05	1.64	0.009	0.006	0.37	0.01	0.04	0.02	0.97	< .01	< .01				0.0056										
C1 / PE7390	0.05	1.36	0.009	0.006	0.24	0.01	0.04	0.02	0.92	< .01	< .01				0.0043										

Diffusible Hydrogen Collected per AWS A4.3

M21-ArC-25	3.0 ml/100g of weld metal for 1/16 in diameter 17% relative humidity
C1	3.9 ml/100g of weld metal for 1/16 in diameter 21.9% relative humidity

James A. Owens, Q.A. Specialist

Certification and Limited Warranty - Data for the above supplied product are those obtained when welded and tested in accordance with the above specification. All tests for the above classification were satisfied. Other tests and procedures may produce different results.

FabCOR® Edge™ XP

AWS A5.18: E70C-6M H4
AWS A5.28: E80C-G H4
EN ISO 17632-A: T46 3 M M21 H5

WELDING POSITIONS:



FEATURES:

- Higher deposition rates and efficiencies than solid wires.
- Smooth arc Characteristics
- Formulation specifically addresses silicon island formation and distribution when welding scale-free base metal.
- Excellent bead appearance and contour when welding over mill scale.

BENEFITS

- Allows for improved welding travel speeds and productivity.
- Provides good operator appeal and produces welds with uniform appearance.
- Reduces time spent on post-weld silicon removal in preparation for paint/coating application or other weld passes.
- Helps minimize the need for pre-weld cleaning.

APPLICATIONS:

- Automatic and mechanized welding
- Semi-automatic welding
- Truck and trailer fabrication
- Non-alloyed and fine grain steels
- Structural steel fabrication
- Rail cars
- Earthmoving equipment
- Agricultural equipment
- General fabrication

WIRE TYPE: Gas-shielded, metal-powder, metal cored wire
SHIELDING GAS: 75-95% Argon (Ar)/Balance Carbon Dioxide (CO_2), 35-50 cfh (19-24 l/min)
TYPE OF CURRENT: Direct Current Electrode Positive (DCEP)
STANDARD DIAMETERS: 0.035” (0.9), 0.045” (1.2 mm), 0.052” (1.4 mm), 1/16” (1.6 mm)
RE-DRYING: Not Recommended
STORAGE: Product should be stored in a dry, enclosed environment and in its original intact packaging

TYPICAL WELD METAL CHEMICAL COMPOSITION* (Chem Pad):

Weld Metal Analysis (%)	75% Ar/25% CO_2	90% Ar/10% CO_2	95% Ar/5% CO_2	AWS Spec.
Carbon (C)	0.04	0.04	0.04	0.12
Manganese (Mn)	1.43	1.52	1.62	1.75
Silicon (Si)	0.62	0.72	0.77	0.90
Sulphur (S)	0.009	0.010	0.011	0.030
Phosphorus (P)	0.006	0.008	0.008	0.030

Note: AWS Specification single values are maximums

TYPICAL WELD METAL DIFFUSIBLE HYDROGEN*:

Hydrogen Equipment	75% Ar/25% CO_2	90% Ar/10% CO_2	95% Ar/5% CO_2	AWS Spec.
(GAS CHROMOTOGRAPHY)	2.8 ml/100 g	2.8 ml/100 g	2.9 ml/100 g	4.0 ml/100 g Maximum

TYPICAL MECHANICAL PROPERTIES (As Welded)*:

Mechanical Tests	75% Ar/25% CO_2	90% Ar/10% CO_2	95% Ar/5% CO_2	AWS Spec.
Tensile Strength	85,000 psi (586 MPa)	87,000 psi (600 MPa)	90,000 psi (634 MPa)	70,000 psi (480 MPa) Min.
Yield Strength	73,000 psi (503 MPa)	75,000 psi (517 MPa)	81,000 psi (558 MPa)	58,000 psi (400 MPa) Min.
Elongation % in 2” (50 mm)	28%	28%	25%	22% Minimum

TYPICAL CHARPY V-NOTCH IMPACT VALUES* (As Welded):

CVN Temperatures	75% Ar/25% CO_2	90% Ar/10% CO_2	95% Ar/5% CO_2	AWS Spec.
Avg. @ -20°F (-30°C)	40 ft-lbs (54 Joules)	36 ft-lbs (49 Joules)	30 ft-lbs (41 Joules)	20 ft-lbs (27 Joules)

*The information contained or otherwise referenced herein is presented only as “typical” without guarantee or warranty, and Hobart Brothers Company expressly disclaims any liability incurred from any reliance thereon. Typical data are those obtained when welded and tested in accordance with the AWS A5.18 specification. Other tests and procedures may produce different results. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers LLC.

Hobart Brothers LLC • 101 Trade Square East • Troy, OH 45373
PH: (800) 424-1543 • FX: 800-541-6607 • www.hobartbrothers.com

FabCOR® Edge™ XP

Typical Operating Parameters*:

Diameter		Weld Position	Amps	Volts	Wire Feed Speed		Deposition Rate		Contact Tip to Work Distance	
Inches	(mm)				in/min	(m/min)	lbs/hr	(kg/hr)	Inches	(mm)
0.035	(0.9)	Flat & Horizontal	150	24	320	(8.1)	4.6	(2.1)	1/2	(13)
0.035	(0.9)	Flat & Horizontal	200	26	450	(11.4)	6.9	(3.1)	1/2	(13)
0.035	(0.9)	Flat & Horizontal	250	29	590	(15.0)	9.2	(4.2)	1/2	(13)
0.045	(1.2)	Flat & Horizontal	200	23	240	(6.1)	6.6	(3.0)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	250	25	340	(8.6)	8.9	(4.0)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	300	26	420	(10.7)	11.5	(5.2)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	350	28	570	(14.5)	16.1	(7.3)	7/8	(22)
0.045	(1.2)	Flat & Horizontal	400	30	725	(18.4)	20.1	(9.1)	7/8	(22)
0.052	(1.4)	Flat & Horizontal	200	23	190	(4.8)	6.9	(3.1)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	250	24	240	(6.1)	9.1	(4.1)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	300	26	320	(8.1)	11.4	(5.2)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	350	28	405	(10.3)	14.6	(6.6)	7/8	(22)
0.052	(1.4)	Flat & Horizontal	400	30	515	(13.1)	19.2	(8.7)	7/8	(22)
1/16	(1.6)	Flat & Horizontal	250	24	155	(3.9)	7.6	(3.4)	7/8	(22)
1/16	(1.6)	Flat & Horizontal	300	25	205	(5.2)	10.4	(4.7)	7/8	(22)
1/16	(1.6)	Flat & Horizontal	350	27	265	(6.7)	12.1	(5.5)	7/8	(22)
1/16	(1.6)	Flat & Horizontal	400	29	325	(8.3)	15.6	(7.1)	1	(25)
1/16	(1.6)	Flat & Horizontal	500	31	500	(12.7))	24.7	(11/2)	1	(25)

- **Maintaining a proper welding procedure - including pre-heat and interpass temperatures - may be critical depending on the type and thickness of the steel being welded.**
- **For out of position welding, short circuit or pulsed spray transfer mode must be used.** Pulse waveforms are designed with nominal operating points that may result in average voltage and current values that differ from the table above. Generally, pulse processes can be expected to produce lower heat inputs than a standard CV process.
- **See Above:** This information was determined by welding using 90% Ar/10% CO2 shielding gas with a flow rate between 35-50 cfh (17-24 l/min). When welding using 75% Ar/25% CO_2 shielding gas, increase voltage by 1-3 volts.

Available Diameters and Packages: For a complete list of diameters and packaging, please contact Hobart Brothers at (800) 424-1543 or (937) 332-5188

Diameter		33-lb. (15kg) Spool	50-lb. (22.7kg) Spool	500-lb. (226.8kg) X-Pak	1000-lb. (453.6kg) Recyclable X-Pak
Inches	(mm)				
Net Pallet Weight		2376-lb (1078 kg)	1600-lb (726 kg)	2000-lb (907 kg)	2000-lb. (907 kg)
0.035	(0.9)	S250608-029	S250608-029	—	—
0.045	(1.2)	S250612-029	S250612-027	S250612-050	S250612-058
0.052	(1.4)	S250615-029	S250615-027	S250615-050	S250615-058
1/16	(1.6)	S250619-029	S250619-027	—	S250619-058

Conformances And Approvals

- **AWS A5.18,** E70C-6M H4
- **AWS A5.18M,** E49C-6M H4
- **AWS A5.28,** E80C-G H4
- **AWS A5.28M,** E55C-G H4
- **ASME SFA 5.18,** E70C-6M H4
- **CWB,** E491T15-(M12, M20, M21)A3-CS1-H4
- **EN ISO 17632-A,** T46 3 M M21 H5
- **AWS D1.8,** See Approval Certificate for Details [0.045" (1.2 mm) - 1/16" (1.6 mm) diameters]
- **CE Marked** per CPR 305/2011 (1.2 mm - 1.6 mm diameter electrodes)

Technical Questions? For technical support of Hobart Filler Metals products, contact the Applications Engineering department by phone toll-free at 1-800-532-2618 or by e-mail at Applications.Engineering@HobartBrothers.com

Caution:

Consumers should be thoroughly familiar with the safety precautions on the warning label posted in each shipment and in the American National Standard Z49.1, "Safety in Welding and Cutting," published by the American Welding Society, 8669 NW 36 St, Miami, FL 33166-6672 (can also be downloaded online at www.aws.org); OSHA Safety and Health Standards 29 CFR 1910 is available from the U.S. Department of Labor, Washington, D.C. 20210

Safety Data Sheets on any Hobart Brothers LLC product may be obtained from Hobart Customer Service or at www.hobartbrothers.com.

Because Hobart Brothers Company is constantly improving products, Hobart reserves the right to change design and/or specifications without notice.

Edge is a trademark of Hobart Brothers Company, Troy Ohio.
Hobart and FabCOR are registered trademarks of Hobart Brothers LLC, Troy, Ohio.

Revision Date: 230616 (Replaces 221010)

HOBART FILLER METALS

HOBART FILLER METALS

Certificate of Conformance to Requirements for Welding Electrode

Product Type:	**FabCOR Edge XP**
Classification:	**E70C-6M H4, E80C-G H4**
Specifications:	**AWS A5.18, A5.28; SFA 5.18, 5.28**
Diameter Tested:	**1/16**
Date Tested:	**02/23/2023**
Date Generated:	**3/21/2023**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001, ANSI/AWS A5.01, and other specification and Military requirements, as applicable. This document supplies actual test results of non-specific inspection in conformance with the requirements of EN 10204, type 2.2 certification.

THE STEEL USED IN THIS LOT OF MATERIAL WAS MELTED AND MANUFACTURED IN THE U.S.A.

Test Settings

Shielding Medium	Amps / Polarity	Volts	WFS in/min(m/min)	ESO in(mm)	Preheat F(C)	Interpass F(C)	Travel Speed in/min(cm/min)
M21-ArC-25	325 / DCEP	29	240 (6.1)	3/4 (19)	Room Temp	300(149)	14 (35.6)
M20-ArC-10	325 / DCEP	27	240 (6.1)	3/4 (19)	Room Temp	300(149)	14 (35.6)
M12-ArC-5	325 / DCEP	26	240 (6.1)	3/4 (19)	Room Temp	300(149)	14 (35.6)

Mechanical Properties - Tensile

Shielding Medium	Ref. No.	Testing Conditions	Ult. Tensile Strength psi (MPa)	Yield Strength psi (MPa)	Elong.% in 2"
M21-ArC-25	PE5718	Aged 48 Hrs 220F	77,000 (528)	65,000 (447)	30
M20-ArC-10	PE5721	Aged 48 Hrs 220F	80,000 (555)	70,000 (485)	29
M12-ArC-5	PE5726	Aged 48 Hrs 220F	83,000 (570)	70,000 (483)	29

Mechanical Properties - Impact

Shielding Medium	Ref. No.	Testing Conditions	Temp. F (C)	Individuals ft.lb.(J)	Avg. ft.lb.(J)	Type
M21-ArC-25	PE5718	As Welded	-20 (-29)	16,40,42 (22,54,57)	33 (44)	Charpy-V-Notch
M20-ArC-10	PE5721	As Welded	-20 (-29)	31,17,20 (42,23,27)	23 (31)	Charpy-V-Notch
M12-ArC-5	PE5726	As Welded	-20 (-29)	43,42,45 (58,57,61)	43 (59)	Charpy-V-Notch

Ref.No.	Radiographic Inspection	Fillet Weld Test					
PE5718	Conforms	Horizontal :		Overhead :		Vertical :	
PE5721	Conforms	Horizontal :		Overhead :		Vertical :	
PE5726	Conforms	Horizontal :		Overhead :		Vertical :	

Chemical Analysis

Shielding Medium / Ref. No	C	Mn	P	S	Si	Cu	Cr	V	Ni	Mo	Al	Ti	Nb	Co	B	W	Sn	Fe	Sb	N	Mg	Zn	Be	Sb	As
M21-ArC-25 / PE5718	0.04	1.28	0.012	0.011	0.59	0.06	0.05	< .01	0.03	0.01		0.010			0.0007										
M20-ArC-10 / PE5721	0.03	1.48	0.013	0.011	0.73	0.05	0.05	< .01	0.03	0.01		0.014			0.0007										
M12-ArC-5 / PE5726	0.03	1.60	0.012	0.010	0.80	0.05	0.04	< .01	0.02	0.01		0.018			0.0009										

Diffusible Hydrogen Collected per AWS A4.3

M20-ArC-10	3.3 ml/100g of weld metal for 1/16 in diameter 15% relative humidity
M12-ArC-5	3.3 ml/100g of weld metal for 1/16 in diameter 15% relative humidity
M21-ArC-25	2.0 ml/100g of weld metal for 1/16 in diameter 15% relative humidity

James A. Owens, Q.A. Specialist

Certification and Limited Warranty - Data for the above supplied product are those obtained when welded and tested in accordance with the above specification. All tests for the above classification were satisfied. Other tests and procedures may produce different results.

Product: FabCOR Edge XP
Diameter: .045”
Shielding Gas: M20-ArC-10
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 4/21/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# D670911005	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.8 kJ/in	27.8 kJ/in	Mechanical Properties		78.8 kJ/in	27.8 kJ/in
Voltage	27	25.5	Test Reference #		PE2254	PE2257
Current (amps)	350	280				
WFS (ipm)	575	385				
Travel Speed (ipm)	7.2	15.4	Tensile Strength (psi)	70,000	81,000	88,600
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	65,900	77,400
# of passes	8	16	Elongation (%)	22	27	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	97	92
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F62327	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	81.1 kJ/in	29.8 kJ/in	Mechanical Properties		81.1 kJ/in	29.8 kJ/in
Voltage	27	25.5	Test Reference #		PE2212	PE2210
Current (amps)	350	280				
WFS (ipm)	560	385				
Travel Speed (ipm)	7.0	14.44	Tensile Strength (psi)	70,000	77,600	84,500
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	60,800	72,500
# of passes	6	16	Elongation (%)	22	30	28
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	80	68
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# D608031003121	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	81.1 kJ/in	29.9 kJ/in	Mechanical Properties		81.1 kJ/in	29.9 kJ/in
Voltage	27	25.5	Test Reference #		PE2194	PE2195
Current (amps)	350	285				
WFS (ipm)	560	385				
Travel Speed (ipm)	7.0	14.35	Tensile Strength (psi)	70,000	74,800	82,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	59,700	71,000
# of passes	6	17	Elongation (%)	22	30	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	92	79
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	D670911005	HB4803	1.5 (ml/100g)
7 Day Exposure	D670911005	HB4828	3.0 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCOR Edge XP
Diameter: .045”
Shielding Gas: M20-ArC-15
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 10/20/2022

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot- # G63488	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	72.0 kJ/in	24.3 kJ/in	Mechanical Properties		72.0 kJ/in	24.3 kJ/in
Voltage	28.6	31	Test Reference #		PE4852	PE4856
Current (amps)	315	285				
WFS (ipm)	565	480				
Travel Speed (ipm)	6.7	16.5	Tensile Strength (psi)	70,000	78,000	88,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	61,900	77,000
# of passes	6	18	Elongation (%)	22	29	25
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	64	78
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # G62855	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.9 kJ/in	24.9 kJ/in	Mechanical Properties		79.9 kJ/in	24.9 kJ/in
Voltage	27	26	Test Reference #		PE4862	PE4861
Current (amps)	315	285				
WFS (ipm)	575	390				
Travel Speed (ipm)	6.7	16.35	Tensile Strength (psi)	70,000	80,000	89,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	64,000	79,000
# of passes	6	17	Elongation (%)	22	28	25
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	74	89
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # G63517	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	75.3 kJ/in	25.8 kJ/in	Mechanical Properties		81.1 kJ/in	25.8 kJ/in
Voltage	27	25.5	Test Reference #		PE4870	PE4869
Current (amps)	340	250				
WFS (ipm)	575	480				
Travel Speed (ipm)	7.37	15.72	Tensile Strength (psi)	70,000	78,000	84,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	62,000	72,000
# of passes	6	18	Elongation (%)	22	29	27
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	69	90
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	G63488	HB6248	1.7 (ml/100g)
7 Day Exposure	G63488	HB6249	2.7 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

James Owens, Quality Assurance Specialist

Product: FabCOR Edge XP
Diameter: .045”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 5/4/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# D670911005	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	81.6 kJ/in	27.5 kJ/in	Mechanical Properties		81.6 kJ/in	27.5 kJ/in
Voltage	28	26	Test Reference #		PE2252	PE2261
Current (amps)	340	270				
WFS (ipm)	560	400				
Travel Speed (ipm)	7.0	15.3	Tensile Strength (psi)	70,000	79,100	85,500
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	62,600	74,100
# of passes	8	16	Elongation (%)	22	29	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	88	78
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F62327	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	82.5 kJ/in	29.2 kJ/in	Mechanical Properties		82.5 kJ/in	29.2 kJ/in
Voltage	28	26	Test Reference #		PE2211	PE2209
Current (amps)	350	275				
WFS (ipm)	560	370				
Travel Speed (ipm)	7.14	14.83	Tensile Strength (psi)	70,000	76,300	82,200
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	59,900	71,500
# of passes	6	18	Elongation (%)	22	29	27
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	71	54
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# D608031003121	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.6 kJ/in	29.0 kJ/in	Mechanical Properties		78.6 kJ/in	29.0 kJ/in
Voltage	28	26	Test Reference #		PE2356	PE2193
Current (amps)	345	275				
WFS (ipm)	560	370				
Travel Speed (ipm)	7.42	14.84	Tensile Strength (psi)	70,000	74,800	80,800
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	61,100	68,400
# of passes	7	18	Elongation (%)	22	32	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	89	70
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	D670911005	HB4802	0.7 (ml/100g)
7 Day Exposure	D670911005	HB4816	1.9 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCOR Edge XP
Diameter: .052”
Shielding Gas: M20-ArC-10
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 4/22/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# F624251201	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.4 kJ/in	28.2 kJ/in	Mechanical Properties		80.4 kJ/in	28.2 kJ/in
Voltage	29.5	26	Test Reference #		PE2262	PE2253
Current (amps)	350	275				
WFS (ipm)	415	265				
Travel Speed (ipm)	7.7	15.2	Tensile Strength (psi)	70,000	75,900	83,300
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	59,800	71,800
# of passes	6	16	Elongation (%)	22	31	26
# of layers	3	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	103	76
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# D670121202031	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.3 kJ/in	29.4 kJ/in	Mechanical Properties		79.3 kJ/in	29.4 kJ/in
Voltage	27	25	Test Reference #		PE2229	PE2227
Current (amps)	375	275				
WFS (ipm)	420	270				
Travel Speed (ipm)	7.68	14.1	Tensile Strength (psi)	70,000	76,100	85,700
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	61,500	75,100
# of passes	7	17	Elongation (%)	22	33	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	107	82
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# D607821203031	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.7 kJ/in	29.5 kJ/in	Mechanical Properties		78.7 kJ/in	29.5 kJ/in
Voltage	27	26	Test Reference #		PE2106	PE1903
Current (amps)	375	275				
WFS (ipm)	415	265				
Travel Speed (ipm)	7.85	14.65	Tensile Strength (psi)	70,000	77,500	86,800
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	61,300	75,700
# of passes	7	16	Elongation (%)	22	30	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	70	78
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F624251201	HB4804	1.7 (ml/100g)
7 Day Exposure	F624251201	HB4828	3.8 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCOR Edge XP
Diameter: .052”
Shielding Gas: M20-ArC-15
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 5/17/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# F62931	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.2 kJ/in	29.6 kJ/in	Mechanical Properties		80.2 kJ/in	29.6 kJ/in
Voltage	27.5	25.5	Test Reference #		PE2286	PE2287
Current (amps)	375	275				
WFS (ipm)	420	270				
Travel Speed (ipm)	7.72	14.34	Tensile Strength (psi)	70,000	72,500	80,400
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	58,500	68,600
# of passes	7	18	Elongation (%)	22	32	27
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	84	64
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# D670121202031	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.0 kJ/in	29.2 kJ/in	Mechanical Properties		80.0 kJ/in	29.2 kJ/in
Voltage	27.5	25.5	Test Reference #		PE2276	PE2275
Current (amps)	375	275				
WFS (ipm)	420	275				
Travel Speed (ipm)	7.74	14.47	Tensile Strength (psi)	70,000	75,200	82,600
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	59,500	70,700
# of passes	7	18	Elongation (%)	22	30	27
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	95	81
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F624251201	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.4 kJ/in	29.7 kJ/in	Mechanical Properties		79.4 kJ/in	29.7 kJ/in
Voltage	29.5	27	Test Reference #		PE2294	PE2263
Current (amps)	350	275				
WFS (ipm)	415	270				
Travel Speed (ipm)	7.8	15.0	Tensile Strength (psi)	70,000	74,200	82,400
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	58,600	71,100
# of passes	7	17	Elongation (%)	22	30	27
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	67	84
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F624251201	HB4813	1.6 (ml/100g)
30 Day Exposure	F624251201	HB4868	2.9 (ml/100g)
45 Day Exposure	F624251201	HB4863	2.9 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCOR Edge XP
Diameter: .052”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 4/23/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# D670121201031	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	81.2 kJ/in	29.5 kJ/in	Mechanical Properties		81.2 kJ/in	29.5 kJ/in
Voltage	29.5	27	Test Reference #		PE2228	PE2226
Current (amps)	350	275				
WFS (ipm)	410	270				
Travel Speed (ipm)	7.65	15.2	Tensile Strength (psi)	70,000	71,800	82,900
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	57,600	72,300
# of passes	7	17	Elongation (%)	22	32	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	102	71
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F624251201	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.4 kJ/in	28.7 kJ/in	Mechanical Properties		78.4 kJ/in	28.7 kJ/in
Voltage	29.5	27	Test Reference #		PE2200	PE2198
Current (amps)	350	275				
WFS (ipm)	410	265				
Travel Speed (ipm)	7.9	15.5	Tensile Strength (psi)	70,000	72,600	81,200
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	58,100	69,800
# of passes	6	17	Elongation (%)	22	31	26
# of layers	3	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	81	51
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# D607821203031	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.0 kJ/in	30.4 kJ/in	Mechanical Properties		79.0 kJ/in	30.4 kJ/in
Voltage	29.5	27	Test Reference #		PE1871	PE1901
Current (amps)	350	275				
WFS (ipm)	410	265				
Travel Speed (ipm)	7.92	14.72	Tensile Strength (psi)	70,000	76,400	84,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	61,400	71,800
# of passes	7	17	Elongation (%)	22	30	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	60	53
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F624251201	HB4805	1.0 (ml/100g)
7 Day Exposure	F624251201	HB4827	1.8 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCOR Edge XP
Diameter: .052”
Shielding Gas: Ozoline C8
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 11/19/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# F64777	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	77.3 kJ/in	29.5 kJ/in	Mechanical Properties		77.3 kJ/in	29.5 kJ/in
Voltage	29	26	Test Reference #		PE3175	PE3176
Current (amps)	350	300				
WFS (ipm)	410	300				
Travel Speed (ipm)	7.89	15.91	Tensile Strength (psi)	70,000	73,000	85,000
Stick Out	1”	3/4”	Yield Strength (psi)	58,000	58,000	74,000
# of passes	7	15	Elongation (%)	22	30	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	56	68
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F65403	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.5 kJ/in	29.7 kJ/in	Mechanical Properties		78.5 kJ/in	29.7 kJ/in
Voltage	29	26	Test Reference #		PE3189	PE3190
Current (amps)	350	300				
WFS (ipm)	410	300				
Travel Speed (ipm)	7.92	15.83	Tensile Strength (psi)	70,000	76,000	88,000
Stick Out	1”	1”	Yield Strength (psi)	58,000	60,000	77,000
# of passes	7	15	Elongation (%)	22	33	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	65	88
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F64916	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	77.0 kJ/in	30.1 kJ/in	Mechanical Properties		77.0 kJ/in	30.1 kJ/in
Voltage	29	26	Test Reference #		PE3191	PE3192
Current (amps)	350	300				
WFS (ipm)	410	300				
Travel Speed (ipm)	7.92	15.59	Tensile Strength (psi)	70,000	75,000	86,000
Stick Out	1”	1”	Yield Strength (psi)	58,000	60,000	76,000
# of passes	7	15	Elongation (%)	22	32	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	81	70
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F64916	HB5277	4.0 (ml/100g)
7 Day Exposure	F64916	HB5278	6.0 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCOR Edge XP
Diameter: 1/16”
Shielding Gas: M20-ArC-10
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 5/12/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# D607811301251	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.9 kJ/in	31.3 kJ/in	Mechanical Properties		78.9 kJ/in	31.3 kJ/in
Voltage	26.5	26	Test Reference #		PE1982	PE1981
Current (amps)	375	300				
WFS (ipm)	295	220				
Travel Speed (ipm)	7.64	15.51	Tensile Strength (psi)	70,000	80,100	90,400
Stick Out	3/4”	7/8”	Yield Strength (psi)	58,000	63,800	78,300
# of passes	7	17	Elongation (%)	22	31	25
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	83	78
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F623171301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.3 kJ/in	30.8 kJ/in	Mechanical Properties		80.3 kJ/in	30.8 kJ/in
Voltage	26.5	30	Test Reference #		PE2339	PE2299
Current (amps)	375	350				
WFS (ipm)	295	200				
Travel Speed (ipm)	7.45	15.0	Tensile Strength (psi)	70,000	73,400	79,400
Stick Out	3/4”	7/8”	Yield Strength (psi)	58,000	58,500	67,000
# of passes	7	16	Elongation (%)	22	31	27
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	80	67
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F62351	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	81.4 kJ/in	29.8 kJ/in	Mechanical Properties		81.4 kJ/in	29.8 kJ/in
Voltage	26.5	26	Test Reference #		PE2387	PE2372
Current (amps)	375	300				
WFS (ipm)	295	220				
Travel Speed (ipm)	7.38	15.7	Tensile Strength (psi)	70,000	75,300	85,400
Stick Out	1”	1”	Yield Strength (psi)	58,000	59,800	73,800
# of passes	7	17	Elongation (%)	22	30	27
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	85	79
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F62351	HB4810	1.4 (ml/100g)
7 Day Exposure	F62351	HB4825	2.6 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCOR Edge XP
Diameter: 1/16”
Shielding Gas: M20-ArC-15
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 5/12/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# D607811301251	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.8 kJ/in	30.3 kJ/in	Mechanical Properties		79.8 kJ/in	30.3 kJ/in
Voltage	27	26.5	Test Reference #		PE2291	PE2292
Current (amps)	360	285				
WFS (ipm)	276	195				
Travel Speed (ipm)	7.32	15.02	Tensile Strength (psi)	70,000	75,900	85,100
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	59,500	72,900
# of passes	7	17	Elongation (%)	22	34	27
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	99	94
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F623171301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.6 kJ/in	30.6 kJ/in	Mechanical Properties		80.6 kJ/in	30.6 kJ/in
Voltage	27	26.5	Test Reference #		PE2344	PE2358
Current (amps)	360	285				
WFS (ipm)	275	191				
Travel Speed (ipm)	7.24	14.85	Tensile Strength (psi)	70,000	72,400	78,600
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	58,600	65,700
# of passes	7	17	Elongation (%)	22	32	27
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	74	87
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F62351	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.0 kJ/in	30.3 kJ/in	Mechanical Properties		78.0 kJ/in	30.3 kJ/in
Voltage	27	26.5	Test Reference #		PE2385	PE2384
Current (amps)	360	285				
WFS (ipm)	275	191				
Travel Speed (ipm)	7.52	15.0	Tensile Strength (psi)	70,000	73,600	80,300
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	59,400	68,900
# of passes	7	17	Elongation (%)	22	30	27
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	77	82
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F62351	HB4807	0.8 (ml/100g)
7 Day Exposure	F62351	HB4823	2.8 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCOR Edge XP
Diameter: 1/16”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 5/13/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# D607811301251	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.2 kJ/in	31.1 kJ/in	Mechanical Properties		80.2 kJ/in	31.1 kJ/in
Voltage	28	27	Test Reference #		PE1979	PE1980
Current (amps)	350	275				
WFS (ipm)	272	195				
Travel Speed (ipm)	7.35	14.35	Tensile Strength (psi)	70,000	76,300	84,100
Stick Out	3/4”	7/8”	Yield Strength (psi)	58,000	61,500	72,300
# of passes	7	16	Elongation (%)	22	32	29
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	89	78
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F623171301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.9 kJ/in	30.5 kJ/in	Mechanical Properties		79.9 kJ/in	30.5 kJ/in
Voltage	28	26.5	Test Reference #		PE2346	PE2352
Current (amps)	350	275				
WFS (ipm)	265	195				
Travel Speed (ipm)	7.37	14.35	Tensile Strength (psi)	70,000	71,200	81,400
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	57,900	68,600
# of passes	7	18	Elongation (%)	22	33	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	65	74
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F62351	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	81.8 kJ/in	29.8 kJ/in	Mechanical Properties		81.8 kJ/in	29.8 kJ/in
Voltage	28	26.5	Test Reference #		PE2381	PE2388
Current (amps)	350	285				
WFS (ipm)	255	191				
Travel Speed (ipm)	7.2	14.73	Tensile Strength (psi)	70,000	71,200	80,700
Stick Out	7/8”	3/4”	Yield Strength (psi)	58,000	58,100	69,600
# of passes	7	17	Elongation (%)	22	33	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	98	71
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F62351	HB4809	1.3 (ml/100g)
7 Day Exposure	F62351	HB4824	2.9 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCOR Edge XP
Diameter: 1/16”
Shielding Gas: Ozoline C8
Current/Polarity: DCEP
Classification: E70C-6M H4
Specification: AWS A5.18/A5.18M:2017
Test Completed: 11/19/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# F63663	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.3 kJ/in	30.0 kJ/in	Mechanical Properties		80.3 kJ/in	30.0 kJ/in
Voltage	26.5	25	Test Reference #		PE3194	PE3195
Current (amps)	360	300				
WFS (ipm)	275	205				
Travel Speed (ipm)	7.16	15.01	Tensile Strength (psi)	70,000	75,000	84,000
Stick Out	1”	1”	Yield Strength (psi)	58,000	60,000	72,000
# of passes	7	15	Elongation (%)	22	30	27
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	98	98
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F62317	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.8 kJ/in	30.1 kJ/in	Mechanical Properties		79.8 kJ/in	30.1 kJ/in
Voltage	26.5	25	Test Reference #		PE3208	PE3209
Current (amps)	360	300				
WFS (ipm)	275	205				
Travel Speed (ipm)	7.19	14.99	Tensile Strength (psi)	70,000	77,000	85,000
Stick Out	1”	1”	Yield Strength (psi)	58,000	61,000	72,000
# of passes	7	15	Elongation (%)	22	31	26
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	82	108
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# F62899	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.9 kJ/in	30.0 kJ/in	Mechanical Properties		78.9 kJ/in	30.0 kJ/in
Voltage	26.5	25	Test Reference #		PE3215	PE3216
Current (amps)	360	300				
WFS (ipm)	275	205				
Travel Speed (ipm)	7.29	15.09	Tensile Strength (psi)	70,000	76,000	86,000
Stick Out	1”	1”	Yield Strength (psi)	58,000	62,000	75,000
# of passes	7	15	Elongation (%)	22	31	25
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	72	77
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.18/A5.18M, Clause 15 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F62899	HB5279	3.1 (ml/100g)
7 Day Exposure	F62899	HB5280	4.6 (ml/100g)

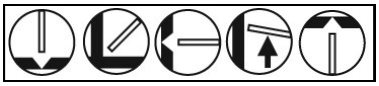
The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

FabCO®Excel-Arc™ 71

AWS A5.20: E71T-1C H8, E71T-1M H8, E71T-9C H8, E71T-9M H8
EN ISO 17632-A: T46 3 P C1 2 H10, T46 3 P M21 2 H10

WELDING POSITIONS:



FEATURES:

- Fast-freezing slag
- Low fumes and spatter
- Easy slag removal
- Able to bridge poor fit-up without burn-through
- Good impact toughness

BENEFITS:

- Excellent out-of-position capability
- Increases welder appeal and productivity
- Reduces clean-up time, minimizes risk of inclusions
- Increases productivity, reduces part rework/rejection
- Resists cracking in severe applications

APPLICATIONS:

- Non-alloyed and fine grain steels
- Single and multi-pass welding
- Structural fabrication
- General Fabrication
- Heavy equipment

SLAG SYSTEM: Fast-freezing, rutile-type, flux-cored wire

SHIELDING GAS: 100% Carbon Dioxide (CO_2), 75-80% Argon (Ar)/Balance Carbon Dioxide (CO_2), 35-50 cfh (17-24 l/min)

TYPE OF CURRENT: Direct Current Electrode Positive (DCEP)

STANDARD DIAMETERS: 0.035" (0.9 mm), 0.045" (1.2 mm), 0.052" (1.4 mm), 1/16" (1.6 mm)

RE-DRYING: Not recommended

STORAGE: Product should be stored in a dry, enclosed environment, and in its original intact packaging

TYPICAL WELD METAL CHEMISTRY* (Chem Pad):

Weld Metal Analysis (%)	100% CO_2	75% Ar/25% CO_2	AWS Spec
Carbon (C)	0.021	0.022	0.12
Manganese (Mn)	1.30	1.60	1.75
Silicon (Si)	0.69	0.82	0.90
Sulphur (S)	0.011	0.010	0.03
Phosphorus (P)	0.015	0.014	0.03

Note: AWS specification single values are maximums.

TYPICAL DIFFUSIBLE HYDROGEN*:

Hydrogen Equipment	100% CO_2	75% Ar/25% CO_2	AWS Spec
(GAS CHROMATOGRAPHY)	3.8 ml/100g	4.8 ml/100g	8.0 ml/100g Maximum

TYPICAL MECHANICAL PROPERTIES* (As Welded):

Mechanical Tests	100% CO_2	75% Ar/25% CO_2	AWS Spec
Tensile Strength	84,000 psi (579 MPa)	90,000 psi (619 MPa)	70,000-95,000 psi (490-670 MPa)
Yield Strength	77,000 psi (531 MPa)	83,000 psi (571 MPa)	58,000 psi (390 MPa) Minimum
Elongation % in 2" (50 mm)	28%	26%	22% Minimum

CVN Temperatures	100% CO_2	75% Ar/25% CO_2	AWS Spec
Avg. at 0°F (-20°C)	101 ft•lbs (137 Joules)	91 ft•lbs (123 Joules)	20 ft•lbs (27 Joules) Minimum
Avg. at -20°F (-30°C)	48 ft•lbs (65 Joules)	72 ft•lbs (98 Joules)	20 ft•lbs (27 Joules) Minimum

*The information contained or otherwise referenced herein is presented only as "typical" without guarantee or warranty, and Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Typical data are those obtained when welded and tested in accordance with AWS A5.20 specification. Other tests and procedures may produce different results. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers LLC.

Hobart Brothers LLC • 101 Trade Square East • Troy, OH 45373
PH: (800) 424-1543 • FX: 800-541-6607 • www.hobartbrothers.com

FabCO® Excel-Arc™ 71

Diameter Inches	(mm)	Weld Position	Amps	Volts	Wire-Feed Speed in/min	(m/min)	Deposition Rate lbs/hr	(kg/hr)	Contact Tip to Work Distance Inches	(mm)
0.035	(0.9)	All Position	125	23	330	(8.4)	3.8	(1.7)	1/2	(13)
0.035	(0.9)	All Position	150	24	410	(10.4)	4.7	(2.1)	1/2	(13)
0.035	(0.9)	All Position	175	25	545	(13.5)	6.3	(2.9)	1/2	(13)
0.035	(0.9)	Flat & Horizontal	200	26	645	(16.4)	7.6	(3.4)	1/2	(13)
0.035	(0.9)	Flat & Horizontal	225	28	785	(19.9)	9.4	(4.3)	1/2	(13)
0.045	(1.2)	All Position	170	23	260	(6.6)	4.4	(2.0)	5/8	(16)
0.045	(1.2)	All Position	185	24	310	(7.9)	6.1	(2.7)	5/8	(16)
0.045	(1.2)	All Position	200	25	340	(7.7)	6.2	(2.8)	5/8	(16)
0.045	(1.2)	All Position	220	25	380	(9.7)	7.5	(3.4)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	260	27	500	(12.7)	8.9	(4.0)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	300	29	590	(15.0)	12.3	(5.6)	3/4	(19)
0.052	(1.4)	All Position	170	24	190	(4.8)	5.0	(2.3)	3/4	(19)
0.052	(1.4)	All Position	200	25	210	(5.3)	5.6	(2.5)	3/4	(19)
0.052	(1.4)	All Position	250	26	275	(7.0)	7.5	(3.4)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	260	27	320	(8.1)	8.1	(3.7)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	300	28	380	(9.6)	9.5	(4.3)	1	(25)
0.052	(1.4)	Flat & Horizontal	350	30	570	(14.5)	14.4	(6.5)	1	(25)
1/16	(1.6)	All Position	180	23	130	(4.1)	4.6	(2.1)	3/4	(19)
1/16	(1.6)	All Position	245	25	190	(4.8)	6.5	(3.0)	1	(25)
1/16	(1.6)	All Position	275	26	225	(5.7)	7.8	(3.5)	1	(25)
1/16	(1.6)	Flat & Horizontal	280	27	240	(6.0)	9.3	(4.2)	1	(25)
1/16	(1.6)	Flat & Horizontal	360	28	330	(8.4)	12.0	(5.4)	1	(25)
1/16	(1.6)	Flat & Horizontal	400	30	430	(10.9)	16.5	(7.5)	1	(25)

- **Maintaining a proper welding procedure - including pre-heat and interpass temperatures - may be critical depending on the type and thickness of steel being welded.**
- **See Above:** This information was determined by welding using 100% CO_2 shielding gas with a flow rate between 35-50 cfh (17-24 l/min). When using 75% Ar/25% CO_2 shielding gas, reduce voltage by 1 volt.
- **All positions include:** Flat, Horizontal, Vertical Up, and Overhead.

Standard Diameters And Packages: For a complete list of diameters and packaging, please contact Hobart Brothers at (800) 424-1543 or (937) 332-5188 for International Customer Service.

Diameter Inches	(mm)	15-lb. (7kg) Spool	33-lb. (15kg) Spool	44-lb. (20kg) Spool	50-lb. (22.7kg) Spool	60-lb. (27.2kg) Coil	500-lb. (227kg) Exacto-Pak	600-lb. (272kg) Drum
Net Pallet Weight		2400 lbs (1089 kg)	2376 lbs (1078 kg)	2376 lbs (1078 kg)	1600 lbs (726 kg)	1920 lbs (871 kg)	2000 lbs (907 kg)	2400 lbs (1089 kg)
0.035	(0.9)	—	S247108-029	—	—	—	—	—
0.045	(1.2)	S247112-023	S247112-029	S247112-044	—	S247112-002	S247112-050	—
0.052	(1.4)	S247115-023	S247115-029	—	S247115-027	—	—	S247115-056
1/16	(1.6)	—	S247119-029	S247119-044	S247119-027	S247119-002	—	S247119-056

Conformances and Approvals:
- **AWS A5.20,** E71T-1C H8, E71T-1M H8, E71T-9C H8, E71T-9M H8
- **AWS A5.20M,** E491T-1C H8, E491T-1M H8, E491T-9C H8, E491T-9M H8
- **ASME SFA 5.20,** E71T-1C H8, E71T-1M H8, E71T-9C H8, E71T-9M H8
- **ABS,** 100% CO_2 3YSA H10, 75% Ar/25% CO_2, 3YSA H10 (0.045" - 1/16" diameter electrodes)
- **Burea Veritas,** 100% CO_2, S3YM HH (0.045" - 1/16" diameter electrodes)
- **CWB,** 100% CO_2 E491T-9-H8, 75-80% Ar/Balance CO_2, E491T-9M-H8 (1.2 mm - 1.6 mm diameter electrodes)
- **CWB,** E491T1-(C1A3, M20A3, M21A3, GA3)-CS1-H8 (E491T-9-H8, E491T-9M-H8)
- **DNV-GL,** 100% CO_2, III YMS(H10)
- **EN ISO 17632-A:** T46 3 P C1 2 H10, T46 3 P M21 2 H10
- **CE Marked** per CPR 305/2011
- **Lloyd's Register,** 100% CO_2, 3YS H10
- **AWS D1.8/D1.8M,** 100% CO_2 & 75% Ar/25% CO_2, (0.045" [1.2 mm] & 1/16" [1.6 mm] diameter electrodes)

Technical Questions? For technical support of Hobart Filler Metals products, contact the Applications Engineering department by phone toll-free at 1-800-532-2618 or by e-mail at Applications.Engineering@hobartbrothers.com

Caution:
Consumers should be thoroughly familiar with the safety precautions on the warning label posted in each shipment and in the American National Standard Z49.1, "Safety in Welding and Cutting," published by the American Welding Society, 8669 NW 36th St., Miami, FL 33166 (can also be downloaded online at www.aws.org); OSHA Safety and Health Standards 29 CFR 1910 is available from the U.S. Department of Labor, Washington, D.C. 20210

Safety Data Sheets on any Hobart Brothers LLC product may be obtained from Hobart Customer Service or at www.hobartbrothers.com.

Because Hobart Brothers LLC is constantly improving products, Hobart reserves the right to change design and/or specifications without notice.

Hobart and FabCO are registered trademarks of Hobart Brothers LLC, Troy, Ohio.

Excel-Arc is a trademark of Hobart Brothers LLC, Troy, Ohio.

Revision Date: 230629 (Replaces 230427)
636-Y, INDEX

HOBART FILLER METALS

Certificate of Conformance to Requirements for Welding Electrode

Product Type:	**FabCO Excel-Arc 71**
Classification:	**E71T-1C, E71T-1M, E71T-9C, E71T-9M H8**
Specifications:	**AWS A5.20/A5.20M; ASME SFA 5.20**
Diameter Tested:	**.045"**
Date Tested:	**4/10/2023**
Date Generated:	**12/6/2023**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001, ANSI/AWS A5.01, and other specification and Military requirements, as applicable. This document supplies actual test results of non-specific inspection in conformance with the requirements of EN 10204, type 2.2 certification.

THE STEEL USED IN THIS LOT OF MATERIAL WAS MELTED AND MANUFACTURED IN THE U.S.A.

Test Settings

Shielding Medium	Amps / Polarity	Volts	WFS in/min(m/min)	ESO in(mm)	Preheat F(C)	Interpass F(C)	Travel Speed in/min(cm/min)
M21-ArC-25	275 / DCEP	27	540 (13.7)	5/8 (16)	Room Temp	300(149)	11 (27.9)
C1 (100% CO2)	275 / DCEP	28	540 (13.7)	5/8 (16)	Room Temp	300(149)	11 (27.9)

Mechanical Properties - Tensile

Shielding Medium	Ref. No.	Testing Conditions	Ult. Tensile Strength psi (MPa)	Yield Strength psi (MPa)	Elong.% in 2"
C1 (100% CO2)	PE6052	Aged 48 Hrs 220F	87,000 (599)	83,000 (572)	27
M21-ArC-25	PE6065	Aged 48 Hrs 220F	93,000 (643)	88,000 (605)	26

Mechanical Properties - Impact

Shielding Medium	Ref. No.	Testing Conditions	Temp. F (C)	Individuals ft.lb.(J)	Avg. ft.lb.(J)	Type
M21-ArC-25	PE6046	As Welded	0 (-18)	63,69,79 (85,94,107)	70 (95)	Charpy-V-Notch
M21-ArC-25	PE6046	As Welded	-20 (-29)	60,59,53 (81,80,72)	57 (78)	Charpy-V-Notch
C1 (100% CO2)	PE6052	As Welded	0 (-18)	107,104,97 (145,141,132)	103 (139)	Charpy-V-Notch
C1 (100% CO2)	PE6052	As Welded	-20 (-29)	89,89,84 (121,121,114)	87 (118)	Charpy-V-Notch

Ref.No.	Radiographic Inspection	Fillet Weld Test					
PE6046	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms
PE6052	Conforms	Horizontal :		Overhead :	Conforms	Vertical :	Conforms

Chemical Analysis

Shielding Medium / Ref. No	C	Mn	P	S	Si	Cu	Cr	V	Ni	Mo	Al	Ti	Nb	Co	B	W	Sn	Fe	Sb	N	Mg	Zn	Be	Sb	As
M21-ArC-25 / PE6046	0.02	1.57	0.009	0.008	0.80	0.03	0.05	0.02	0.01	< .01					0.0048										
C1 (100% CO2) / PE6052	0.02	1.41	0.009	0.008	0.70	0.03	0.04	0.02	0.01	< .01					0.0048										

Diffusible Hydrogen Collected per AWS A4.3

M21-ArC-25	7.6 ml/100g of weld metal for .045 in diameter 41% relative humidity
C1	6.5 ml/100g of weld metal for .045 in diameter 44% relative humidity

James A. Owens, Q.A. Specialist

Certification and Limited Warranty - Data for the above supplied product are those obtained when welded and tested in accordance with the above specification. All tests for the above classification were satisfied. Other tests and procedures may produce different results.

Product: FabCO Excel-Arc 71
Diameter: .045”
Shielding Gas: C1 (100% CO2)
Current/Polarity: DCEP
Classification: E71T-1 H8, E71T-9 H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 6/23/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# F000852301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	84.4 kJ/in	26.7 kJ/in	Mechanical Properties		84.4 kJ/in	26.7 kJ/in
Voltage	25	26	Test Reference #		PE2544	PE2551
Current (amps)	225	250				
WFS (ipm)	380	450				
Travel Speed (ipm)	4	14.6	Tensile Strength (psi)	70,000	80,400	93,100
Stick Out	3/4“	3/4“	Yield Strength (psi)	58,000	69,900	87,000
# of passes	8	20	Elongation (%)	22	27	22
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	116	106
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# B611752703191	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.4 kJ/in	27.9 kJ/in	Mechanical Properties		80.4 kJ/in	27.9 kJ/in
Voltage	25	26	Test Reference #		PD6265	P6266
Current (amps)	225	250				
WFS (ipm)	385	450				
Travel Speed (ipm)	4.2	14	Tensile Strength (psi)	70,000	80,920	89,800
Stick Out	3/4“	3/4“	Yield Strength (psi)	58,000	72,700	83,500
# of passes	8	20	Elongation (%)	22	28	23
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	122	109
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# S609122403191	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.4 kJ/in	27.9 kJ/in	Mechanical Properties		79.4 kJ/in	27.9 kJ/in
Voltage	25	27	Test Reference #		PB6426	PB6175
Current (amps)	225	250				
WFS (ipm)	385	450				
Travel Speed (ipm)	4.25	14.5	Tensile Strength (psi)	70,000	81,500	93,800
Stick Out	1/2“-3/4“	1/2"-3/4“	Yield Strength (psi)	58,000	70,200	89,300
# of passes	6	17	Elongation (%)	22	29	24
# of layers	4	8	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	121	105
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F000852301	HB4844	3.5 (ml/100g)
7 Day Exposure	F000852301	HB4861	7.8 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCO Excel-Arc 71
Diameter: .045”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E71T-1M H8, E71T-9M H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 6/23/2021

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named herein is of the same classification, manufacturing process, and material requirements as the material used for the tests completed on the date shown, the results of which are recorded below. All tests required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality Management System of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot-# F000852301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	82.3 kJ/in	26.8 kJ/in	Mechanical Properties		82.3 kJ/in	26.8 kJ/in
Voltage	25	25	Test Reference #		PE2546	PE2555
Current (amps)	225	250				
WFS (ipm)	380	450				
Travel Speed (ipm)	4.1	14	Tensile Strength (psi)	70,000	82,500	98,900
Stick Out	3/4“	3/4“	Yield Strength (psi)	58,000	72,000	95,500
# of passes	8	20	Elongation (%)	22	27	22
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	127	107
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# B614611305181	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.4 kJ/in	28.4 kJ/in	Mechanical Properties		80.4 kJ/in	28.4 kJ/in
Voltage	25	26.5	Test Reference #		PD6466	PD6465
Current (amps)	225	250				
WFS (ipm)	385	460				
Travel Speed (ipm)	4.2	14	Tensile Strength (psi)	70,000	90,500	99,400
Stick Out	3/4“	3/4“	Yield Strength (psi)	58,000	79,000	93,900
# of passes	8	18	Elongation (%)	22	32	23
# of layers	4	8	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	120	81
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot-# X613682106211	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	82.3 kJ/in	27.8 kJ/in	Mechanical Properties		82.3 kJ/in	27.8 kJ/in
Voltage	25	26	Test Reference #		PC6755	PC6757
Current (amps)	225	250				
WFS (ipm)	385	450				
Travel Speed (ipm)	4.1	14	Tensile Strength (psi)	70,000	90,400	104,000
Stick Out	1/2“-3/4“	1/2"-3/4“	Yield Strength (psi)	58,000	75,700	98,200
# of passes	6	17	Elongation (%)	22	26	24
# of layers	3	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	107	105
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F000852301	HB4843	5.9 (ml/100g)
7 Day Exposure	F000852301	HB4860	7.2 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Please refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets.

David A. Thomas, Quality Specialist

Product: FabCO Excel-Arc 71
Diameter: .052”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E71T-1M; E71T-9M H8
Specification: AWS A5.20/A5.20M:2010
Test Completed: 3/16/2020

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot- # D600272902291	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.8 kJ/in	32.4 kJ/in	Mechanical Properties		78.8 kJ/in	32.4 kJ/in
Voltage	24.5	26	Test Reference #		PD9213	PD9216
Current (amps)	225	260				
WFS (ipm)	240	330				
Travel Speed (ipm)	4.2	12.5	Tensile Strength (psi)	70,000	82,000	95,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	72,000	89,000
# of passes	8	19	Elongation (%)	22	29	25
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @			
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF	40	125	102
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # A602452905221	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	81.0 kJ/in	29.0 kJ/in	Mechanical Properties		78.8 kJ/in	28.8 kJ/in
Voltage	24.5	26	Test Reference #		PC3161	PC3166
Current (amps)	225	260				
WFS (ipm)	245	360				
Travel Speed (ipm)	4.1	14.1	Tensile Strength (psi)	70,000	88,000	104,000
Stick Out	5/8”	3/4”	Yield Strength (psi)	58,000	77,000	99,000
# of passes	7	19	Elongation (%)	22	25	22
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @			
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF	40	122	74
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # W606483003182	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	81.0 kJ/in	29.0 kJ/in	Mechanical Properties		81.0 kJ/in	29.0 kJ/in
Voltage	24.5	26	Test Reference #		PC3073	PC3032
Current (amps)	225	260				
WFS (ipm)	245	365				
Travel Speed (ipm)	4.1	14	Tensile Strength (psi)	70,000	90,000	103,000
Stick Out	5/8“	3/4“	Yield Strength (psi)	58,000	74,000	99,000
# of passes	7	18	Elongation (%)	22	28	22
# of layers	4	6	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @			
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF	40	107	116
Weld Position	3G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	D600272902291	HB4023	4.6 (ml/100g)
7 Day Exposure	D600272902291	HB4037	7.0 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC ("Hobart") expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart. Please refer to the Hobart Brothers Company website at www.hobartbrothers.com for current Safety Data Sheets ("SDS").

David A. Thomas, Quality Assurance Representative

Product: FabCO Excel-Arc 71
Diameter: 1/16”
Shielding Gas: C1 (100% CO2)
Current/Polarity: DCEP
Classification: E71T-1 C/M, E71T-9 C/M H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 9/26/2022

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot- # C604351904291	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.8 kJ/in	31.0 kJ/in	Mechanical Properties		78.8 kJ/in	31.0 kJ/in
Voltage	24	26	Test Reference #		PD7581	PD7733
Current (amps)	230	282				
WFS (ipm)	170	240				
Travel Speed (ipm)	4.2	13.9	Tensile Strength (psi)	70,000	83,000	86,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	73,000	82,000
# of passes	8	17	Elongation (%)	22	26	25
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @ +70 ºF	40	144	111
Interpass Temp. ºF	500+/-50	200+/-25				
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # Z601232203162	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	82.5 kJ/in	31.0 kJ/in	Mechanical Properties		82.5 kJ/in	31.0 kJ/in
Voltage	28	27	Test Reference #		PD2034	PD2033
Current (amps)	275	279				
WFS (ipm)	235	240				
Travel Speed (ipm)	4.0	15	Tensile Strength (psi)	70,000	72,600	83,100
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	63,400	76,200
# of passes	7	21	Elongation (%)	22	31	25
# of layers	4	8	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @ +70 ºF	40	197	134
Interpass Temp. ºF	500+/-50	200+/-25				
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # F04119	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.7 kJ/in	31.2 kJ/in	Mechanical Properties		79.7 kJ/in	31.2 kJ/in
Voltage	24	27	Test Reference #		PE4413	PE4416
Current (amps)	220	290				
WFS (ipm)	170	245				
Travel Speed (ipm)	4.02	14.8	Tensile Strength (psi)	70,000	71,400	82,700
Stick Out	5/8“	3/4“	Yield Strength (psi)	58,000	62,700	77,000
# of passes	7	17	Elongation (%)	22	31	25
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @ +70 ºF	40	116	115
Interpass Temp. ºF	500+/-50	200+/-25				
Weld Position	3G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	C600301902292	HB6002	6.7 (ml/100g)
7 Day Exposure	C600301902292	HB6100	7.9 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets ("SDS").



James Owens, Quality Assurance Spec

Product: FabCO Excel-Arc 71
Diameter: 1/16”
Shielding Gas: M21-ArC-25
Current/Polarity: DCEP
Classification: E71T-1M H8, E71T-9M H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 9/27/2022

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot- # C604351904291	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	78.8 kJ/in	31.0 kJ/in	Mechanical Properties		78.8 kJ/in	31.0 kJ/in
Voltage	24	25.5	Test Reference #		PD7581	PD7733
Current (amps)	230	282				
WFS (ipm)	170	240				
Travel Speed (ipm)	4.2	13.9	Tensile Strength (psi)	70,000	83,000	90,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	73,000	82,000
# of passes	8	17	Elongation (%)	22	26	24
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	144	126
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # Z601232203162	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.2 kJ/in	31.0 kJ/in	Mechanical Properties		79.2 kJ/in	31.0 kJ/in
Voltage	24	25.5	Test Reference #		PD1878	PD1876
Current (amps)	220	282				
WFS (ipm)	170	230				
Travel Speed (ipm)	4.0	13.9	Tensile Strength (psi)	70,000	84,000	94,000
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	72,000	84,000
# of passes	8	19	Elongation (%)	22	30	24
# of layers	4	8	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	128	126
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # F04119	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	79.4 kJ/in	30.6 kJ/in	Mechanical Properties		79.4 kJ/in	30.6 kJ/in
Voltage	24.5	25.6	Test Reference #		PE4417	PE4418
Current (amps)	225	289				
WFS (ipm)	170	245				
Travel Speed (ipm)	4.03	14.3	Tensile Strength (psi)	70,000	78,100	89,000
Stick Out	3/4“	3/4“	Yield Strength (psi)	58,000	66,900	84,100
# of passes	8	17	Elongation (%)	22	30	25
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	122	134
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	3G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F04119	HB6003	7.0 (ml/100g)
7 Day Exposure	F04119	HB6025	10.3 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets ("SDS").



James Owens, Quality Assurance Specialist

FabCO® TR-70

AWS A5.20: E70T-1C H8, E70T-9C H8

WELDING POSITIONS:



FEATURES:	BENEFITS:
• Low fume generation rate	• Provides cleaner work environment, enhances welder appeal
• High deposition rates	• Increases productivity, more parts per hour
• Flat bead profile with fillet welds	• Assists in producing high-quality welds
• Easy slag removal	• Reduces clean-up time, excellent for deep groove applications
• Smooth stable arc, tolerant to changes in stick-out	• Assists in compensating for gaps and producing welds of uniform appearance and quality
• Weld deposit with low diffusible hydrogen and good impact toughness	• Minimizes risk of cracking in restrained joints, thick sections, and critical applications
• Very flexible amperage/voltage range	• Promotes versatility

APPLICATIONS:

- Earthmoving equipment
- Steel structures
- Non-alloyed and fine grain steels
- Heavy fabrication
- Storage vessels
- Rail cars

SLAG SYSTEM: Slow freezing, rutile-type, flux-cored wire

SHIELDING GAS: 100% Carbon Dioxide (CO_2), 35-50 cfh (17-24 l/min)

TYPE OF CURRENT: Direct Current Electrode Positive (DCEP)

STANDARD DIAMETERS: 0.045” (1.2 mm), 1/16” (1.6 mm), 5/64” (2.0 mm), 3/32” (2.4 mm)

RE-DRYING: Not recommended

STORAGE: Product should be stored in a dry, enclosed environment, and in its original intact packaging

TYPICAL WELD METAL CHEMISTRY* (Chem Pad):

Weld Metal Analysis	100% CO_2	AWS Spec
Carbon (C)	0.02	0.12
Manganese (Mn)	1.62	1.75
Silicon (Si)	0.57	0.90
Sulphur (S)	0.006	0.03
Phosphorus (P)	0.013	0.03

Note: AWS specification single values are maximums.

TYPICAL DIFFUSIBLE HYDROGEN*:

Hydrogen Equipment	100% CO_2	AWS Spec
(GAS CHROMATOGRAPHY)	6.3ml/100g	8.0ml/100g Maximum

TYPICAL MECHANICAL PROPERTIES* [Aged 48 Hrs. @ 200°F (93°C)]:

Mechanical Tests	100% CO_2	AWS Spec
Tensile Strength	84,000 psi (579 MPa)	70,000-95,000 (490-670 MPa)
Yield Strength	77,000 psi (531 MPa)	58,000 psi (390 MPa) Minimum
Elongation % in 2” (50 mm)	28%	22% Minimum

TYPICAL CHARPY V-NOTCH IMPACT VALUES* (As Welded):

CVN Temperatures	100% CO_2	AWS Spec
Avg. at 0°F (-20°C)	55 ft•lbs (75 Joules)	20 ft•lbs (27 Joules) Minimum
Avg. at -20°F (-30°C)	44 ft•lbs (60 Joules)	20 ft•lbs (27 Joules) Minimum

*The information contained or otherwise referenced herein is presented only as “typical” without guarantee or warranty, and Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Typical data are those obtained when welded and tested in accordance with the AWS A5.20 specification. Other tests and procedures may produce different results. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers LLC.

Hobart Brothers LLC • 101 Trade Square East • Troy, OH 45373
PH: (800) 424-1543 • FX: 800-541-6607 • www.hobartbrothers.com

FabCO® TR-70

Diameter Inches	(mm)	Weld Position	Amps	Volts	Wire-Feed Speed in/min	(m/min)	Deposition Rate lbs/hr	(kg/hr)	Contact Tip to Work Distance Inches	(mm)
0.045	(1.2)	Flat & Horizontal	150	25	245	(6.2)	5.3	(2.4)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	200	26	365	(9.3)	7.7	(3.5)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	250	26	540	(13.7)	10.9	(4.9)	3/4	(19)
0.045	(1.2)	Flat & Horizontal	280	27	635	(16.1)	13.7	(6.2)	3/4	(19)
1/16	(1.6)	Flat & Horizontal	170	25	140	(3.6)	5.3	(2.4)	1	(25)
1/16	(1.6)	Flat & Horizontal	200	26	170	(4.3)	6.4	(2.9)	1	(25)
1/16	(1.6)	Flat & Horizontal	260	27	210	(5.3)	7.8	(3.5)	1	(25)
1/16	(1.6)	Flat & Horizontal	350	32	345	(8.8)	12.9	(5.9)	1	(25)
5/64	(2.0)	Flat & Horizontal	250	26	110	(2.8)	6.5	(3.0)	1	(25)
5/64	(2.0)	Flat & Horizontal	300	26	140	(3.6)	8.3	(3.8)	1	(25)
5/64	(2.0)	Flat & Horizontal	350	27	170	(4.3)	10.0	(4.6)	1	(25)
5/64	(2.0)	Flat & Horizontal	420	27	225	(5.7)	13.5	(6.1)	1	(25)
5/64	(2.0)	Flat & Horizontal	550	32	345	(8.8)	20.8	(9.4)	1	(25)
3/32	(2.4)	Flat & Horizontal	350	27	125	(3.2)	10.4	(4.7)	1	(25)
3/32	(2.4)	Flat & Horizontal	450	30	174	(4.4)	15.3	(6.9)	1	(25)
3/32	(2.4)	Flat & Horizontal	550	32	245	(6.2)	20.2	(9.2)	1	(25)

- **Maintaining a proper welding procedure - including pre-heat and interpass temperatures - may be critical depending on the type and thickness of steel being welded.**

STANDARD DIAMETERS AND PACKAGES: For a complete list of diameters and packaging, please contact Hobart Brothers at (800) 424-1543 or (937) 332-5188 for International Customer Service.

Diameter Inches	(mm)	33-lb. (15kg) Spool	60-lb. (27.2kg) Coil	600-lb. (272.2kg) Drum / X-Pak	800-lb. (363kg) Flat Reel
Net Pallet Weight		**2376-lb. (1078kg)**	**1920-lb. (871kg)**	**2400-lb. (1089kg)**	**1600-lb. (726kg)**
0.045	(1.2)	S247012-029	—	—	—
1/16	(1.6)	S247019-029	S247019-002	S247019-056	—
5/64	(2.0)	—	S247025-002	S247025-008	—
3/32	(2.4)	—	S247029-002	S247029-008	S247029-069

CONFORMANCES AND APPROVALS:
- **AWS A5.20,** E70T-1C H8, E70T-9C H8
- **AWS A5.20M**, E490T-1C H8, E490T-9C H8
- **ASME SFA 5.20,** E70T-1C H8, E70T-9C H8
- **ABS,** 100% CO_2, E70T-1CJ
- **CWB,** E490T1-C1A3-CS1-H8 (E492T-9-H8)
- **AWS D1.8 Conformance**: 100% CO_2 [1.6 mm, 2.0 mm & 2.4 mm diameter electrodes]

TECHNICAL QUESTIONS? For technical support of Hobart Filler Metals products, contact the Applications Engineering department by phone toll-free at 1-800-532-2618 or by e-mail at Applications.Engineering@hobartbrothers.com

CAUTION:
Consumers should be thoroughly familiar with the safety precautions on the warning label posted in each shipment and in the American National Standard Z49.1, "Safety in Welding and Cutting," published by the American Welding Society, 8669 NW 36th St., Miami, FL 33166 (can also be downloaded online at www.aws.org); OSHA Safety and Health Standards 29 CFR 1910 is available from the U.S. Department of Labor, Washington, D.C. 20210

Safety Data Sheets on any Hobart Brothers LLC product may be obtained from Hobart Customer Service or at www.hobartbrothers.com.

Because Hobart Brothers LLC is constantly improving products, Hobart reserves the right to change design and/or specifications without notice.

Hobart and FabCO are registered trademarks of Hobart Brothers LLC, Troy, Ohio.

Revision Date: 220718 (Replaces 210923)
636-X, INDEX

HOBART FILLER METALS

HOBART FILLER METALS

Certificate of Conformance to Requirements for Welding Electrode

Product Type:	**FabCO TR-70**
Classification:	**E70T-1C H8, E70T-9C H8**
Specifications:	**AWS A5.20/A5.20M; ASME SFA 5.20**
Diameter Tested:	**045"; 3/32"**
Date Tested:	**6/29/2023**
Date Generated:	**7/5/2023**

This is to certify that the product named above and supplied on the referenced order number is of the same classification, manufacturing process, and material requirements as the material which was used for the test that was concluded on the date shown, the results of which are shown below. All tests required by the specifications shown for classification were performed at that time and the material tested met all requirements. It was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001, ANSI/AWS A5.01, and other specification and Military requirements, as applicable. This document supplies actual test results of non-specific inspection in conformance with the requirements of EN 10204, type 2.2 certification.

THE STEEL USED IN THIS LOT OF MATERIAL WAS MELTED AND MANUFACTURED IN THE U.S.A.

Test Settings

Shielding Medium	Amps / Polarity	Volts	WFS in/min(m/min)	ESO in(mm)	Preheat F(C)	Interpass F(C)	Travel Speed in/min(cm/min)
C1	260-290 / DCEP	29	540 (13.7)	5/8 (16)	Room Temp	300(149)	13.7 (34.8)
C1	425 / DCEP	28	155 (3.9)	1 (25)	Room Temp	300(149)	14 (35.6)

Mechanical Properties - Tensile

Shielding Medium	Ref. No.	Testing Conditions	Ult. Tensile Strength psi (MPa)	Yield Strength psi (MPa)	Elong.% in 2"
C1	PE6222	Aged 48 Hrs 220F	84,000 (583)	80,000 (555)	27
C1	PE6292	Aged 48 Hrs 220F	89,000 (612)	80,000 (549)	25

Mechanical Properties - Impact

Shielding Medium	Ref. No.	Testing Conditions	Temp. F (C)	Individuals ft.lb.(J)	Avg. ft.lb.(J)	Type
C1	PE6222	As Welded	-20 (-29)	54,36,49 (73,49,66)	46 (63)	Charpy-V-Notch
C1	PE6222	As Welded	0 (-18)	63,60,38 (85,81,52)	54 (73)	Charpy-V-Notch
C1	PE6292	As Welded	0 (-18)	36,41,40 (49,56,54)	39 (53)	Charpy-V-Notch
C1	PE6292	As Welded	-20 (-29)	28,29,27 (38,39,37)	28 (38)	Charpy-V-Notch

Ref.No.	Radiographic Inspection	Fillet Weld Test					
PE6222	Conforms	Horizontal :	Conforms	Overhead :		Vertical :	
PE6354	Conforms	Horizontal :	Conforms	Overhead :		Vertical :	

Chemical Analysis

Shielding Medium / Ref. No	C	Mn	P	S	Si	Cu	Cr	V	Ni	Mo	Al	Ti	Nb	Co	B	W	Sn	Fe	Sb	N	Mg	Zn	Be	Sb	As
C1 / PE6222	0.02	1.75	0.007	0.007	0.68	0.02	0.03	0.01	0.01	< .01					0.0057										
C1 / PE6292	0.02	1.63	0.009	0.008	0.64	0.04	0.04	0.01	0.02	0.01					0.0055										

Diffusible Hydrogen Collected per AWS A4.3

C1	5.8 ml/100g of weld metal for 3/32 in diameter 36% relative humidity
C1	4.9 ml/100g of weld metal for .045 in diameter 42% relative humidity

James A. Owens, Q.A. Specialist

Certification and Limited Warranty - Data for the above supplied product are those obtained when welded and tested in accordance with the above specification. All tests for the above classification were satisfied. Other tests and procedures may produce different results.

Product: FabCO TR-70
Diameter: 1/16”
Shielding Gas: C1 (100% CO2)
Current/Polarity: DCEP
Classification: E70T-1C H8, E70T-9C H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 10/24/2022

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot- # C000251805321	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	73.0 kJ/in	28.7 kJ/in	Mechanical Properties		73.0 kJ/in	28.7 kJ/in
Voltage	28	26	Test Reference #		PD8116	PD8115
Current (amps)	300	230				
WFS (ipm)	285	190				
Travel Speed (ipm)	6.9	12.5	Tensile Strength (psi)	70,000	77,700	84,100
Stick Out	3/4”	3/4”	Yield Strength (psi)	58,000	67,200	77,300
# of passes	8	19	Elongation (%)	22	26	26
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	111	69
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # Z025131224322	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	73.7 kJ/in	29.0 kJ/in	Mechanical Properties		73.7 kJ/in	29.0 kJ/in
Voltage	28	26	Test Reference #		PD2350	PD2349
Current (amps)	285	232				
WFS (ipm)	285	185				
Travel Speed (ipm)	6.5	12.5	Tensile Strength (psi)	70,000	82,100	88,200
Stick Out	1”	1”	Yield Strength (psi)	58,000	69,600	80,800
# of passes	8	19	Elongation (%)	22	29	25
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	93	82
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # G00030	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	75.5 kJ/in	28.5 kJ/in	Mechanical Properties		75.5 kJ/in	28.5 kJ/in
Voltage	28	26	Test Reference #		PE4663	PE4664
Current (amps)	285	232				
WFS (ipm)	285	185				
Travel Speed (ipm)	6.5	12.5	Tensile Strength (psi)	70,000	76,100	86,200
Stick Out	3/4“	3/4“	Yield Strength (psi)	58,000	65,200	80,600
# of passes	8	19	Elongation (%)	22	32	27
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	114	50
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	G00030	HB6157	7.0 (ml/100g)
7 Day Exposure	G00030	HB6203	9.1 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets ("SDS").



James Owens, Quality Assurance Specialist

Product: FabCO TR-70
Diameter: 5/64”
Shielding Gas: C1 (100% CO2)
Current/Polarity: DCEP
Classification: E70T-1C H8, E70T-9C H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 10/21/2022

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot- # B024530813303	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.7 kJ/in	31.6 kJ/in	Mechanical Properties		80.7 kJ/in	31.6 kJ/in
Voltage	30.5	26	Test Reference #		PD8119	PD8121
Current (amps)	450	290				
WFS (ipm)	280	150				
Travel Speed (ipm)	10.2	14.3	Tensile Strength (psi)	70,000	89,300	86,800
Stick Out	1”	1”	Yield Strength (psi)	58,000	77,600	776200
# of passes	7	17	Elongation (%)	22	25	27
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	57	75
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # Z028041021391	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	84.3 kJ/in	31.0 kJ/in	Mechanical Properties		84.3 kJ/in	31.0 kJ/in
Voltage	30.5	26	Test Reference #		PD2419	PD2417
Current (amps)	447	290				
WFS (ipm)	296	157				
Travel Speed (ipm)	9.7	14.6	Tensile Strength (psi)	70,000	87,700	95,400
Stick Out	3/4”	1”	Yield Strength (psi)	58,000	73,400	87,200
# of passes	7	17	Elongation (%)	22	27	25
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	43	73
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # G00114	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.0 kJ/in	32.9 kJ/in	Mechanical Properties		80.0 kJ/in	32.9 kJ/in
Voltage	30.5	26	Test Reference #		PE4810	PE4811
Current (amps)	447	301				
WFS (ipm)	296	157				
Travel Speed (ipm)	9.7	14.3	Tensile Strength (psi)	70,000	84,000	85,500
Stick Out	1“	1“	Yield Strength (psi)	58,000	70,800	80,300
# of passes	8	18	Elongation (%)	22	25	26
# of layers	4	8	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	57	70
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	G00114	HB6159	6.4 (ml/100g)
7 Day Exposure	G00114	HB6204	8.6 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets ("SDS").



James Owens, Quality Assurance Specialist

Product: FabCO TR-70
Diameter: 3/32”
Shielding Gas: C1 (100% CO2)
Current/Polarity: DCEP
Classification: E70T-1C H8, E70T-9C H8
Specification: AWS A5.20/A5.20M:2005
Test Completed: 10/21/2022

Certificate of Conformance
For AWS D1.8/D1.8M, Seismic Supplement

This is to certify that the product named is of the same classification, manufacturing process, and material requirements as the material, which was used for the test which was concluded on the date shown, the results of which are shown below. All test required by the code or specifications were performed at that time and the material tested met all requirements. The product was manufactured and supplied by the Quality System Program of Hobart Brothers, which meets the requirements of ISO 9001:2015, ANSI/AWS A5.01, and other specification and Military requirements, as applicable.

Test Settings	High Heat Input	Low Heat Input	Lot- # C003051514302	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.0 kJ/in	30.9 kJ/in	Mechanical Properties		80.0 kJ/in	30.9 kJ/in
Voltage	32	26	Test Reference #		PD8169	PD8170
Current (amps)	450	300				
WFS (ipm)	180	108				
Travel Speed (ipm)	10.8	15.1	Tensile Strength (psi)	70,000	78,800	87,200
Stick Out	1”	1”	Yield Strength (psi)	58,000	65,500	79,600
# of passes	8	17	Elongation (%)	22	30	25
# of layers	5	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	76	61
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # Z003331507301	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.3 kJ/in	30.3 kJ/in	Mechanical Properties		80.3 kJ/in	30.3 kJ/in
Voltage	32	26	Test Reference #		PD2352	PD2348
Current (amps)	435	299				
WFS (ipm)	180	108				
Travel Speed (ipm)	10.4	15.4	Tensile Strength (psi)	70,000	81,800	90,600
Stick Out	1”	1”	Yield Strength (psi)	58,000	68,300	85,200
# of passes	7	17	Elongation (%)	22	29	27
# of layers	4	8	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	54	90
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Test Settings	High Heat Input	Low Heat Input	Lot- # F027330928	AWS D1.8 Requirements	High Heat Input	Low Heat Input
	80.3 kJ/in	31.6 kJ/in	Mechanical Properties		80.3 kJ/in	31.6 kJ/in
Voltage	31	26	Test Reference #		PE4902	PE4825
Current (amps)	450	300				
WFS (ipm)	180	100				
Travel Speed (ipm)	10.4	14.8	Tensile Strength (psi)	70,000	80,800	84,600
Stick Out	1“	1“	Yield Strength (psi)	58,000	66,900	78,000
# of passes	7	17	Elongation (%)	22	27	27
# of layers	4	7	Average Charpy V-notch			
Preheat Temp. ºF	300+/-25	RT	Impact Properties ft•lbs @	40	63	75
Interpass Temp. ºF	500+/-50	200+/-25	+70 ºF			
Weld Position	1G	1G				

Diffusible Hydrogen - Tested in accordance with AWS A5.20/A5.20M, Clause 16 & Extended Exposure - in accordance with AWS D1.8/D1.8M

Condition	Lot - #	Test Reference #	Average (ml/100g)
As Received	F027330928	HB5397	7.7 (ml/100g)
7 Day Exposure	F027330928	HB6197	10.0 (ml/100g)

The information contained or otherwise referenced herein is presented without guarantee or warranty. Hobart Brothers LLC expressly disclaims any liability incurred from any reliance thereon. Data for the above-supplied product are those obtained during the welding process and tested in accordance with the above specification with electrodes of the same manufacturing processes and material requirements. All tests for the above classification were performed satisfactorily. No data is to be construed as a recommendation for any welding condition or technique not controlled by Hobart Brothers. Refer to the Hobart Brothers website at www.hobartbrothers.com for current Safety Data Sheets ("SDS").



James Owens, Quality Assurance Specialist

Airgas
an Air Liquide company

Quality Management Systems
Confidential - For Customer Use Only

Certificate of Conformance

Effective Date: January 1, 2023 - December 31, 2025

The product identified below satisfies the specifications listed which meets and exceeds the specifications for Argon.

The information presented on the Certificate of Conformance is based on evaluation of process capabilities and plant periodic data on product delivered by
Airgas USA, LLC.

Liquid Argon	
Test Requirement	**Specification**
Assay*	≥ 99.998%
Oxygen	≤ 5.0 ppm
Nitrogen	≤ 15.0 ppm

Produced by Air Liquefaction process and in compliance with cGMP requirements.

This Certificate of Conformance (COC) does not add to or replace the warranty, limitations of liability or other provisions of the agreement between the parties.

* Assay results are reported to five significant digits by difference of tested impurities.

Approved By:



Mark Jorgensen
Airgas USA, LLC
Sr. Director of Quality & Food Safety

12/1/2022
Rev 1

Airgas
an Air Liquide company

Quality Management Systems
Confidential - For Customer Use Only

Certificate of Conformance

Effective Date: January 1, 2023 - December 31, 2025

The liquid carbon dioxide produced at our plants meet and/or exceeds the specification limits set by the Compressed Gas Association G-6.2-2011, Quality Verification Level G [General Commercial Uses).

Liquid Carbon Dioxide	
Test Requirement	**Specification**
Carbon Dioxide (Assay)	99.00 % Min
Acetaldehyde	0.50 ppm
Total Sulfur	0.50 ppm
Oxygen	50.0 ppm
Moisture (Water)	32.0 ppm (-61°F Dewpoint)
Total Hydrocarbon Content (as methane)	50.0 ppm
Non Volatile Residues (wt/wt)	10.0 ppm
Odor/Taste	No foreign odor/taste

Specification limit in ppm (v\v) maximum allowable unless otherwise stated. N/A: Not Applicable.

Approved By:



Mark Jorgensen
Airgas USA, LLC
Sr. Director of Quality & Food Safety

12/1/2022
Rev 1