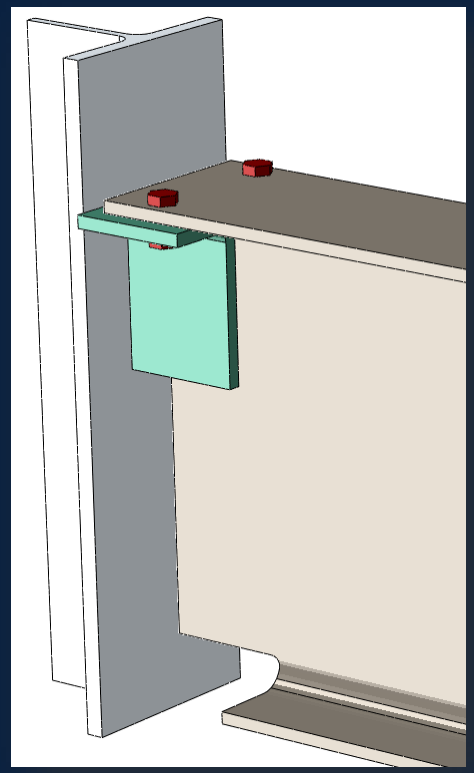
Drop-In Top Flange Connection

70th Annual Structural Engineering Conference
University of Kansas



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AUBURN UNIVERSITY

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Drop-In Top Flange Connection Team

Auburn

- Matthew Yarnold (PI)
- Kadir Sener
- Robel Alemayehu
- Emily Doody

Agency

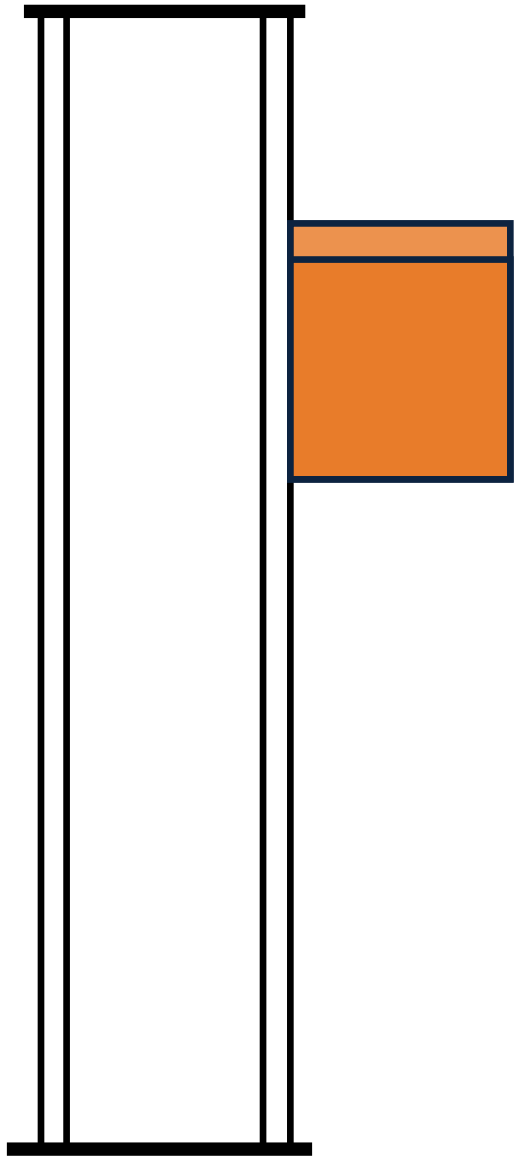
- Devin Huber (Director of Research)
- Carlo Lini
- Eric Bolin
- Erin Conaway
- Larry Kruth (retired)

Industry Members

- Bo Dowswell – ARC International
- W. Duff Zimmerman – Cooper Steel
- Matthew Trammell – Trammell Engineering Group, LLC
- Keith Palmer – Simpson Gumpertz & Heger
- Larry Muir – Consultant (former Cives/AISC)
- Brian Volpe – Cives Steel
- Tom Kuznick – Herrick Steel (retired)
- Victor Shneur – Lejeune Steel (retired)
- Doug Abernathy – NAFCO

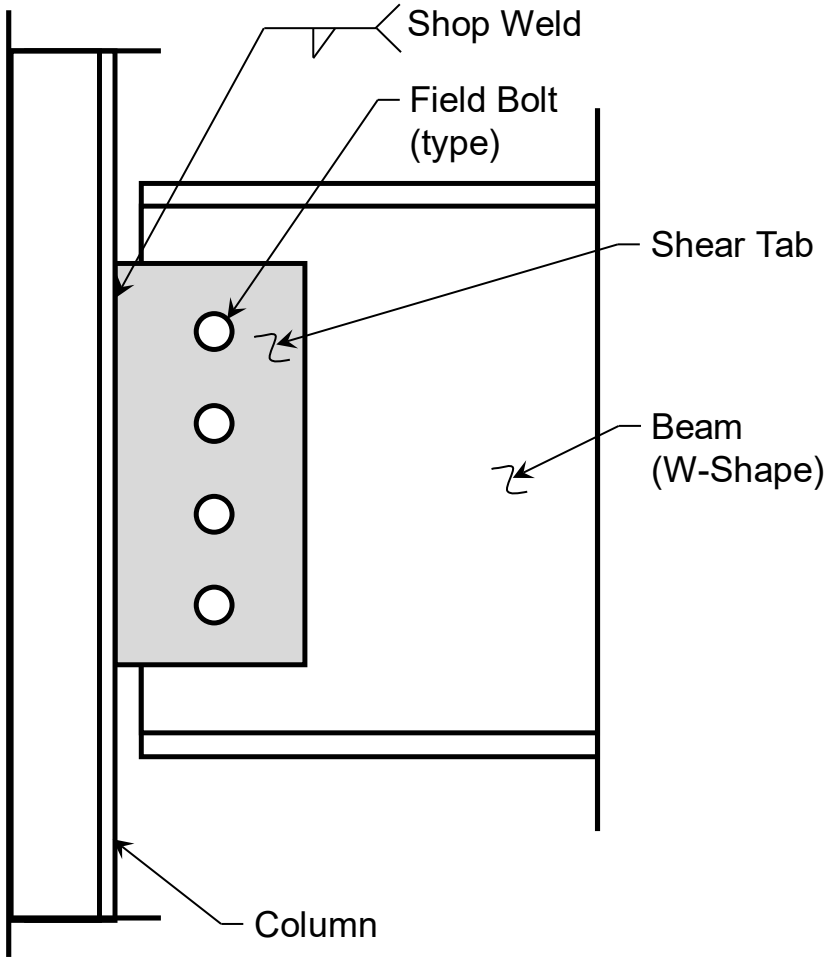
Agenda

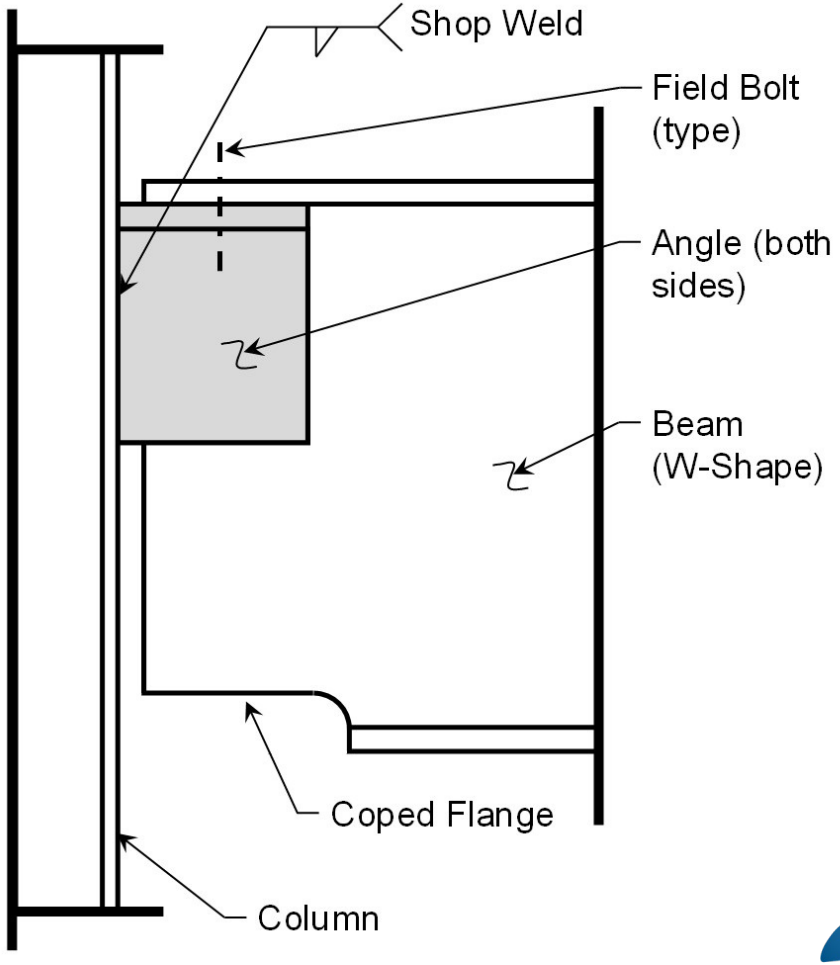
- Project Goal
- Research Summary
  1. Concept Development
  2. Full-Scale Testing
  3. Finite Element Analysis
  4. Design Guidance
- Summary of Findings



Project Goal

Overall – Increase the erection speed of residential and commercial structural steel shear connections.



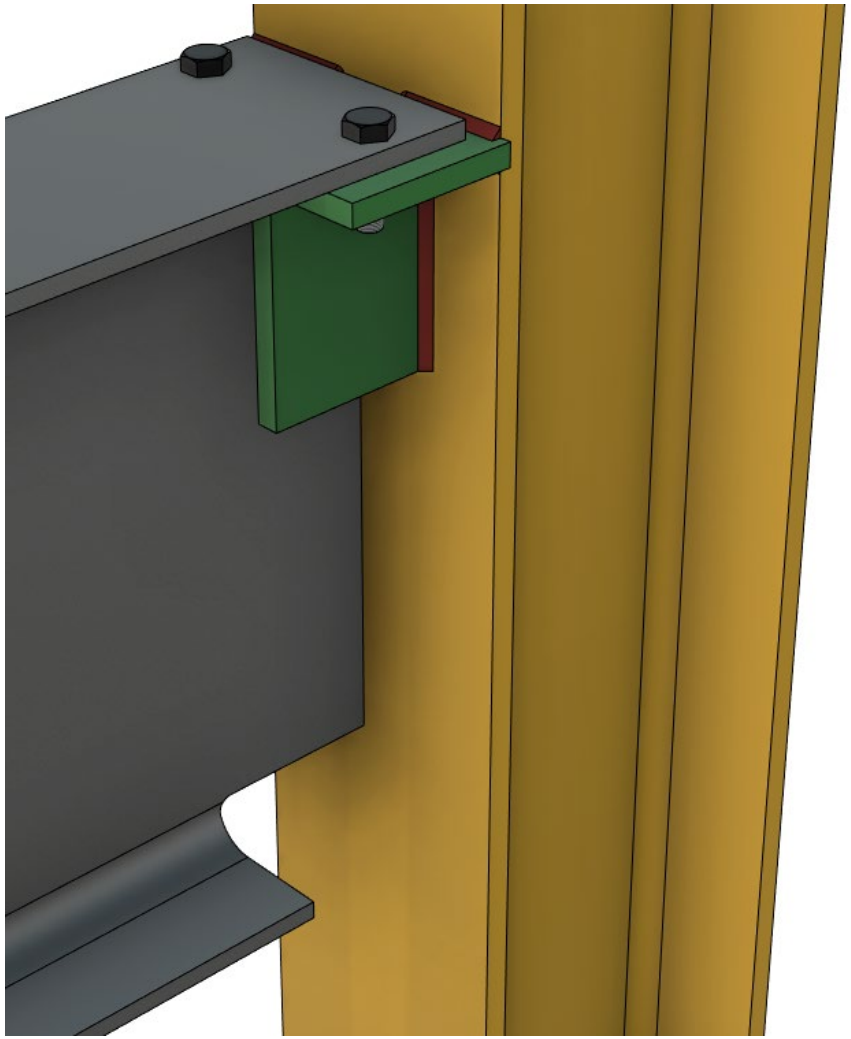


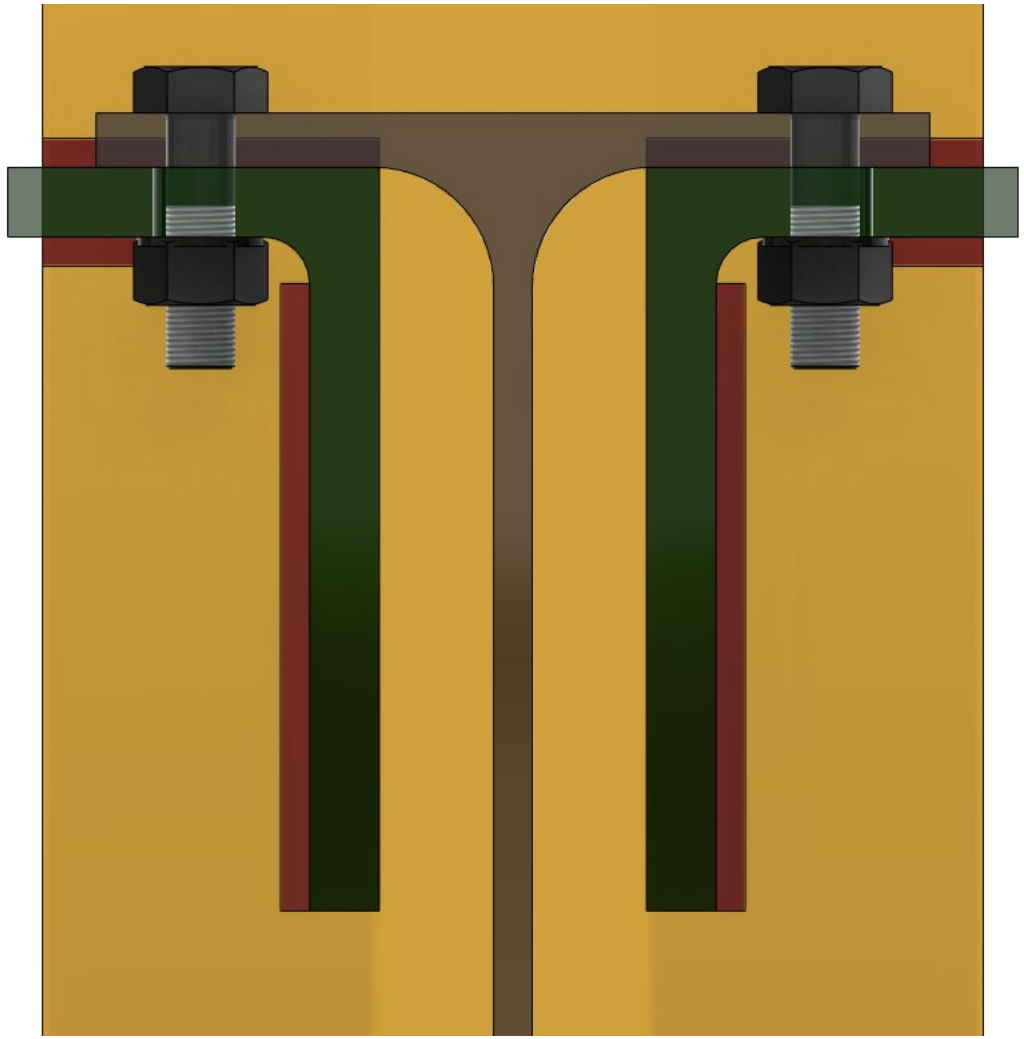
Drop-In Top Flange Connection

NEED FOR SPEED

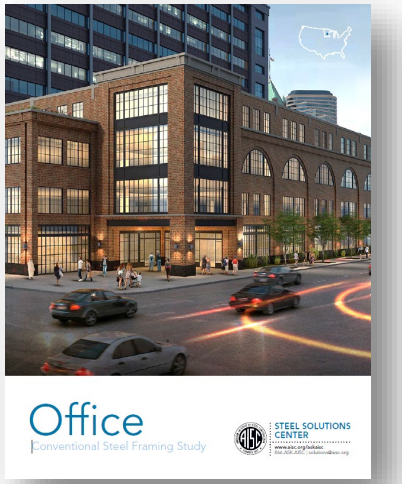
Project Goal

Specifically – Develop design guidance for drop-in top flange connections (not extended).



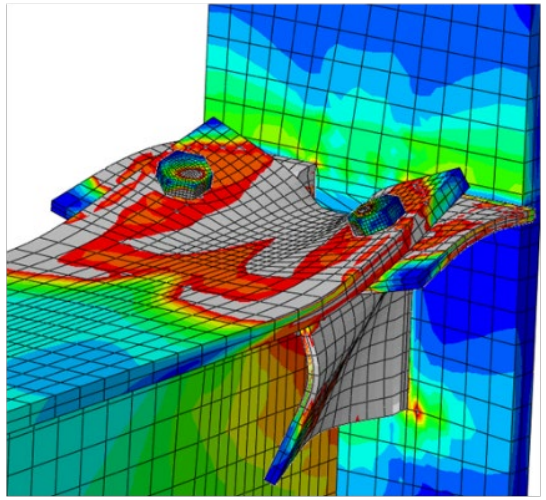


Research Summary



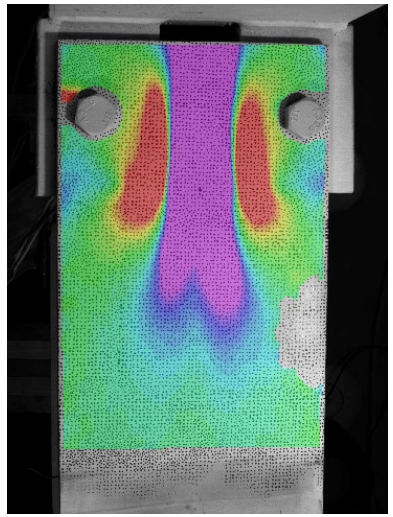
1. Concept Development

3. Finite Element Analysis



2023 — 2024

2. Full-Scale Testing



Drop-In Top Flange Connection

4. Design Guidance

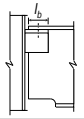
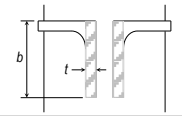


Table 10-E
Drop-In Connetions



Flange Bending Available Strength, kips					Angles Available Strength, kips			
Shape	l_b = 4 in		l_b = 8 in		Angle Vertical Leg		ASD	LRFD
	ASD	LRFD	ASD	LRFD	b, in	t, in		
W30X99	79.1	119.0	126.9	190.8	10	1	359.3	540.0
W30X90	68.2	102.5	109.5	164.6		7/8	314.4	472.5
W27X94	100.2	150.6	161.8	243.2		3/4	269.5	405.0
W27X84	73.9	111.1	119.4	179.5	8	1 1/8	323.4	486.0
W24X94	133.3	200.3	218.3	328.1		1	287.4	432.0
W24X84	103.0	154.8	168.9	253.8		7/8	251.5	378.0
W24X76	80.2	120.6	131.6	197.8		3/4	215.6	324.0
W24X68	59.3	89.2	97.3	146.3		5/8	179.6	270.0
W24X62	75.3	113.2	127.6	191.9		9/16	161.7	243.0

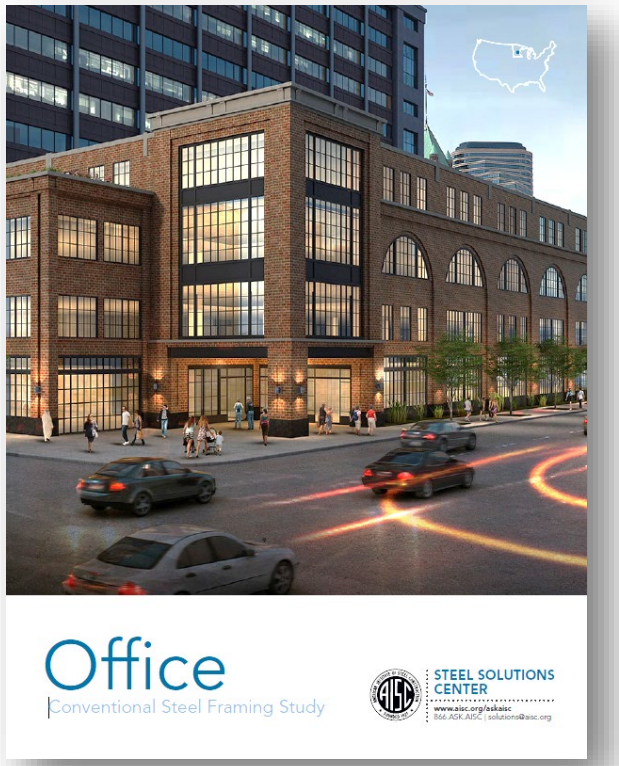
1. Concept Development

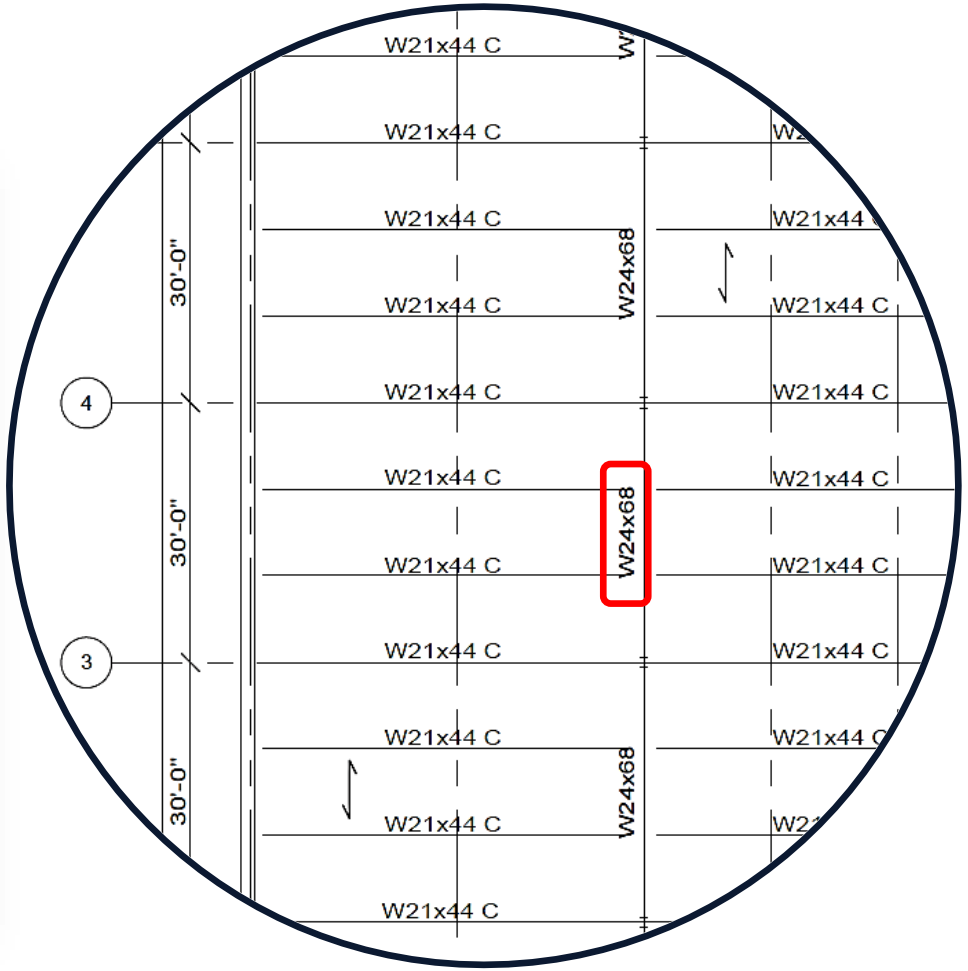
Benchmark Office Building:

- Connection = Girder-to-column
- Span = 30 ft

Girder Design:

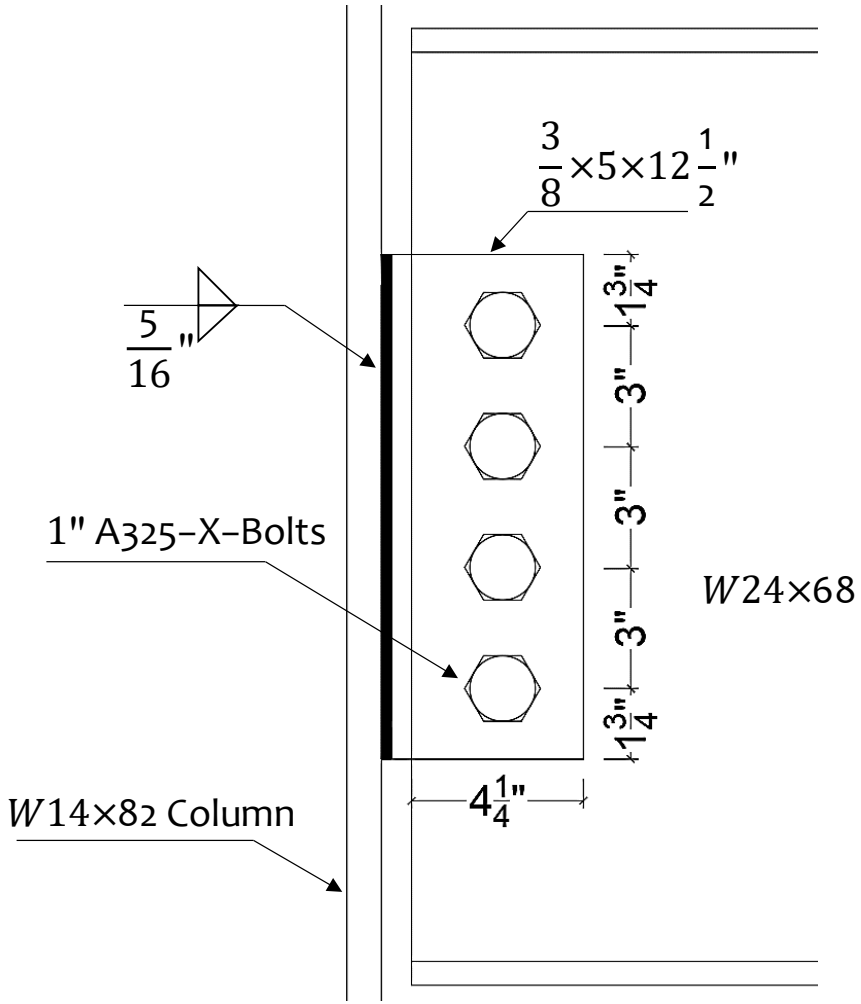
- **W24x68** (composite)
- **Reaction = 78 kips**

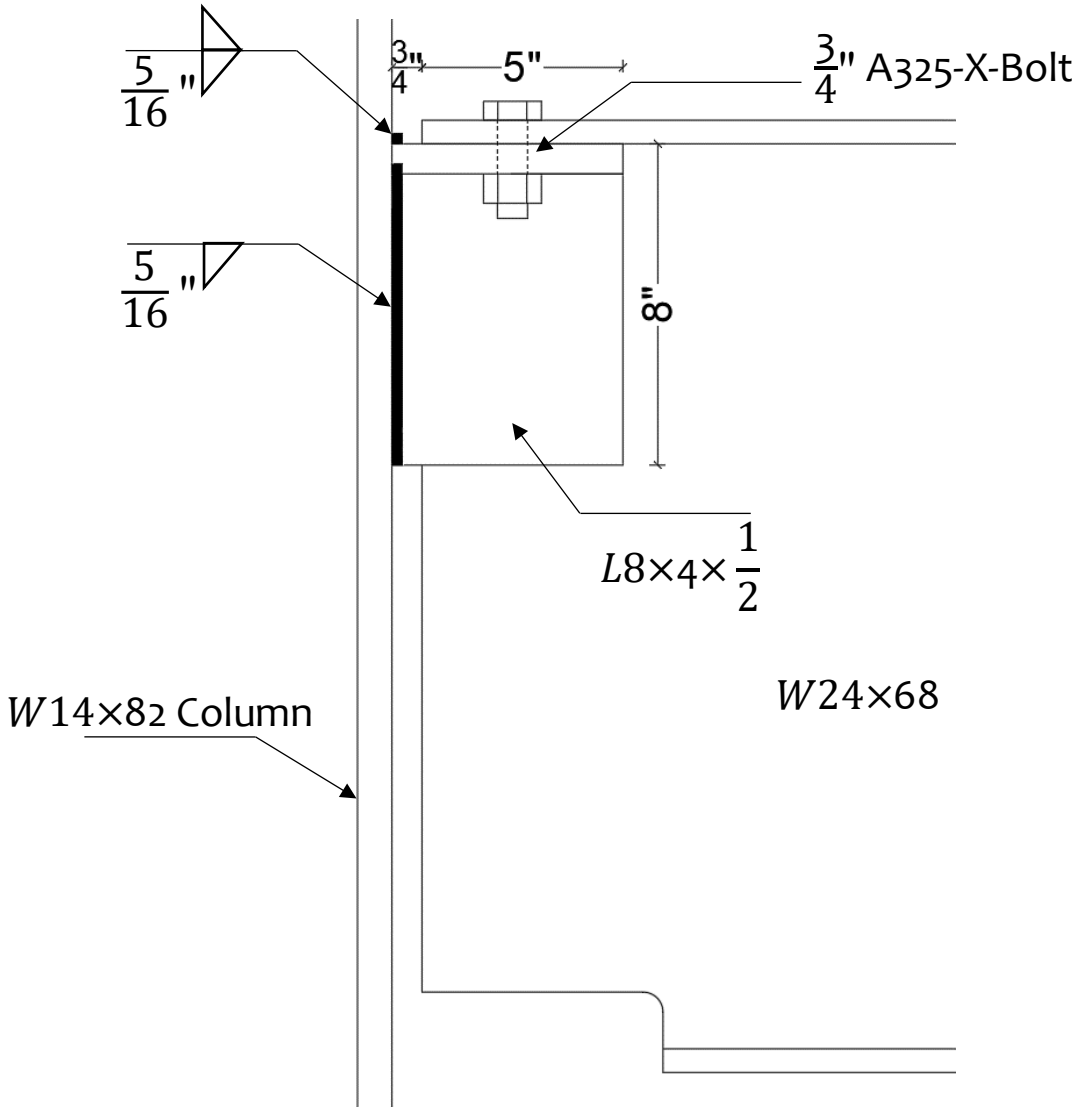




1. Concept Development

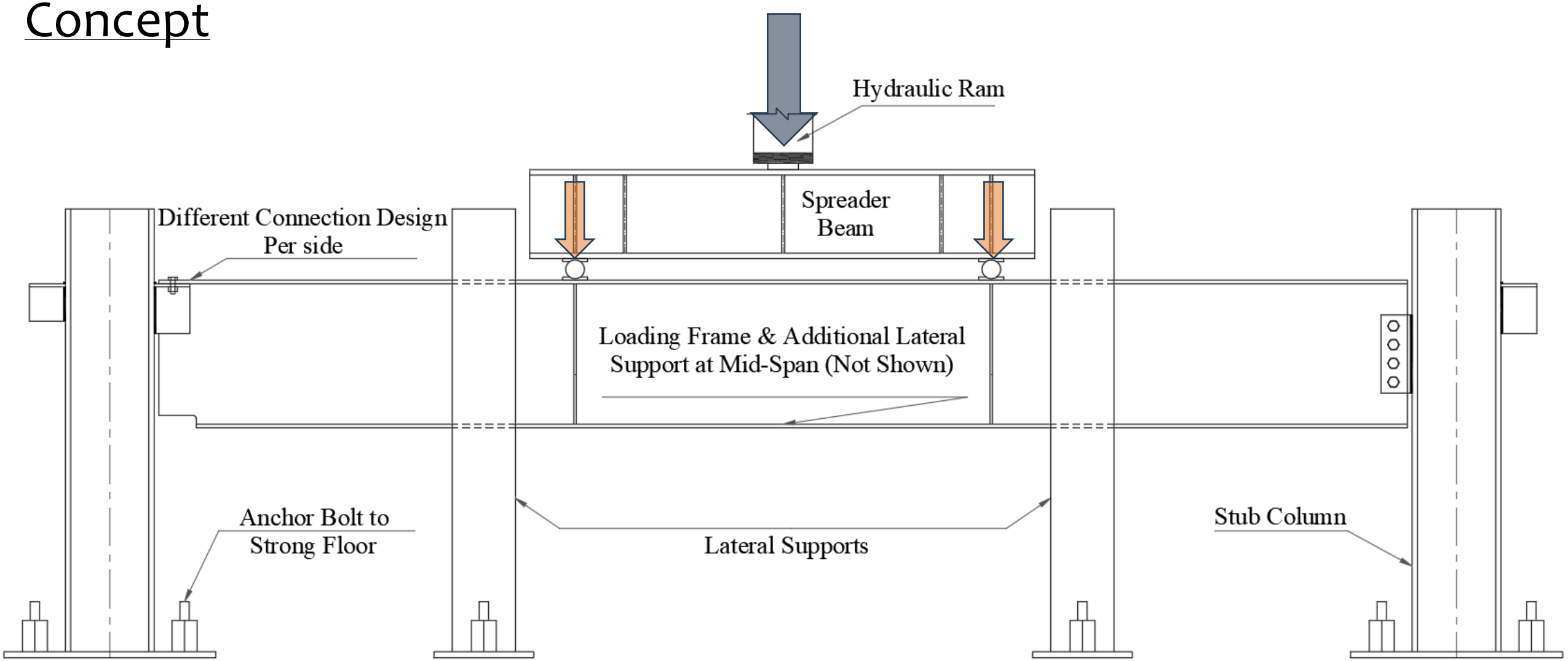
Office Building Connections





2. Full-Scale Testing Program

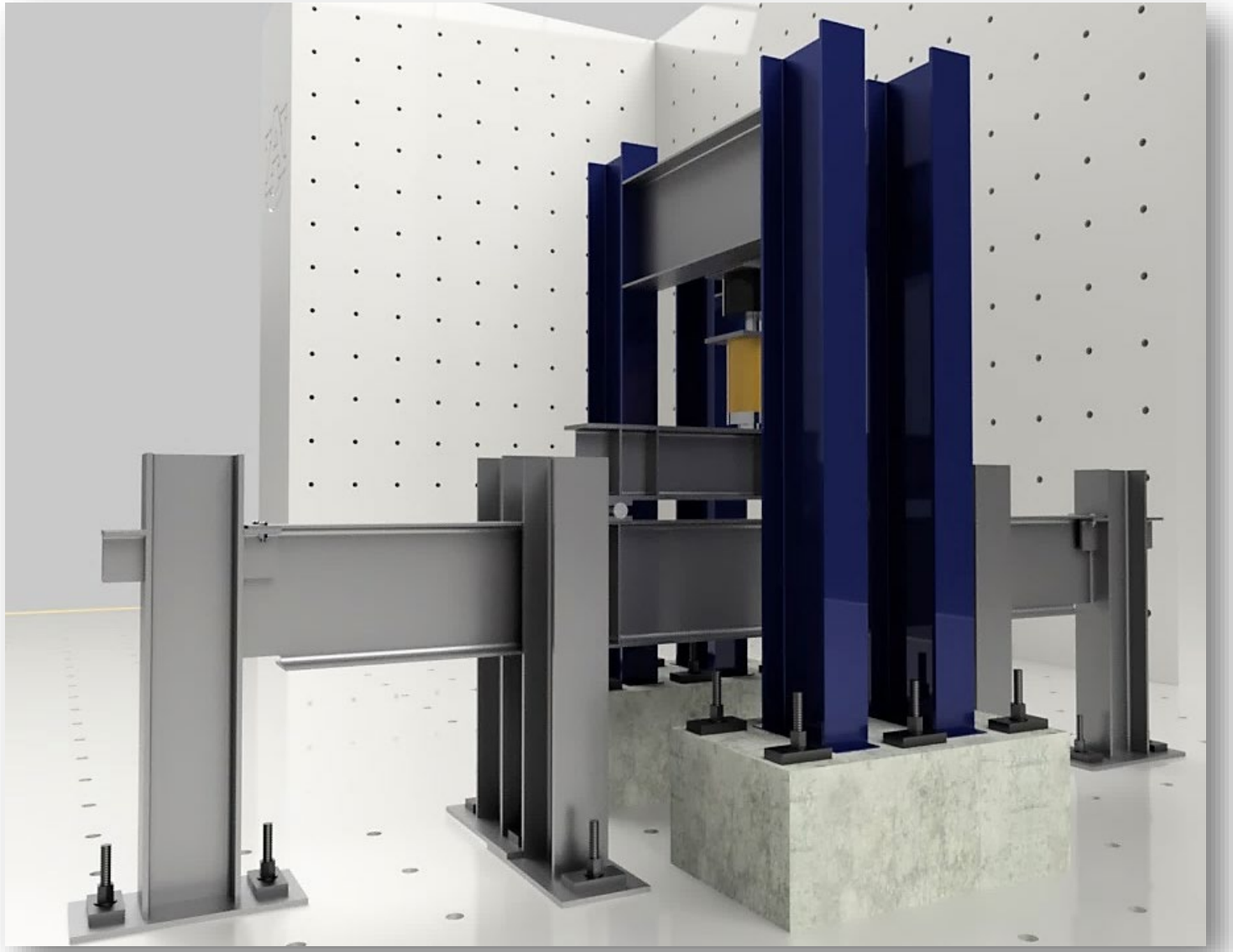
Concept



2. Full-Scale Testing Program

Shear Connection Test Metrics:

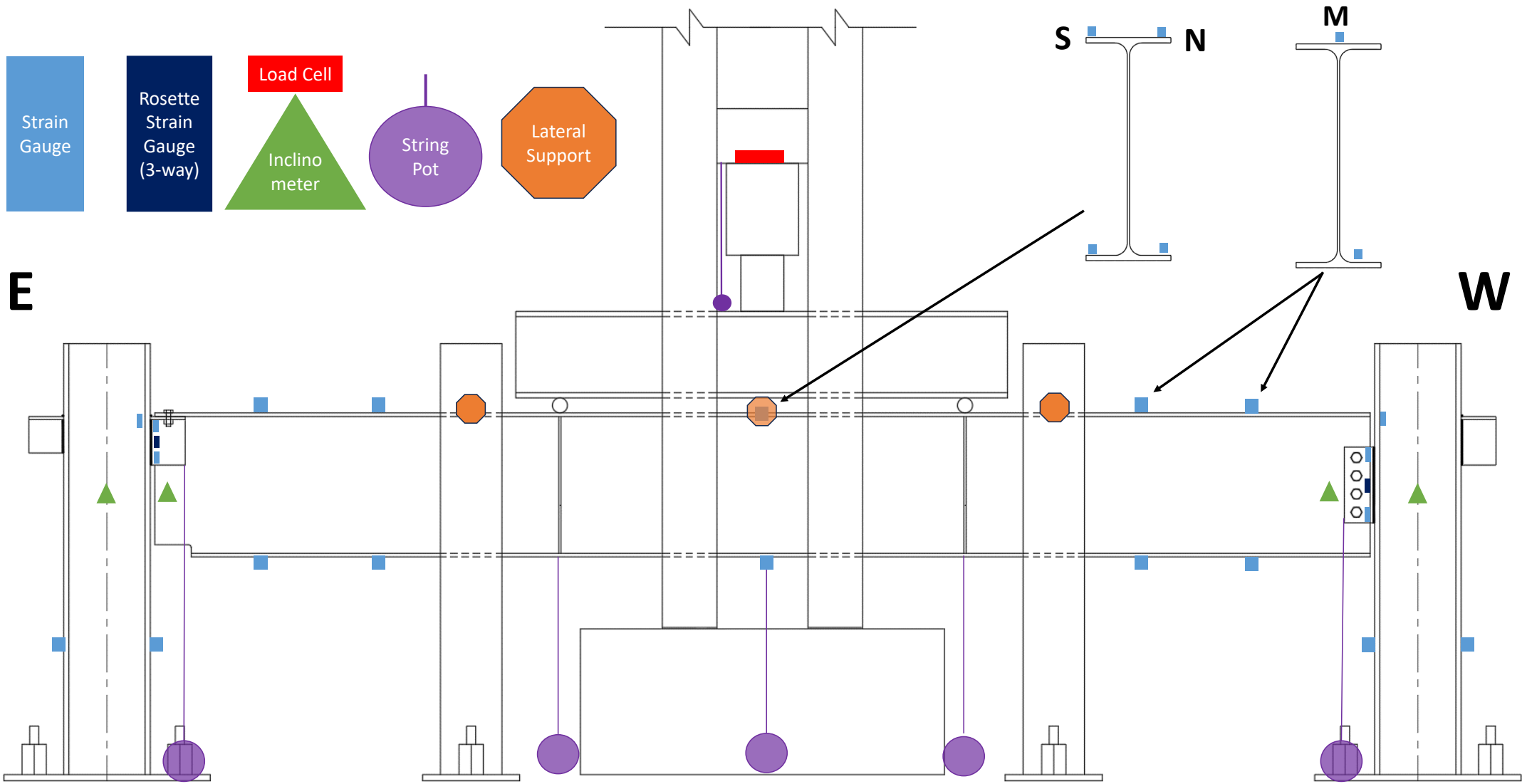
1. Shear Strength [$\geq V_u$]
2. Stiffness [$\leq 2EI/L$]
3. Rotational Ductility [≥ 0.03 rad]
4. Torsional Stiffness [Sufficient Girder LTB Capacity]



Drop-In Top Flange Connection

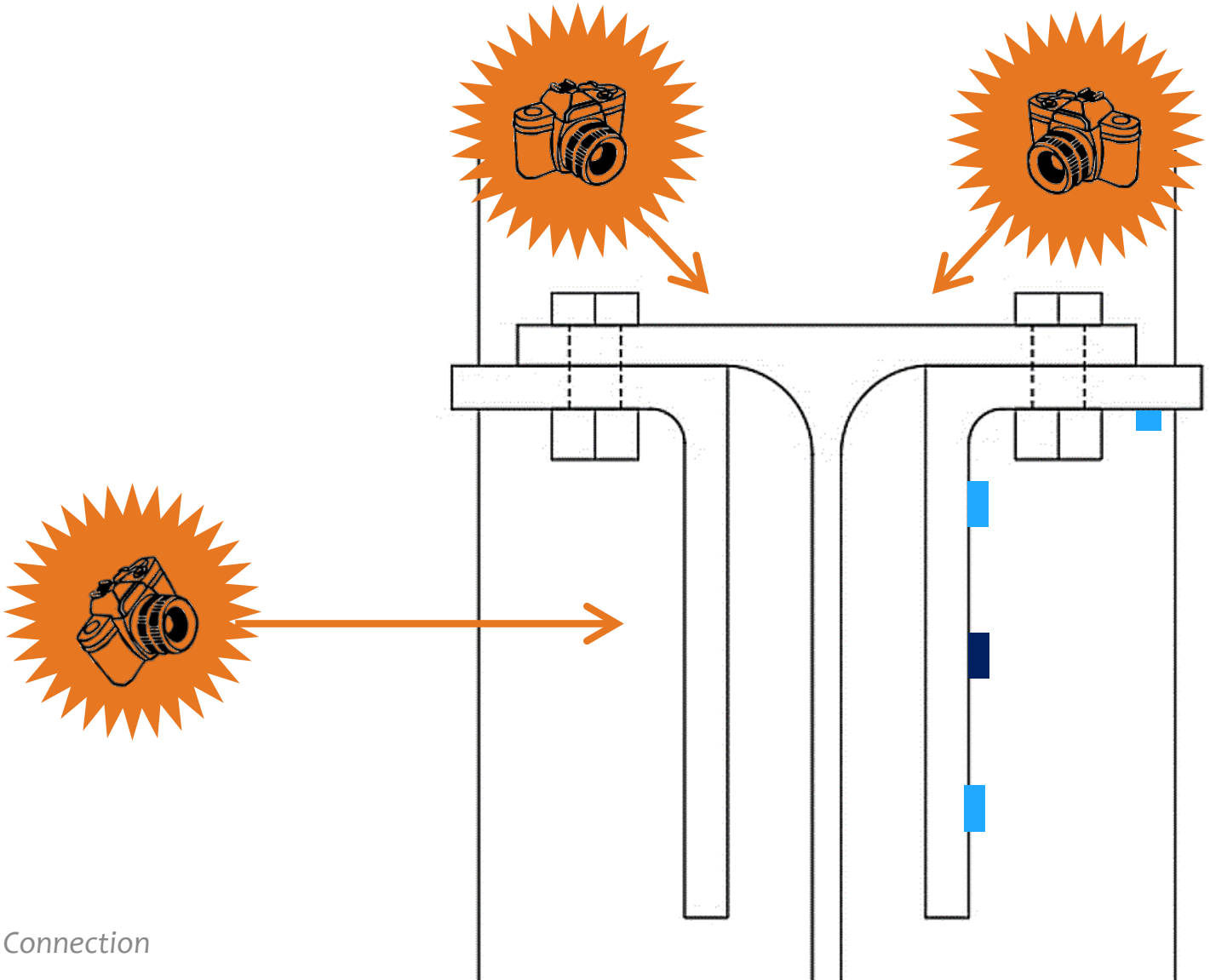
2. Full-Scale Testing Program

Instrumentation



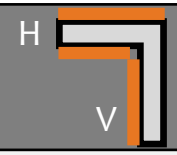
2. Full-Scale Testing Program

Digital Image Correlation (DIC)

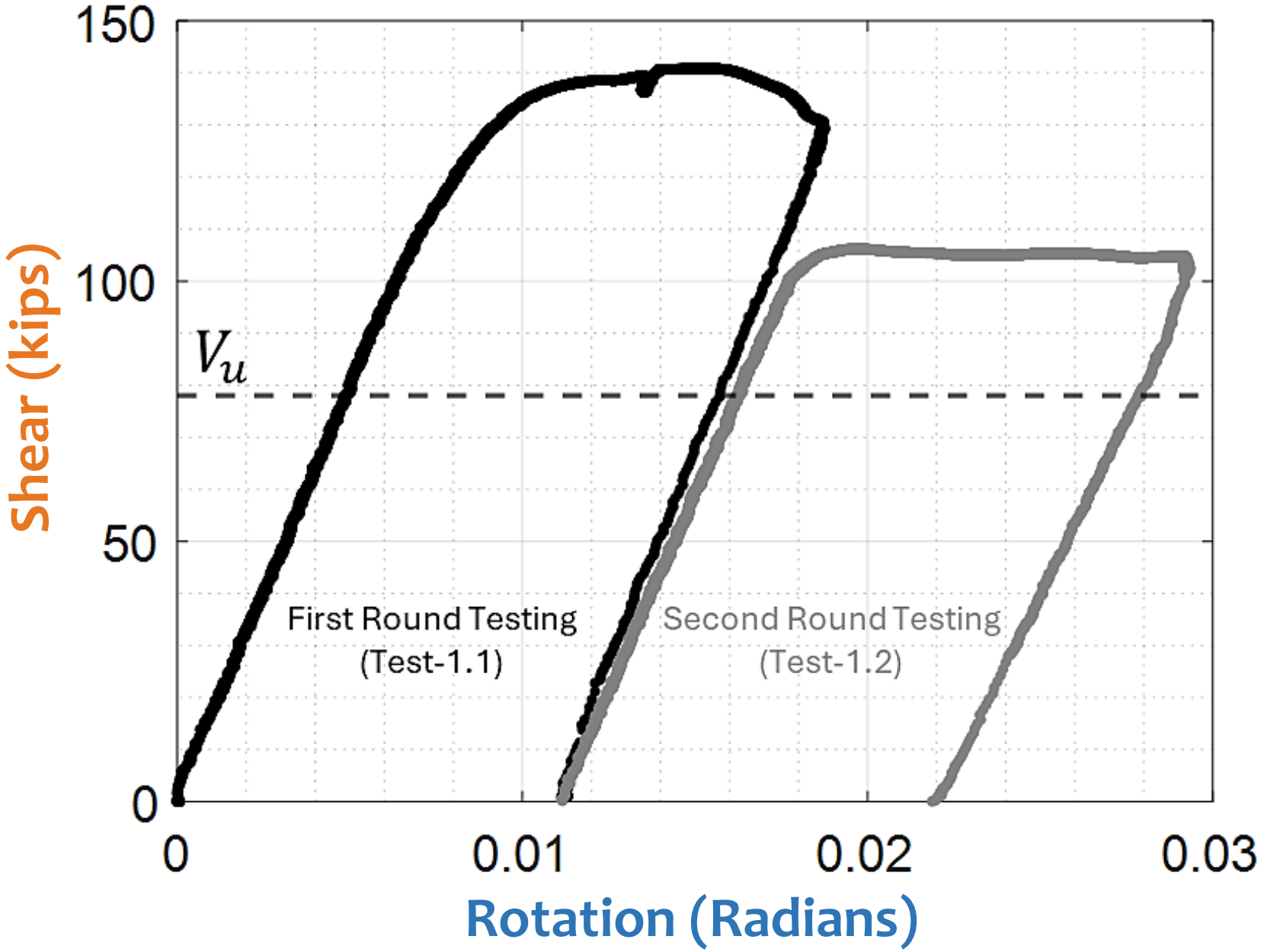


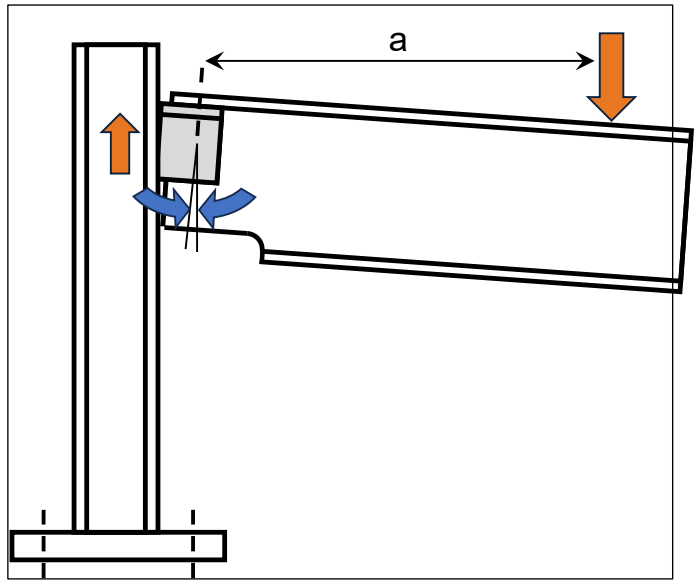
2. Full-Scale Testing Program

Test Matrix

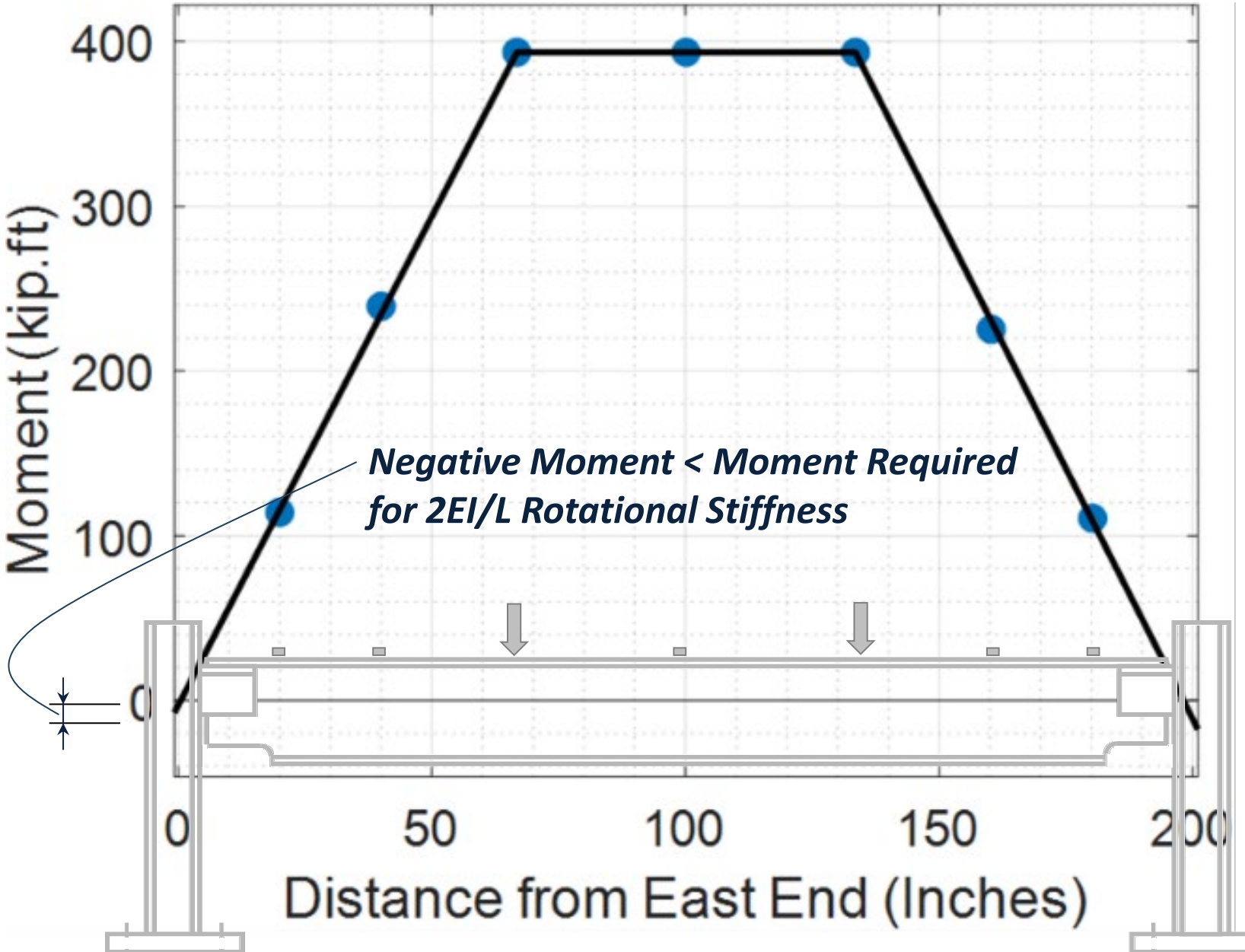
	Con.	Girder	Angles/Tab	Bearing	Welds 	Notes
1	A	W24x68 (18’)	L8x4x3/4	5”	Max	Lateral bracing set back ~1/2”
	B		L8x4x3/4	5”		

Test 1 – Initial Evaluation

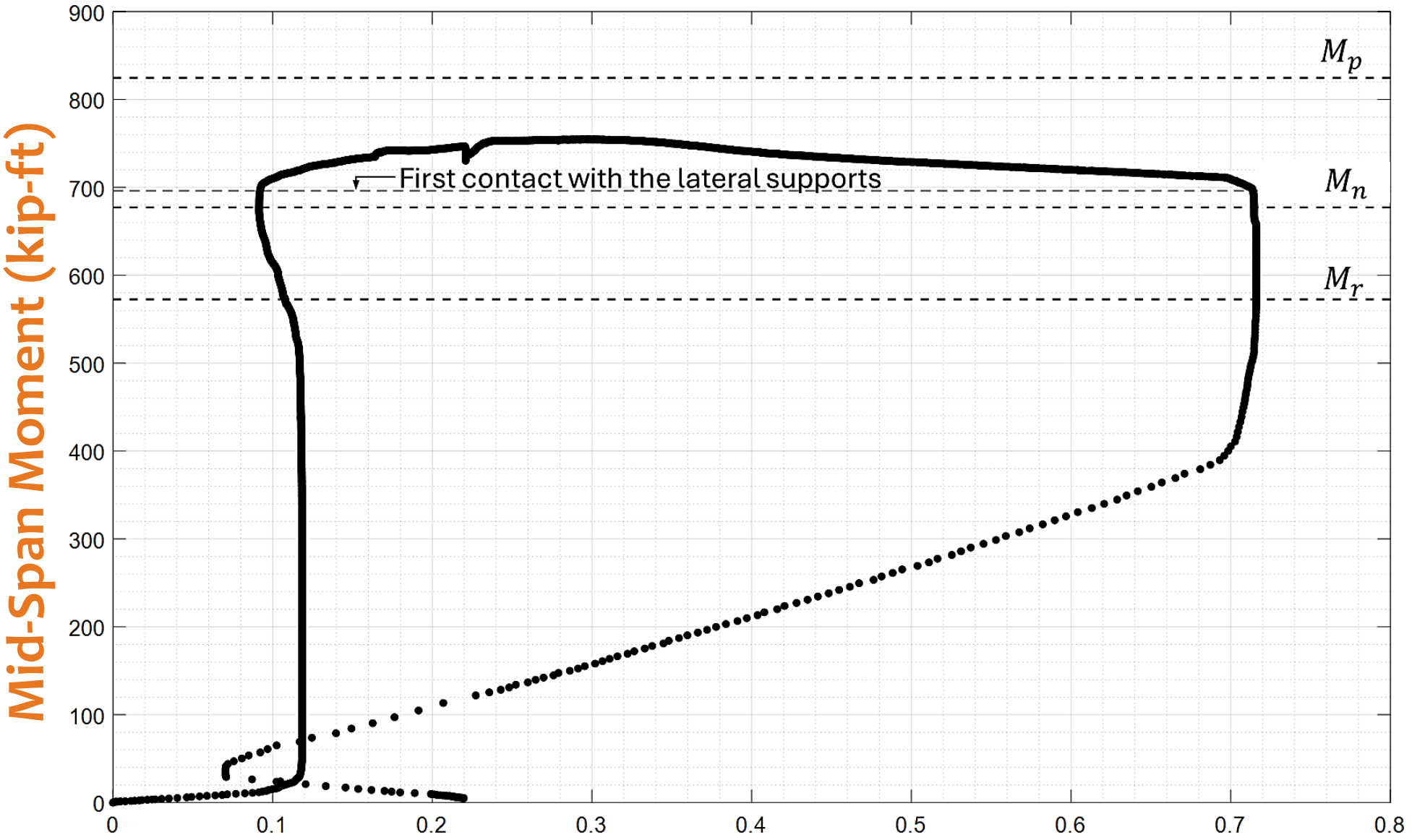


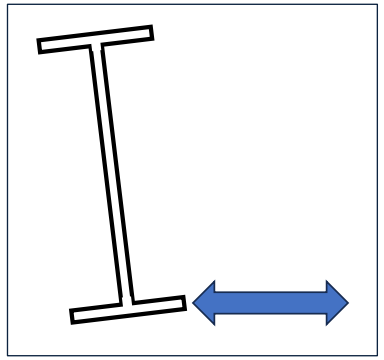


Test 1 – Initial Evaluation



Test 1 – Initial Evaluation

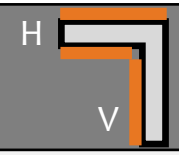




Lateral supports 1/2" away from the specimen at the start of the test

2. Full-Scale Testing Program

Test Matrix

	Con.	Girder	Angles/Tab	Bearing	Welds 	Notes
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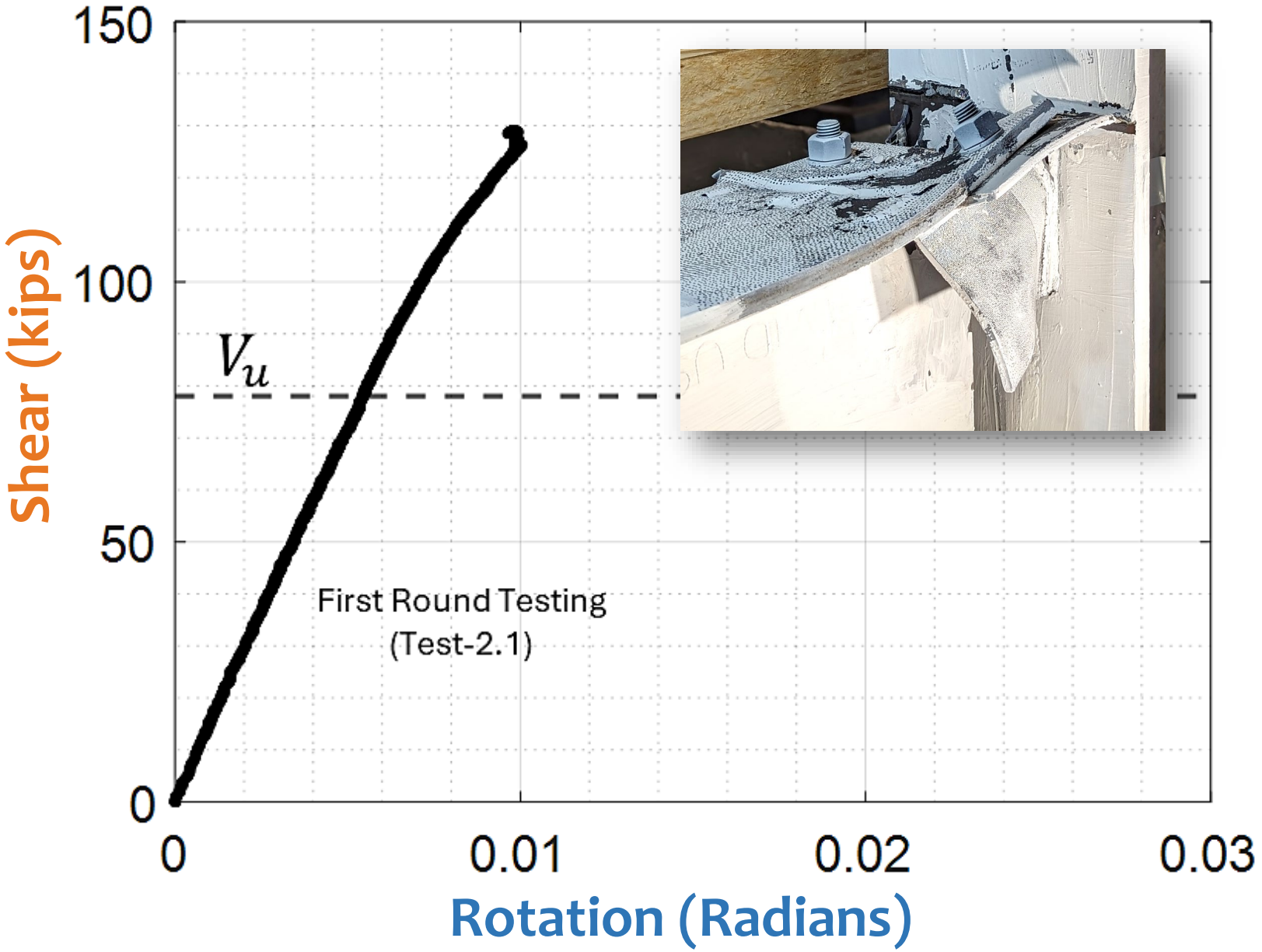
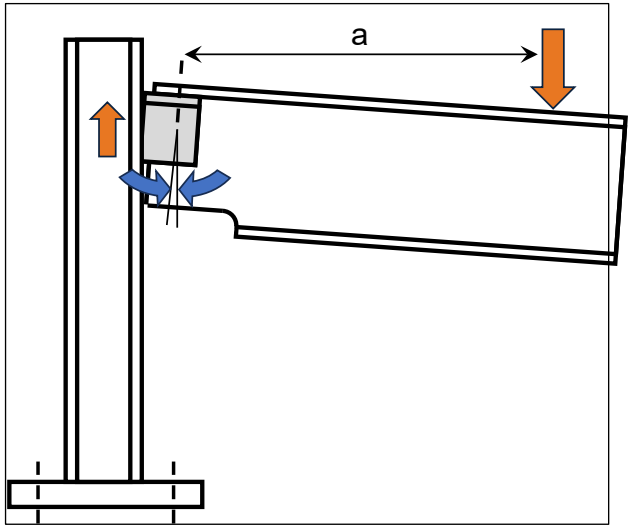
1	B ✓		L8x4x3/4	5”		
2	C		L8x4x3/4	3”	V / 2H (5/16”)	
2	D		L6x4x5/16	5”	V / H (5/16”)	Weld controls

Test 2D – Reduced Angles and Weld



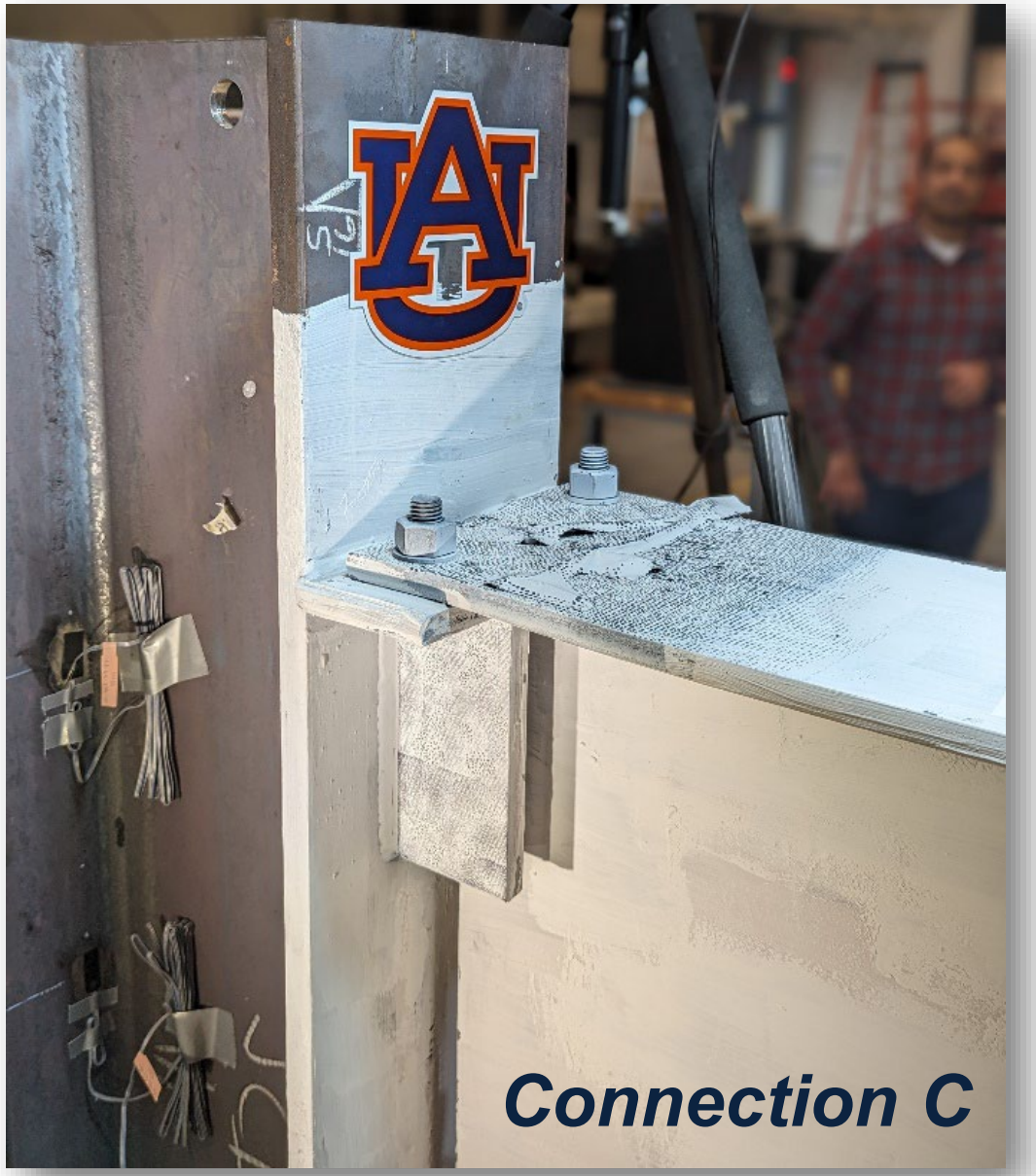


Weld capacity 46% higher than theoretical nominal strength

Test 2C – Reduced Bearing Length

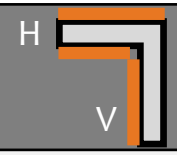
Connection C …

Test 2C – Reduced Bearing Length

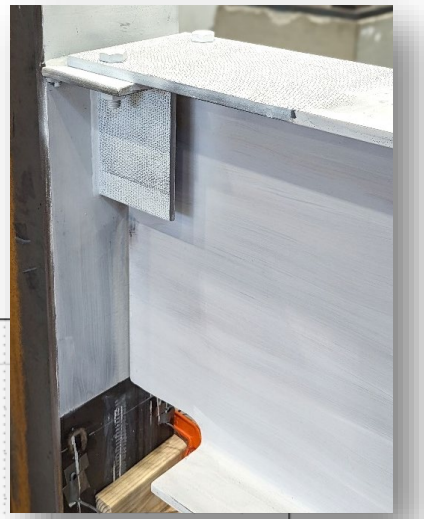


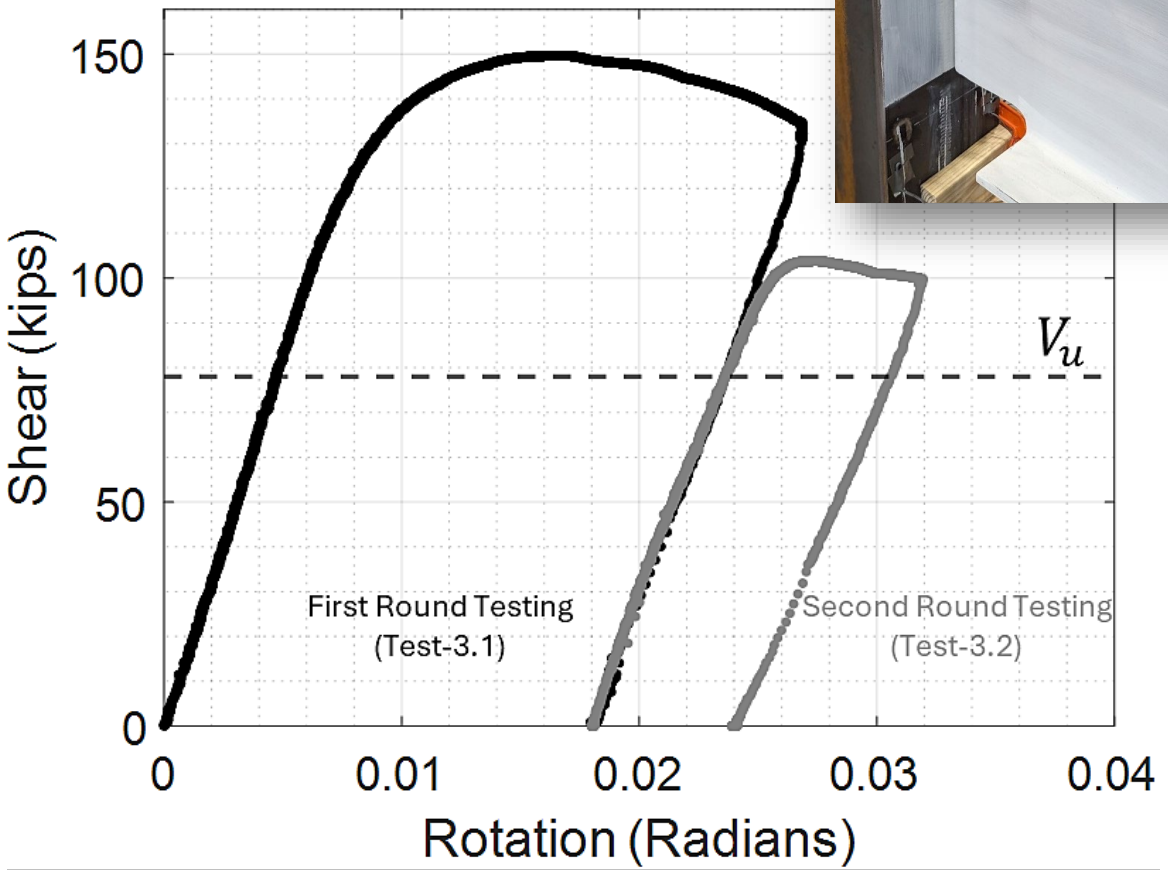
2. Full-Scale Testing Program

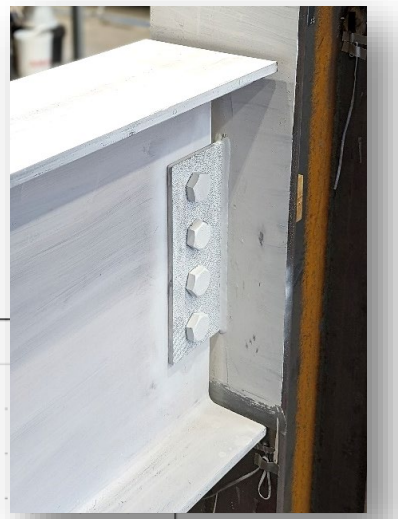
Test Matrix

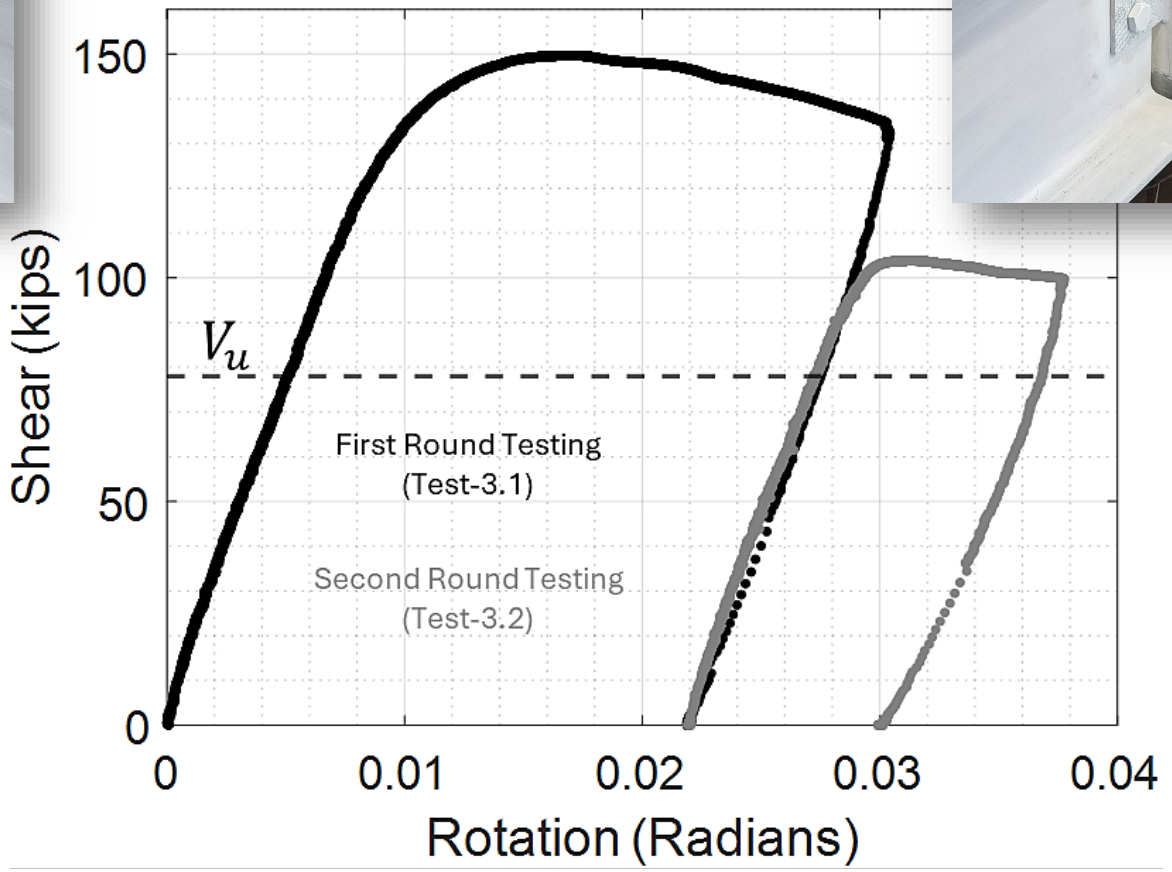
	Con.	Girder	Angles/Tab	Bearing	Welds 	Notes
1	A ✓	W24x68 (18’)	L8x4x3/4	5”	Max	Lateral bracing set back ~1/2”
1	B ✓		L8x4x3/4	5”		
2	C ✓		L8x4x3/4	3”	V / 2H (5/16”)	
2	D		L6x4x5/16	5”	V / H (5/16”)	Weld controls
3	E		L8x4x1/2	5”	V / 2H (5/16”)	
3	F		3/8x5x12.5	N/A	5/16”	Shear tab

Test 3: Comparison with Shear Tab









Test 3: Comparison with Shear Tab

Connection E (Drop-In)

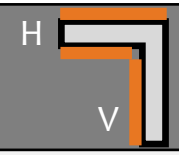
Connection F (Shear Tab)

Test 3: Drop-In Flange Transverse Strains

ε_{yy}

2. Full-Scale Testing Program

Test Matrix

	Con.	Girder	Angles/Tab	Bearing	Welds 	Notes
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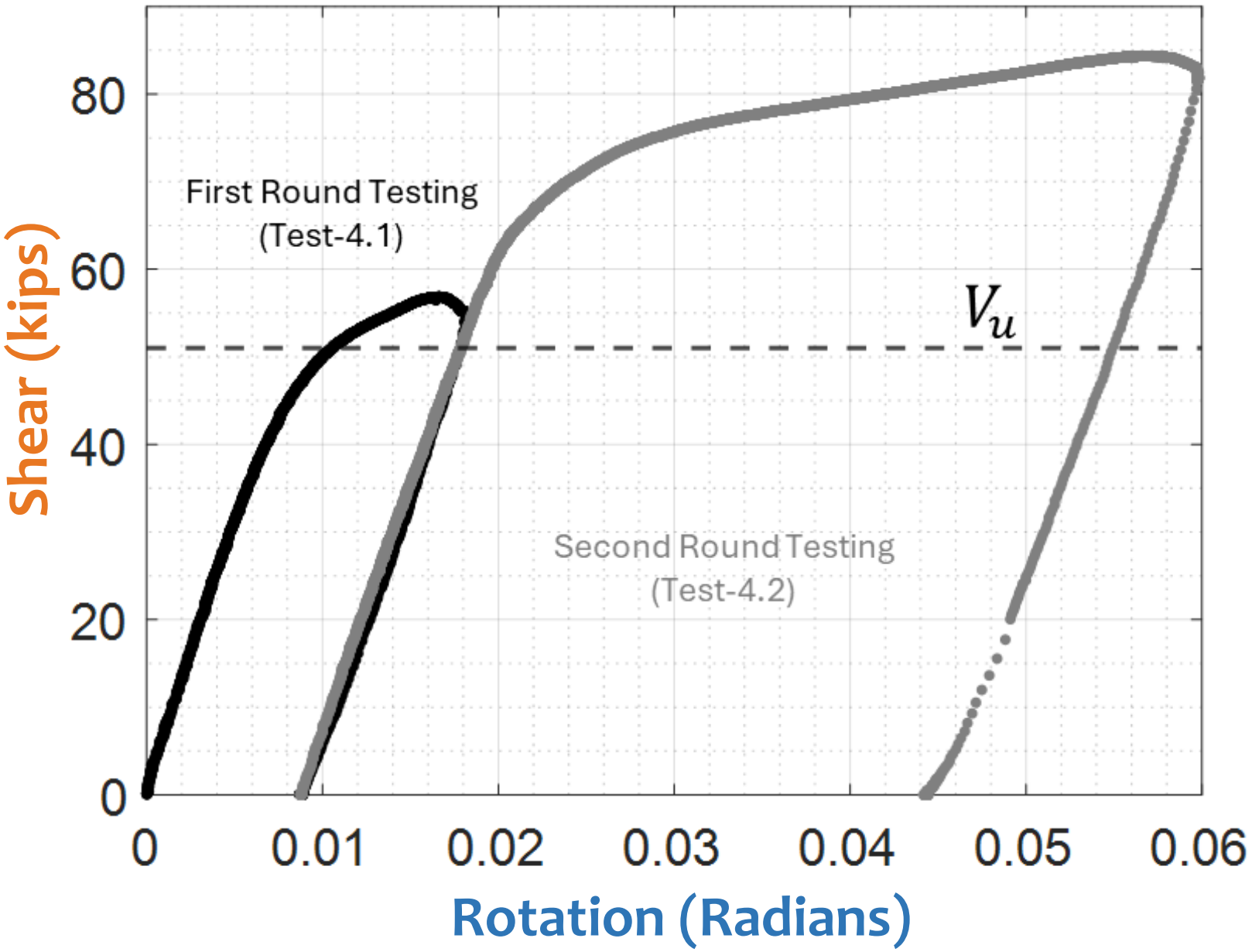
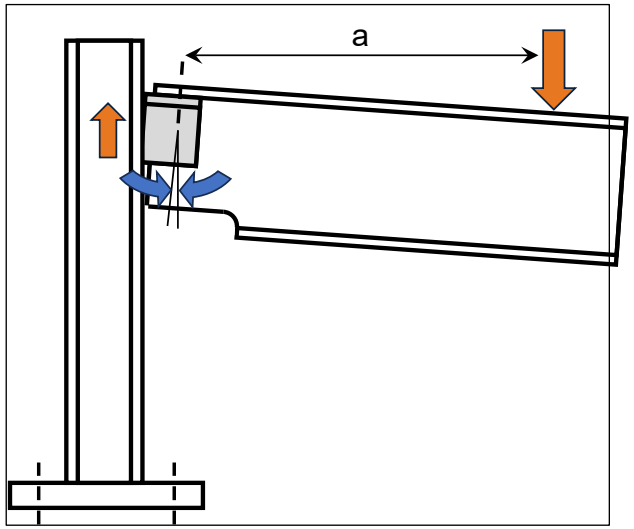
1	B ✓		L8x4x3/4	5”		
2	C ✓		L8x4x3/4	3”	V / 2H (5/16”)	
2	D		L6x4x5/16	5”	V / H (5/16”)	Weld controls
3	E ✓		L8x4x1/2	5”	V / 2H (5/16”)	
3	F ✓		3/8x5x12.5	N/A	5/16”	Shear tab
4	G	W16x36 (14’)	L6x4x5/16	3”	V / 2H (5/16”)	
4	H		L4x3x1/2	3”	2V / 2H (5/16”)	Angles flipped

Test 4G – Reduced Girder Size

Connection G …

Test 4G – Reduced Girder Size



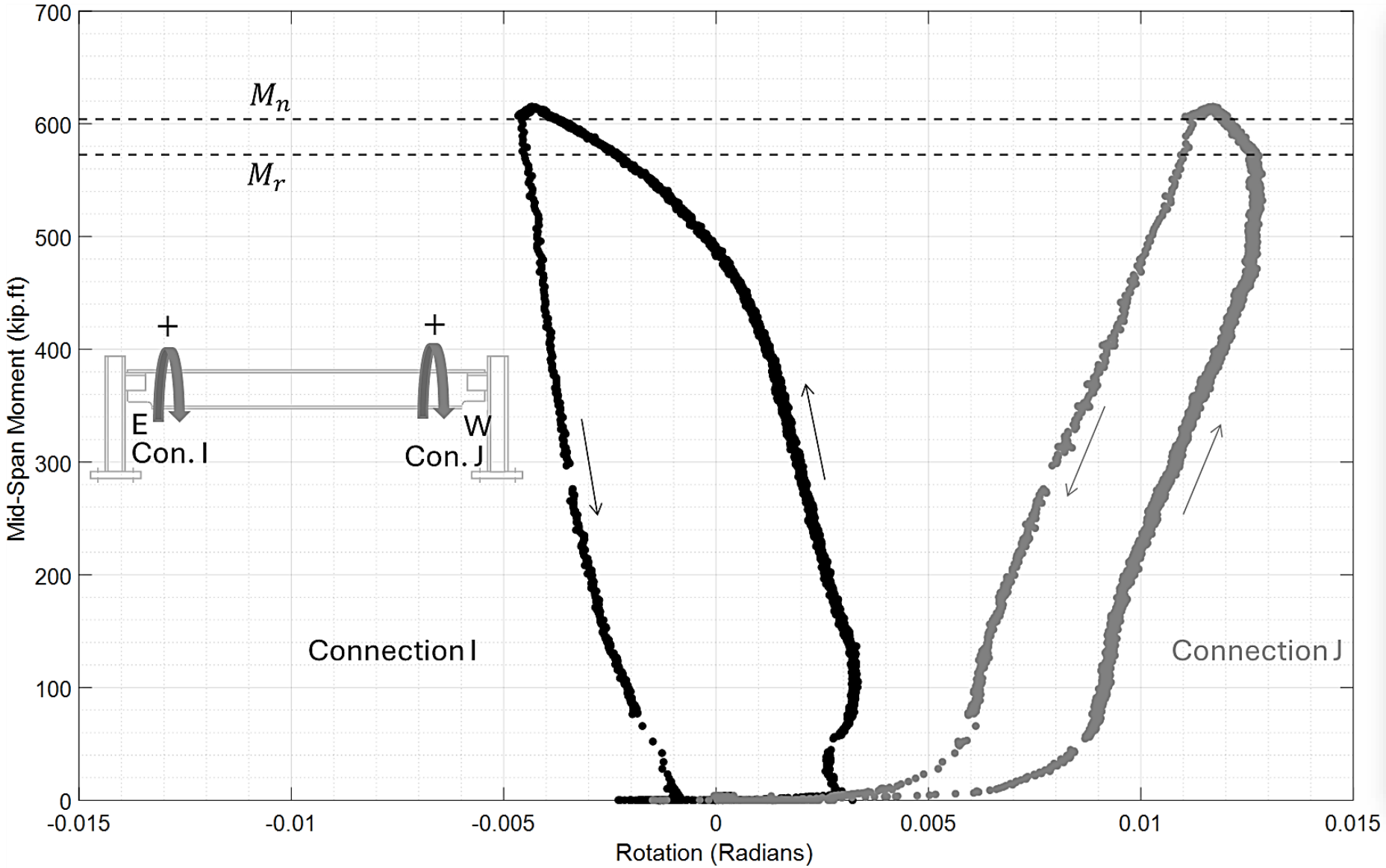


2. Full-Scale Testing Program

Test Matrix

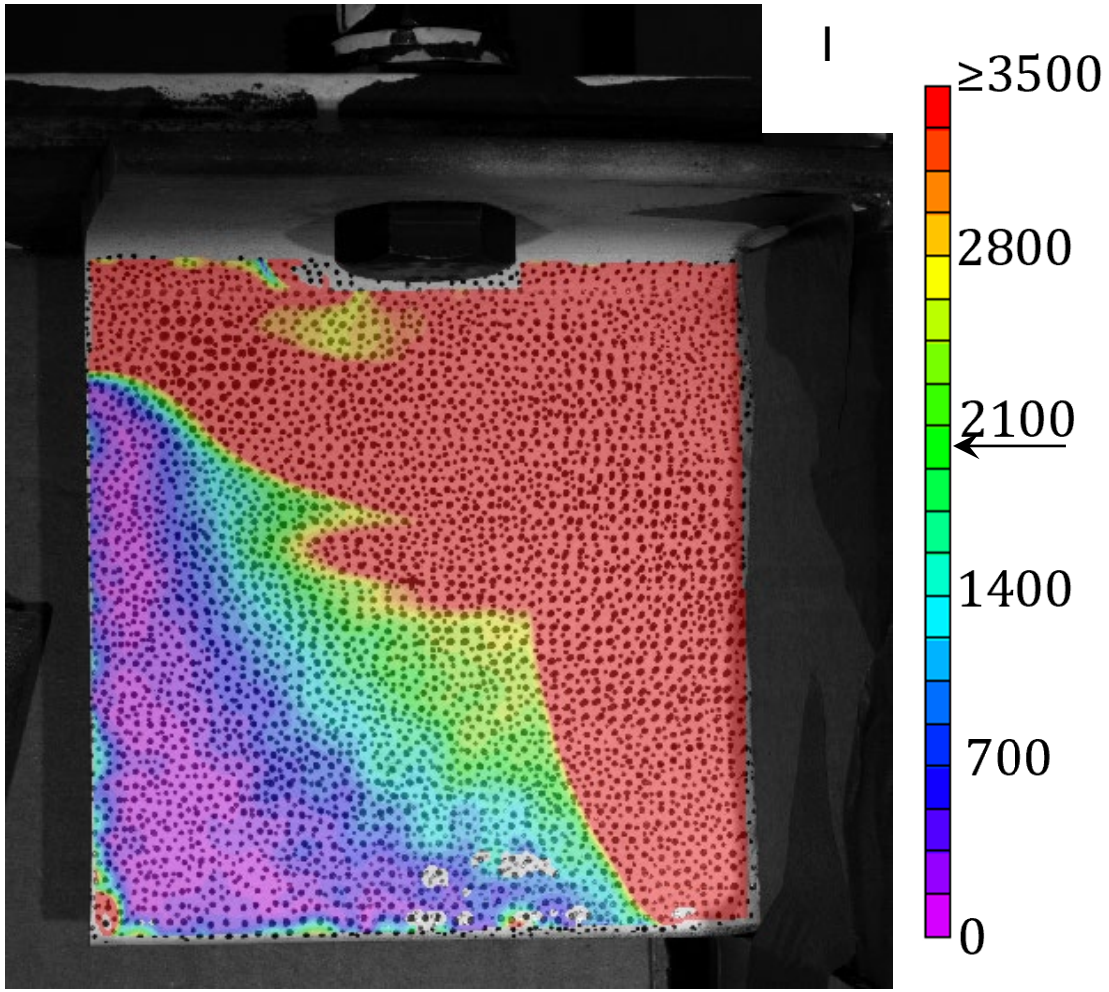
	Con.	Girder	Angles/Tab	Bearing	Welds (H / V)	Notes
1	A ✓	W24x68 (18’)	L8x4x3/4	5”	Max	Lateral bracing set back ~1/2”
	B ✓		L8x4x3/4	5”		
2	C ✓		L8x4x3/4	3”	V / 2H (5/16”)	
	D		L6x4x5/16	5”	V / H (5/16”)	Weld controls
3	E ✓		L8x4x1/2	5”	V / 2H (5/16”)	
	F ✓		3/8x5x12.5	N/A	5/16”	Shear tab
4	G ✓	W16x36 (14’)	L6x4x5/16	3”	V / 2H (5/16”)	
	H		L4x3x1/2	3”	2V / 2H (5/16”)	Angles flipped
5	I	W24x68	L6x4x5/16	5”	2V&2H (5/16)	Unbraced, then Braced Tests
	J		L4x3x1/2	3”		

Test 5 – Unbraced



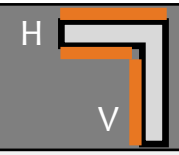
Test 5I – Undersized Angles

Von Mises Strain



2. Full-Scale Testing Program

Test Matrix

	Con.	Girder	Angles/Tab	Bearing	Welds 	Notes
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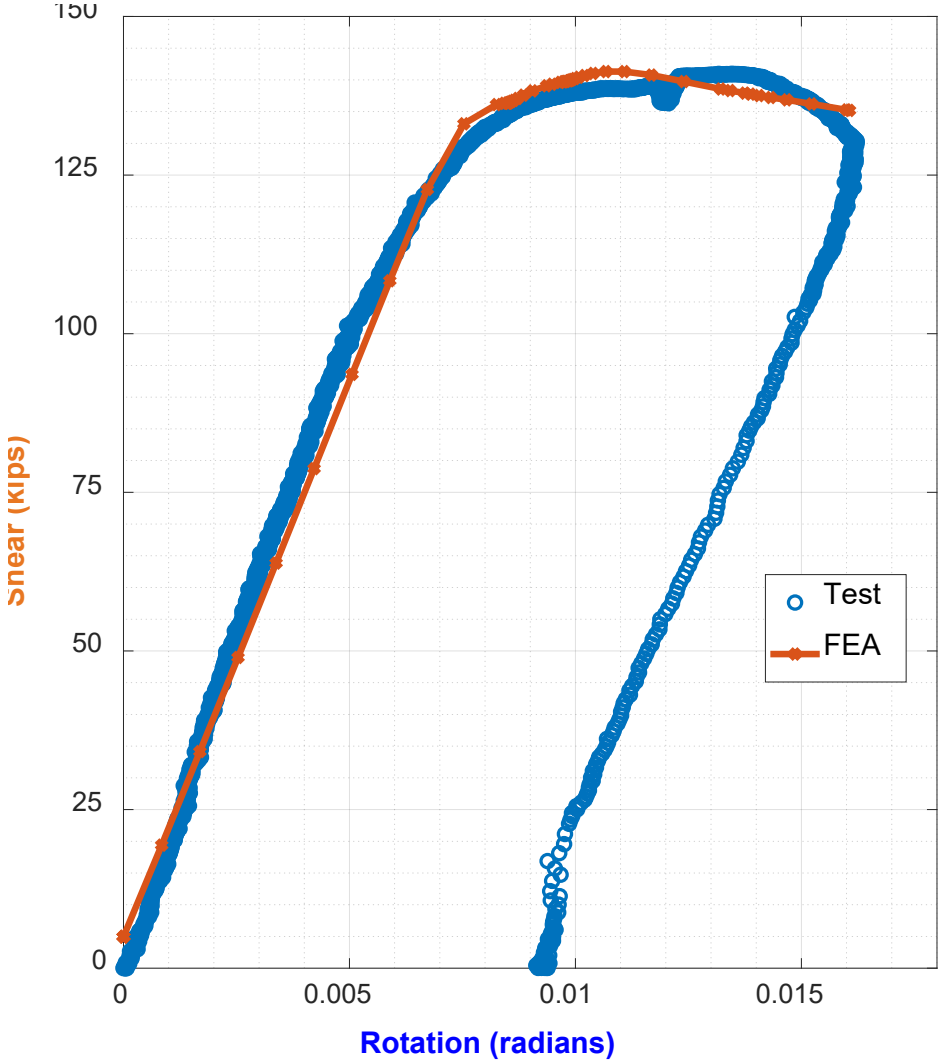
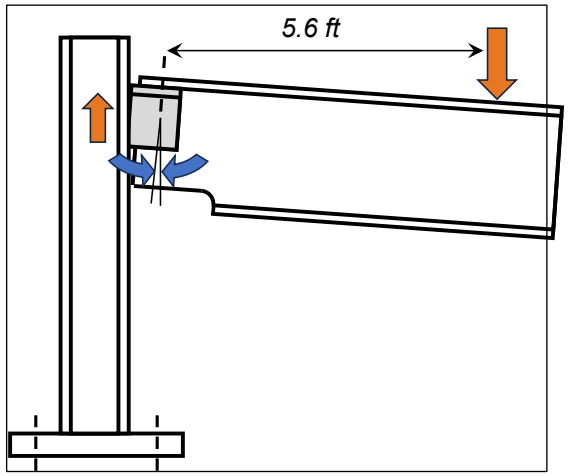
	B ✓		L8x4x3/4	5”		
2	C ✓		L8x4x3/4	3”	V / 2H (5/16”)	
	D		L6x4x5/16	5”	V / H (5/16”)	Weld controls
3	E ✓		L8x4x1/2	5”	V / 2H (5/16”)	
	F ✓		3/8x5x12.5	N/A	5/16”	Shear tab
4	G ✓	W16x36 (14’)	L6x4x5/16	3”	V / 2H (5/16”)	
	H		L4x3x1/2	3”	2V / 2H (5/16”)	Angles flipped
5	I ✓	W24x68 (18’)	L6x4x5/16	5”	2V&2H (5/16)	Unbraced, then Braced Tests
	J		L4x3x1/2	3”		
6	K		L6x4x5/16	5”	2V&2H (5/16)	Beam to Column Web
	L		L4x3x1/2	5”		

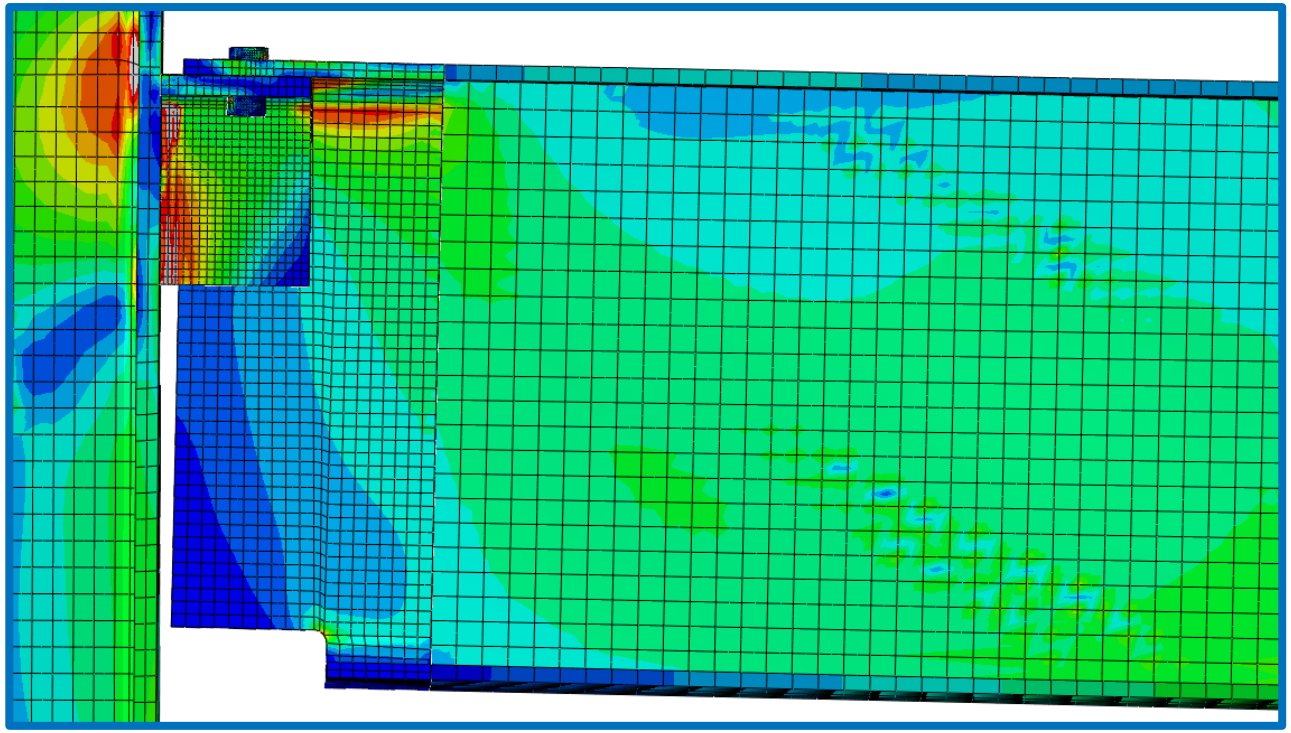
Test 6K – Beam-to-Column Web

3. Finite Element Analysis

Model Validation

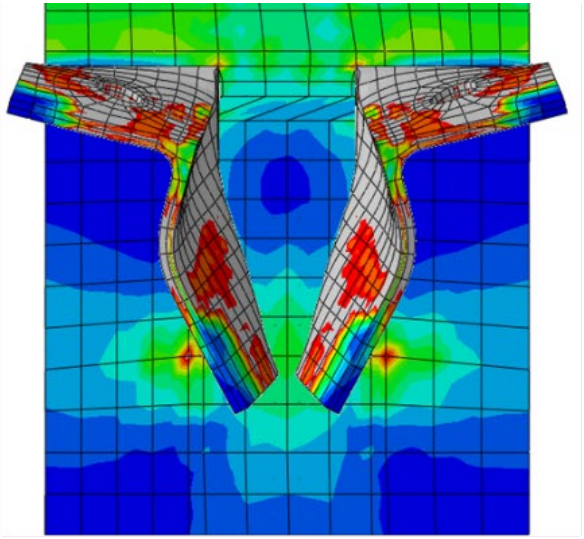


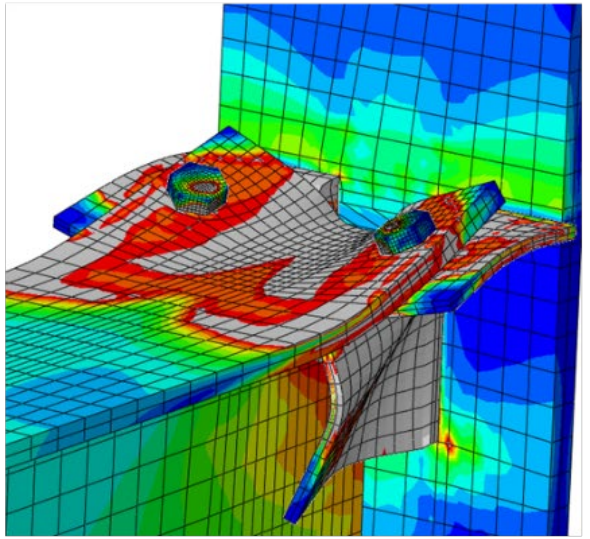


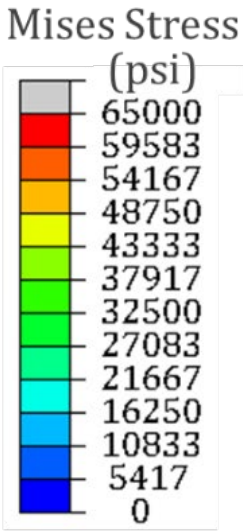


3. Finite Element Analysis

Model Validation





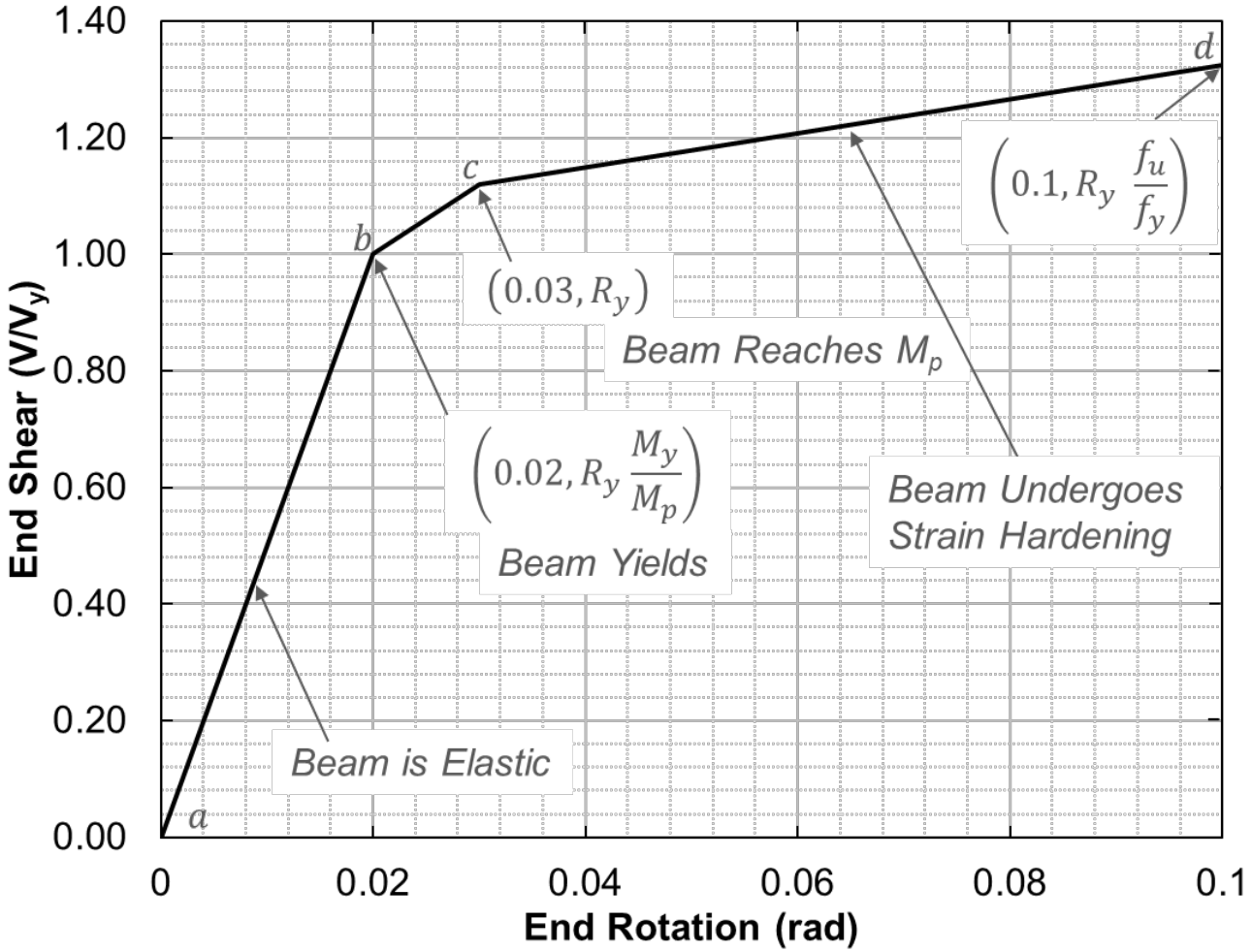


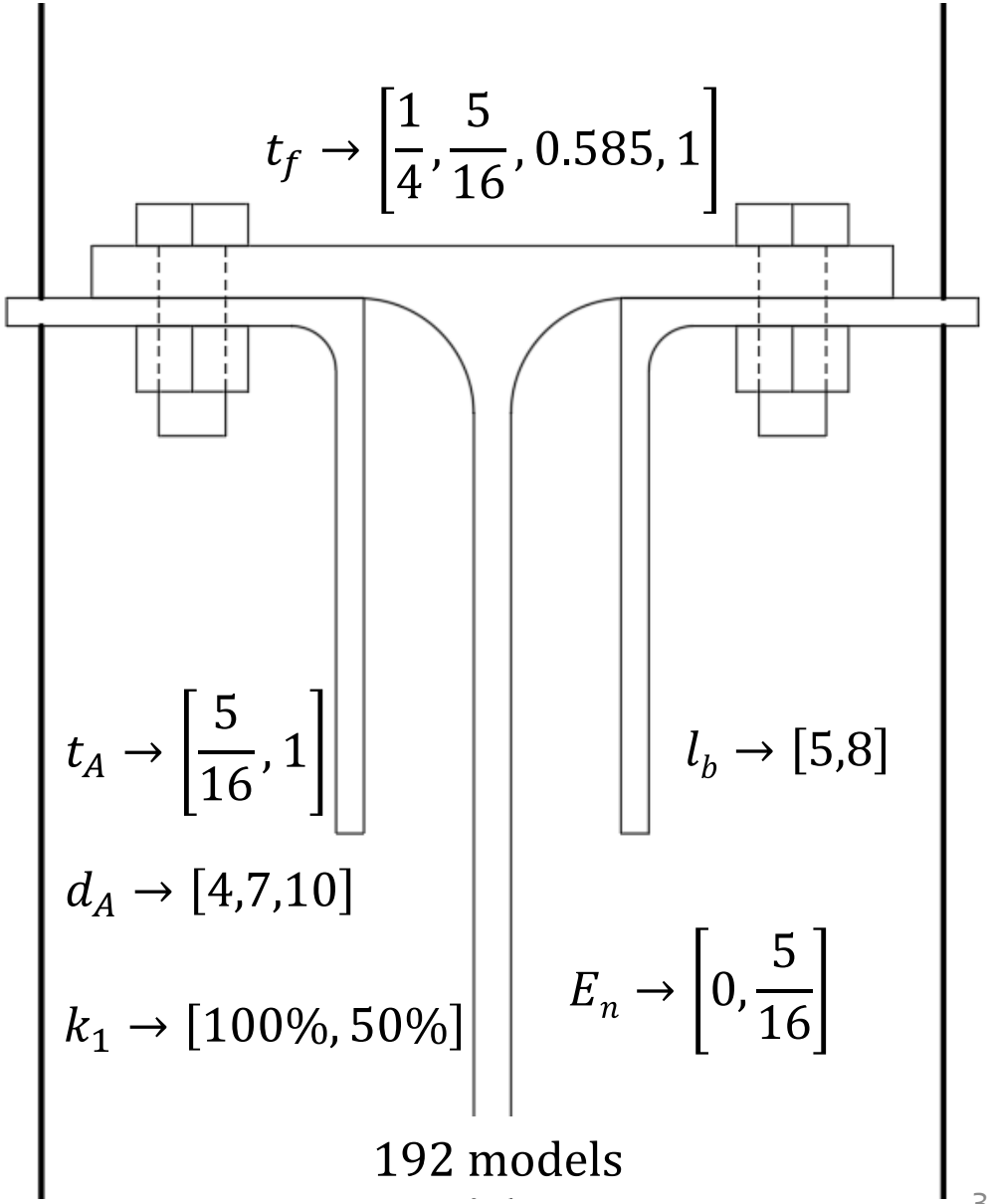
$V_{max} = 147\ kip$

$V_{max} = 149\ kip$

3. Finite Element Analysis

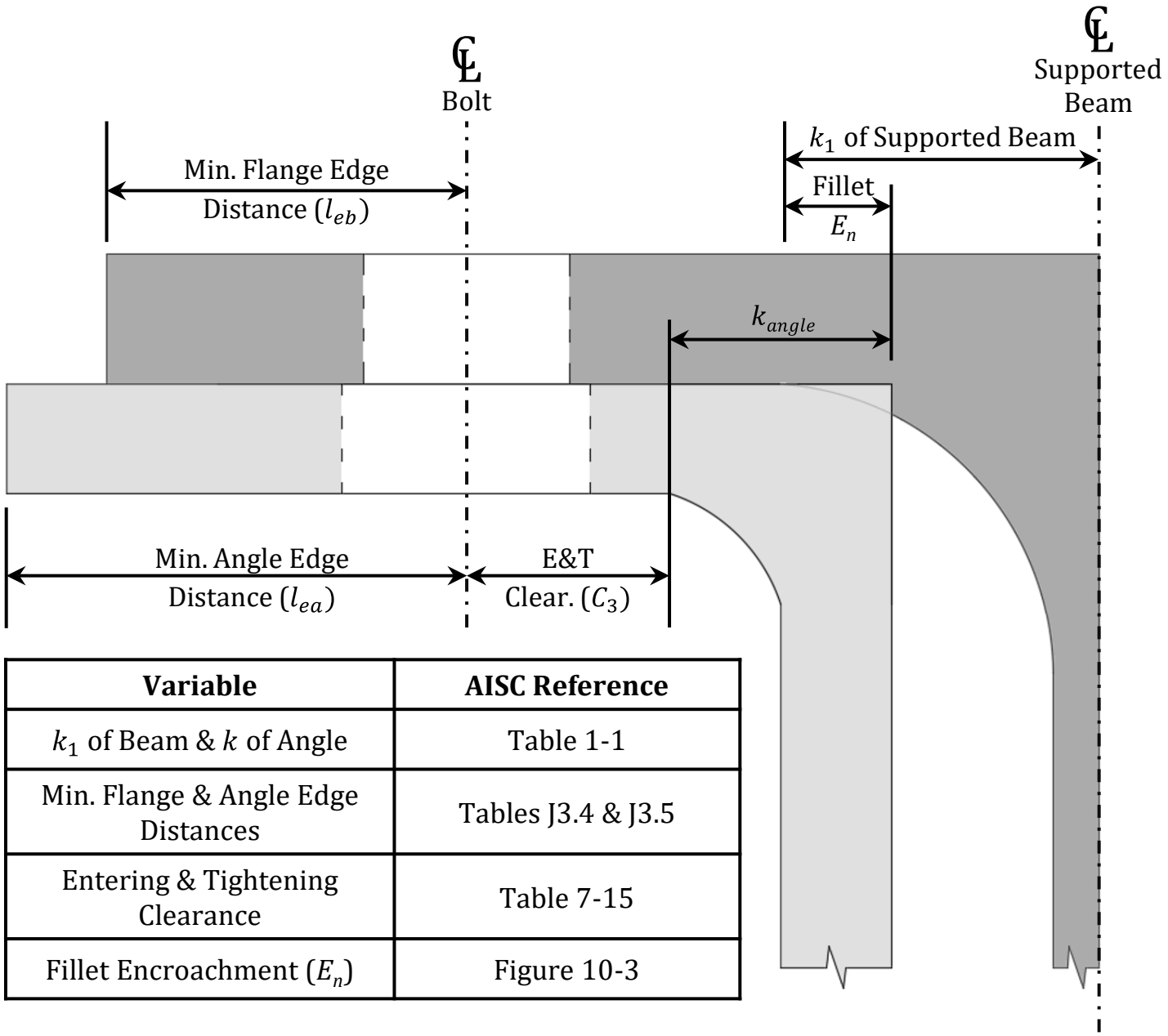
Parametric Study





Astaneh et al. (1989). "Design of single plate shear connections." Engineering Journal*, 26(1), 21-32.*

4. Design Guidance – Dimensional Limitations



Variable	AISC Reference
k_1 of Beam & k of Angle	Table 1-1
Min. Flange & Angle Edge Distances	Tables J3.4 & J3.5
Entering & Tightening Clearance	Table 7-15
Fillet Encroachment (E_n)	Figure 10-3

4. Design Guidance – Design Checks

Main Connection Failure Modes

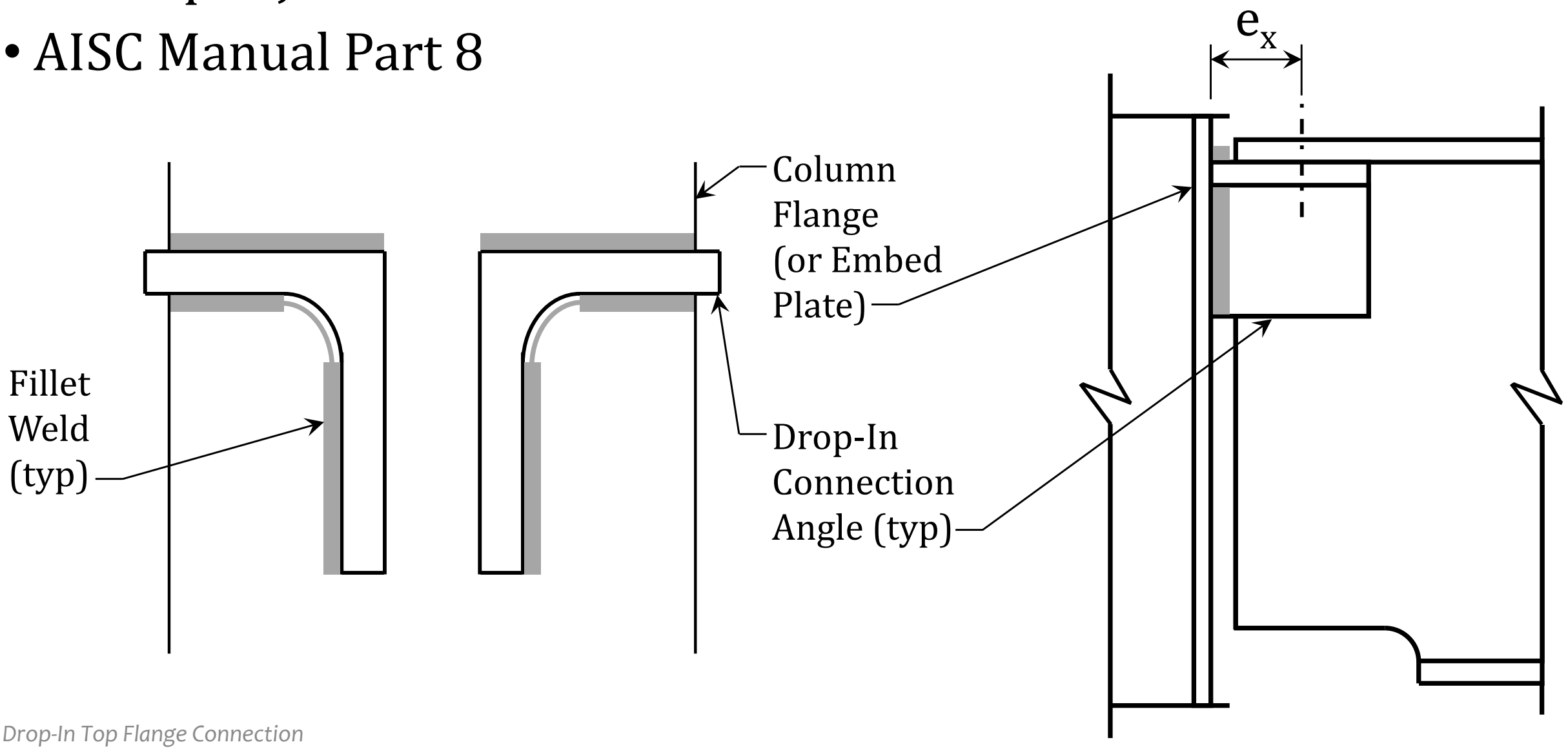
Weld Group

Flange Bending

Angle Shear

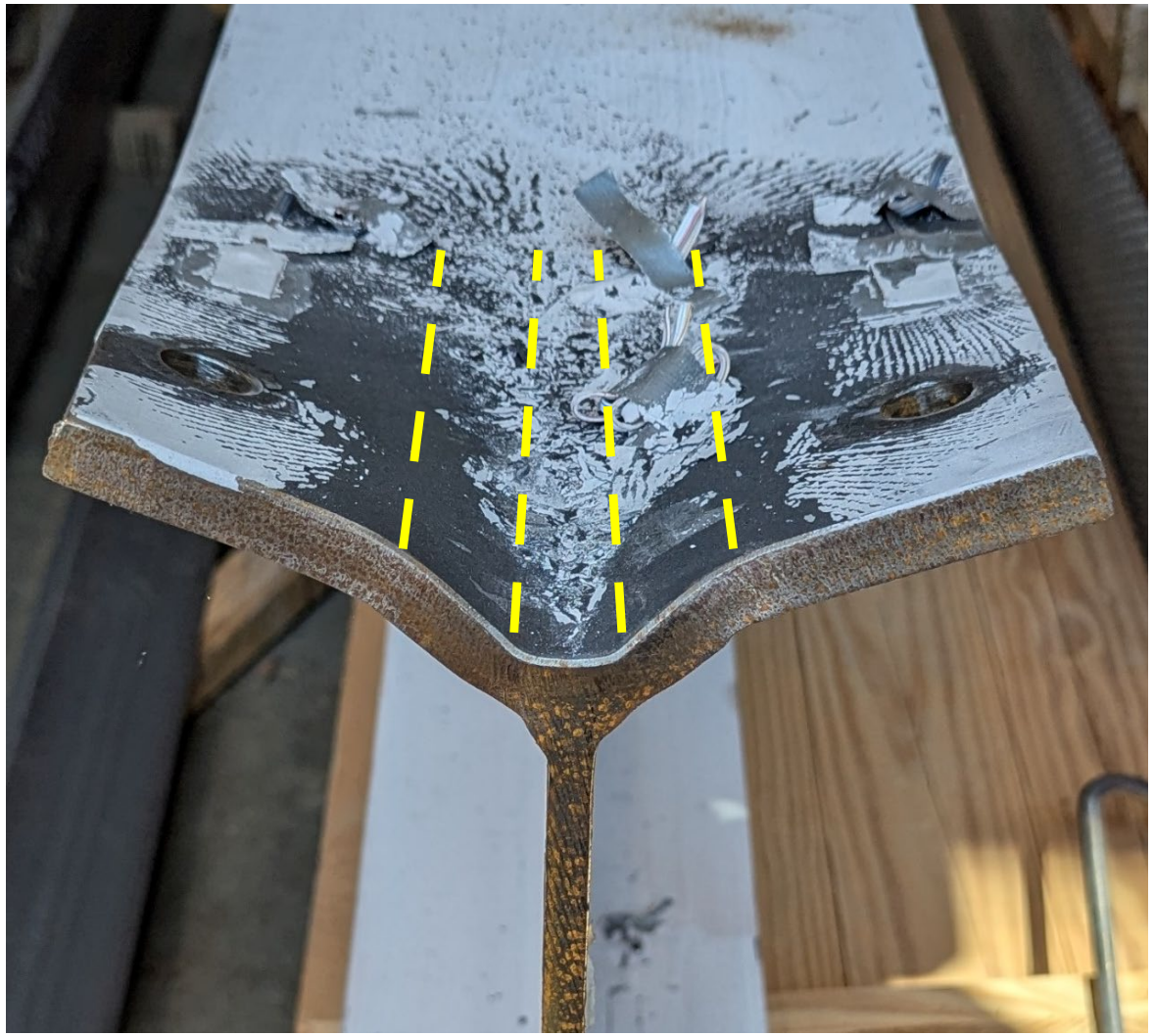
Design Check – Welds (Eccentrically Loaded)

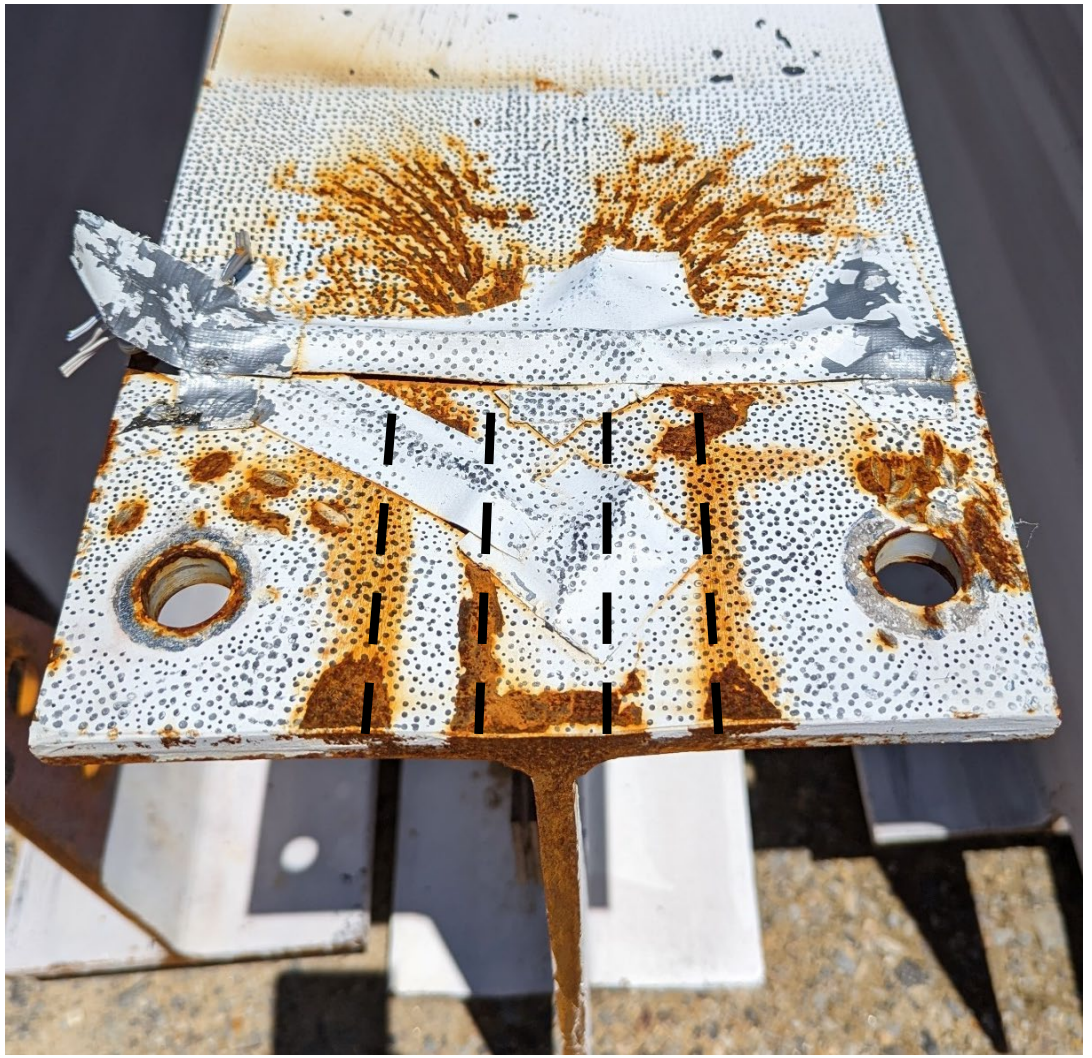
- AISC Spec J2
- AISC Manual Part 8



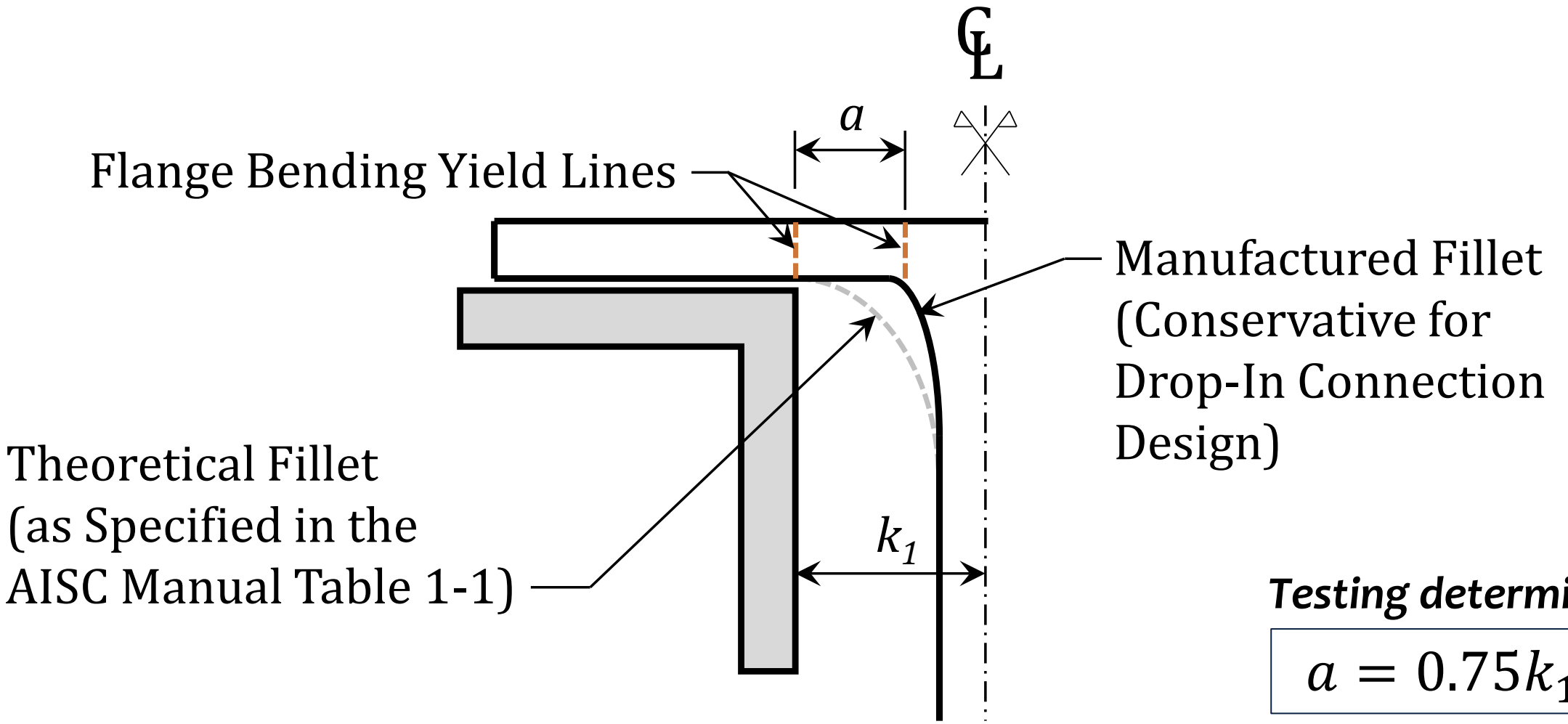
4. Design Guidance – Flange Bending

Yield line analysis ➔ Design expression





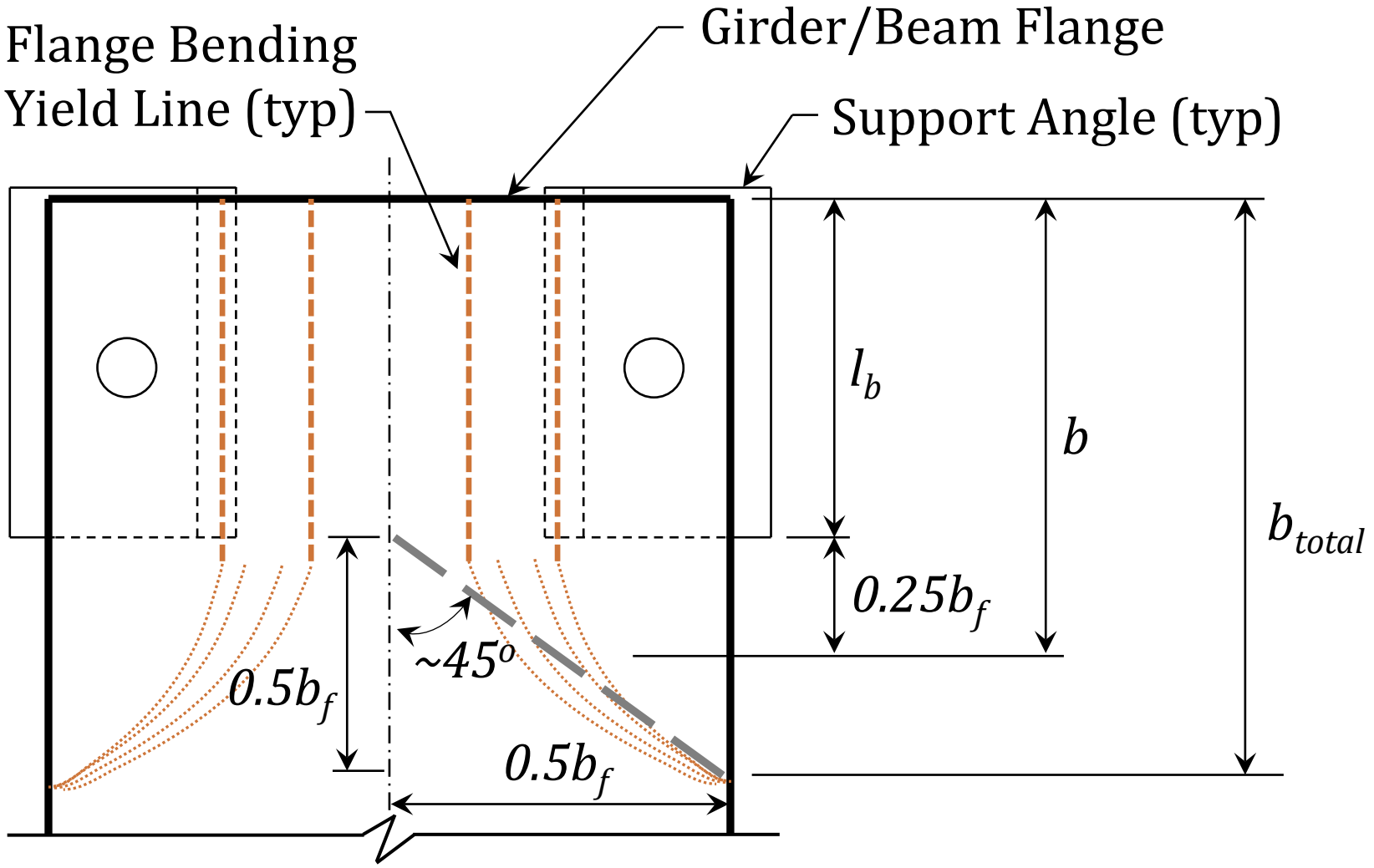
4. Design Guidance – Flange Bending



Testing determined:

$$a = 0.75k_1 - E_n$$

4. Design Guidance – Flange Bending

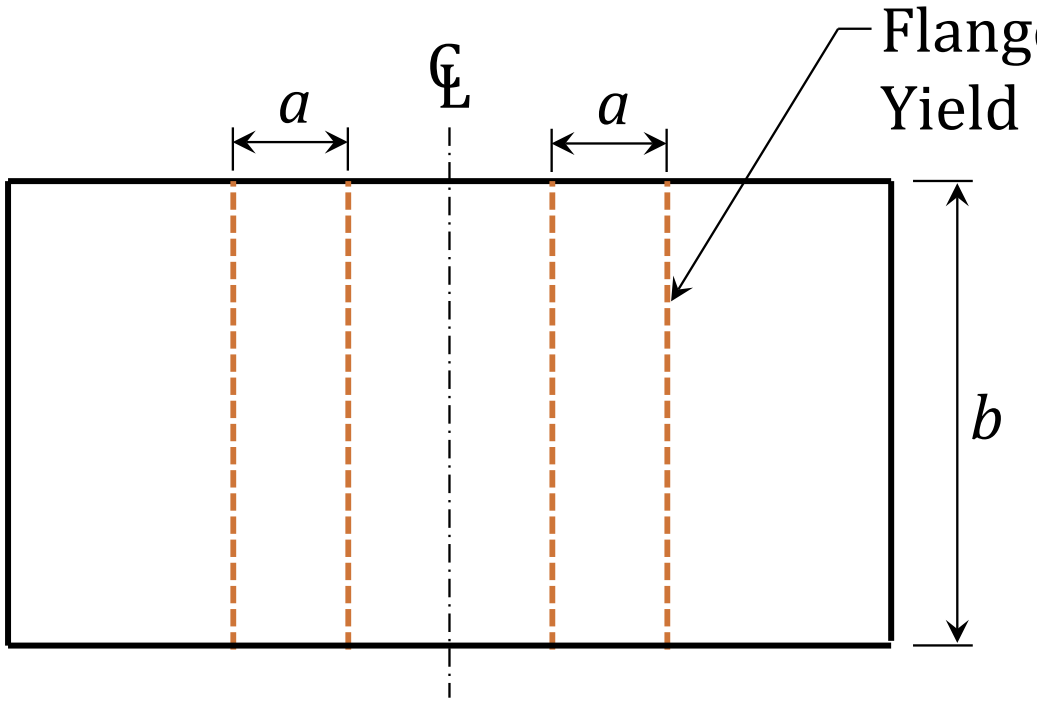


Testing/FEA determined:

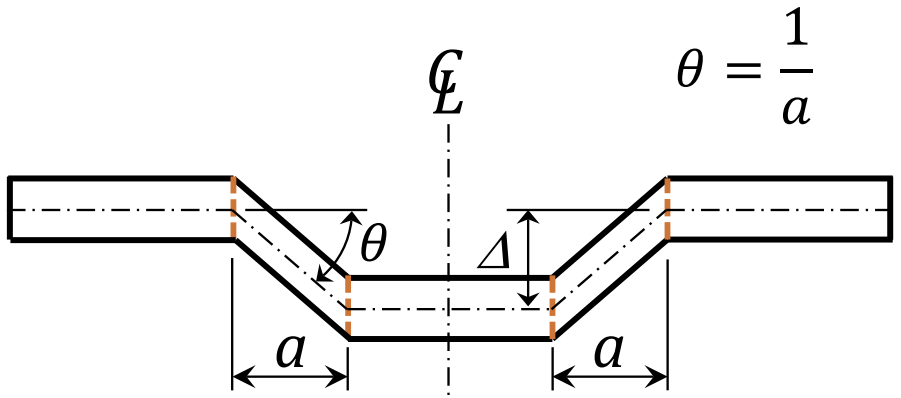
$$b = l_b + 0.25b_f$$

4. Design Guidance – Flange Bending

Yield line analysis ➔ Design expression



Top View – Top Flange "Plate"

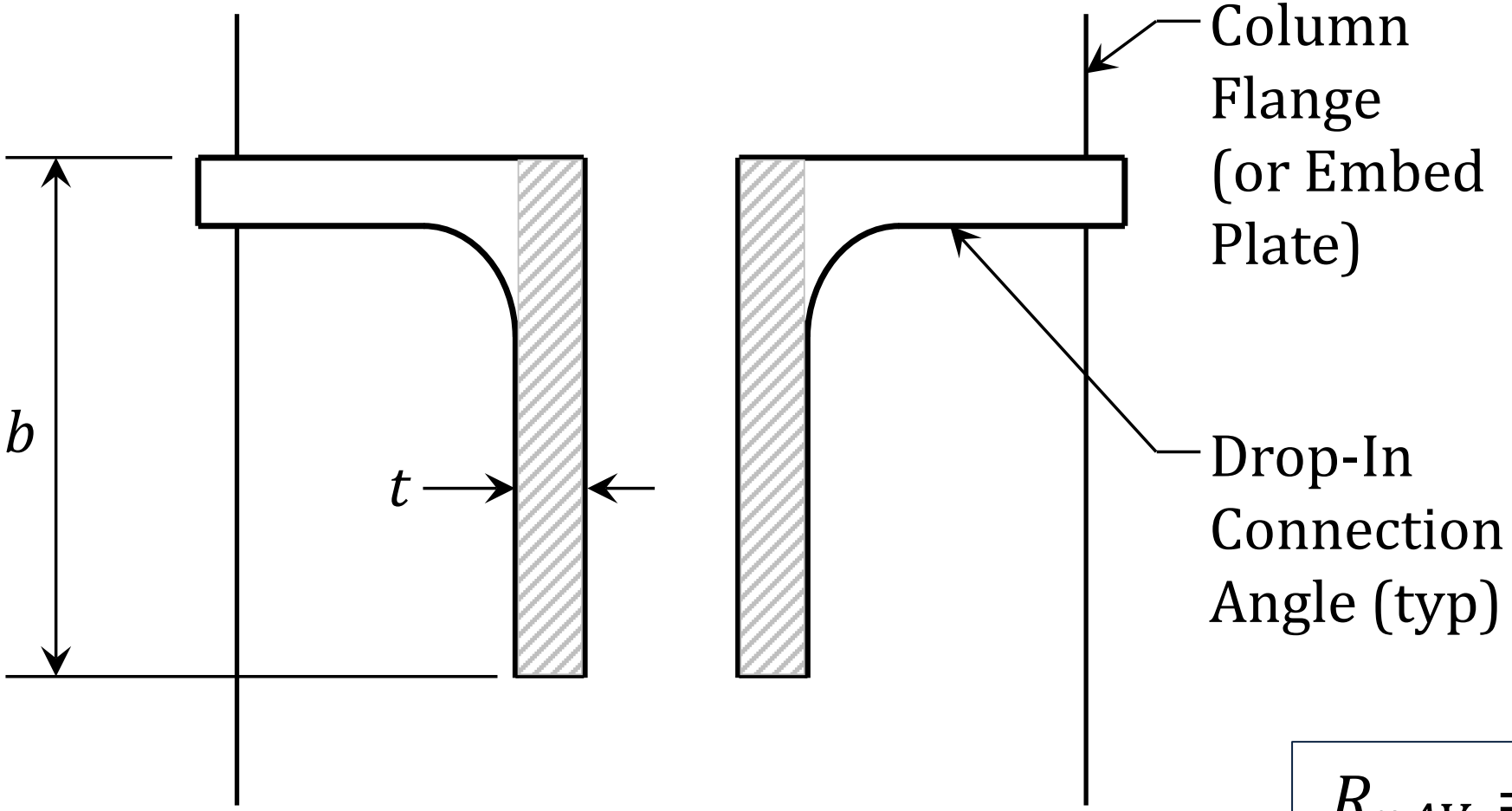


Section View

$$R_{nFB} = \frac{t_f^{\,2}}{a} F_{yf} b$$

4. Design Guidance – Angle Shear

- AISC Spec G3



$$R_{nAV} = 2\left(0.6F_y btC_{v2}\right)$$

4. Design Guidance – Other Considerations

- Beam shear
- Bolt tension
- Sidesway buckling
- Column web or flange bending
- Structural integrity

4. Design Guidance – Possible AISC Manual Table

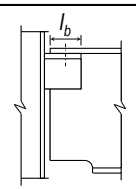
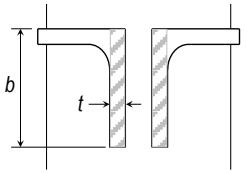


Table 10-E
Drop-In Connetions



Flange Bending Available Strength, kips

Shape	l_b = 4 in		l_b = 8 in	
	ASD	LRFD	ASD	LRFD
W27X84	73.9	111.1	119.4	179.5
W24X84	103.0	154.8	168.9	253.8
W24X76	80.2	120.6	131.6	197.8
W24X68	59.3	89.2	97.3	146.3
W24X62	75.3	113.2	127.6	191.9
W24X55	58.6	88.0	99.3	149.2
W21X83	193.7	291.2	321.0	482.4
W21X73	151.8	228.1	251.7	378.3
W21X68	129.9	195.2	215.5	323.9
W21X62	112.6	169.3	186.9	281.0
W21X55	81.1	121.8	134.6	202.3
W21X48	54.8	82.4	91.2	137.0
W18X86	150.9	226.8	240.0	360.8
W18X76	117.3	176.3	186.8	280.7
W18X71	176.9	265.9	296.6	445.8
W18X65	151.3	227.5	254.0	381.8
W18X60	139.8	210.1	234.7	352.8
W18X55	114.7	172.4	192.7	289.7
W18X50	93.8	141.0	157.6	236.9
W16X89	189.9	285.4	304.9	458.3
W16X77	142.7	214.5	229.5	344.9
W16X67	115.6	173.8	186.2	279.9
W16X57	134.8	202.6	228.1	342.8
W16X50	112.5	169.0	190.5	286.3
W16X45	90.3	135.8	153.1	230.1
W16X40	72.0	108.3	122.2	183.6
W16X36	56.6	85.0	95.9	144.2
W14X82	179.2	269.4	289.1	434.5
W14X74	151.1	227.1	243.7	366.3
W14X68	126.6	190.3	204.5	307.4
W14X61	108.0	162.2	174.4	262.1
W14X53	104.6	157.2	174.2	261.8
W14X48	84.9	127.6	141.4	212.6
W14X43	67.3	101.1	112.1	168.5
W12X87	173.2	260.3	271.8	408.5
W12X79	142.6	214.3	223.8	336.3
W12X72	118.1	177.4	185.5	278.8
W12X65	102.3	153.7	160.7	241.6
W12X58	113.4	170.4	183.1	275.3
W12X53	91.5	137.5	147.8	222.2
W12X50	105.0	157.8	174.8	262.7
W12X45	84.6	127.2	141.0	211.9
W12X40	72.6	109.2	121.0	181.9
Beam F_y = 50 ksi			ASD Ω = 1.67	LRFD ϕ = 0.90

Drop-In Top Flange Connection

Summary of Findings – Drop-In Connections

Capable of meeting shear connection criteria:

- Shear Strength [≥ Vu]
- Stiffness [≤ 2EI/L]
- Rotational Ductility [≥ 0.03 rad]
- Torsional Stiffness [Sufficient Girder LTB Capacity]

Primary design considerations:

- Satisfy geometry
- Meet limit states (weld, flange bending, angle shear, etc.)

Summary of Findings – Drop-In Connections

Advantages	Disadvantages
Erection	
Faster	Requires Vertical Placement
Improved Stability / Safer	

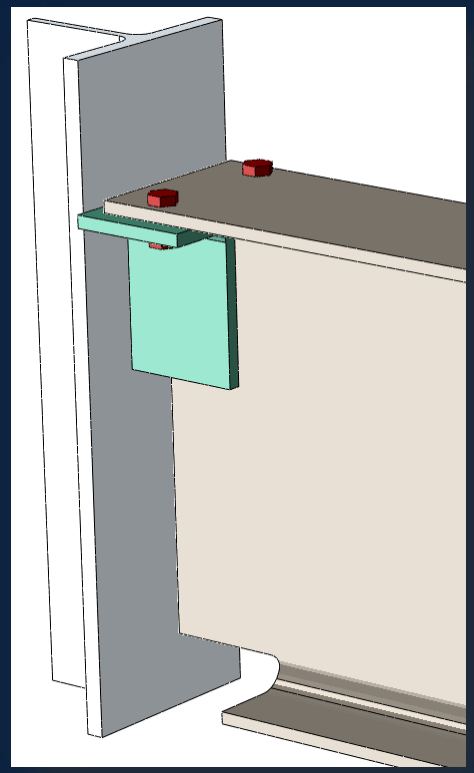
Take the Bull by the Horns with Drop-In Shear Connections

- Thursday 4:15 - 5:15pm ET
- Marriott: Ballroom 5

  (and NASCC Online)

Drop-In Top Flange Connection

70th Annual Structural Engineering Conference
University of Kansas



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