Rack Connection Test

per

RMI/ANSI MH16.1: 2021
13.5 CYCLIC TESTING OF BEAM-TO-COLUMN CONNECTIONS

JISE

Test
Report Number: **23-0255T**

Date: 5/20/2023

Report for: Jiangsu JISE Intelligent Storage Equipment Co., Ltd.

of racks manufactured by
Jiangsu JISE Intelligent Storage Equipment Co., Ltd.

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1.0 SCOPE

A rack beam-to-column connection cyclic displacement test was performed for *Jiangsu JISE Intelligent Storage Equipment Co., Ltd.* components manufactured by Jiangsu JISE Intelligent Storage Equipment Co., Ltd. in accordance with the 2021 RMI “Specification for the Design, Testing, and Utilization of Industrial Steel Storage Racks,” Section 13.5 (previously 9.6).

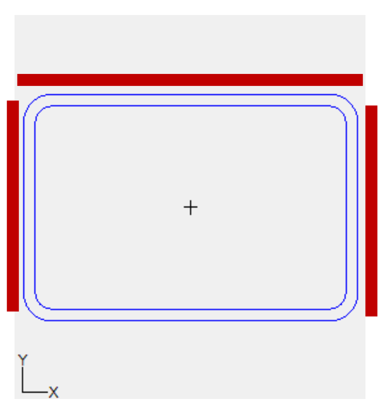
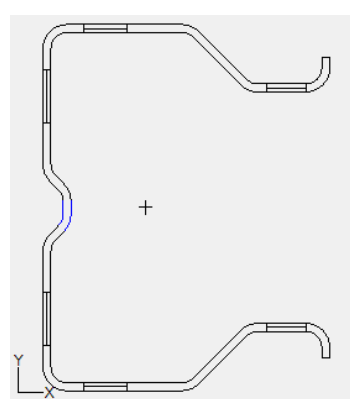
The purpose of this test was to evaluate rack beam-to-column connection and **determine** its **spring constant** and its cyclic **moment capacity** (seismic).

The specimens analyzed in this report are as follows:

Table 1. List of combinations for testing

Column			Beam			End Connector			Test
ID	Description	Thk	ID	Description	Thk	Thk	Connection	Ref.	ID
O09007008020	O 3-1/2 x 2-3/4	0.079”	T03805620	T 1-1/2 x 2-1/4	0.079”	0.097”	3-Tab	B - 3” drop	A

Following weldment pattern ID are assigned:

		
	“B” three-sided top weldment	

*See appendix for supplied dimensions and details

Figure 1. Test Component Dimensions and Profiles

Test materials were received on May 10, 2023 manufactured and shipped from China; All test materials were assembled and tested as shown.

2.0 TEST APPARATUS

The test apparatus was developed in accordance with RMI 2021 Specification, Section 13.5 as illustrated in Figure 2.

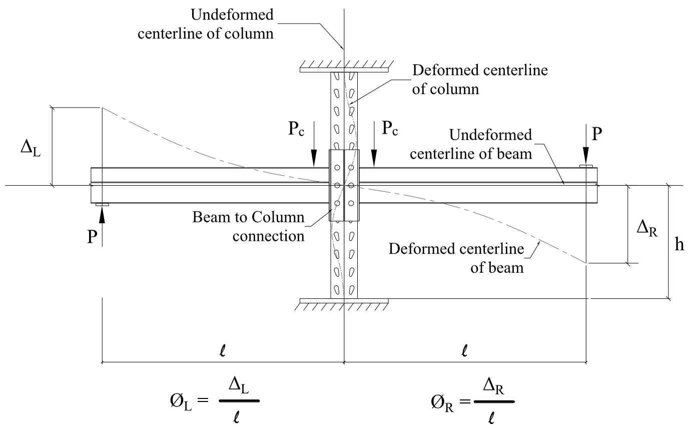


Figure 2. RMI specified connection test setup

Figure 3 Typical SMHE rack connection test setup

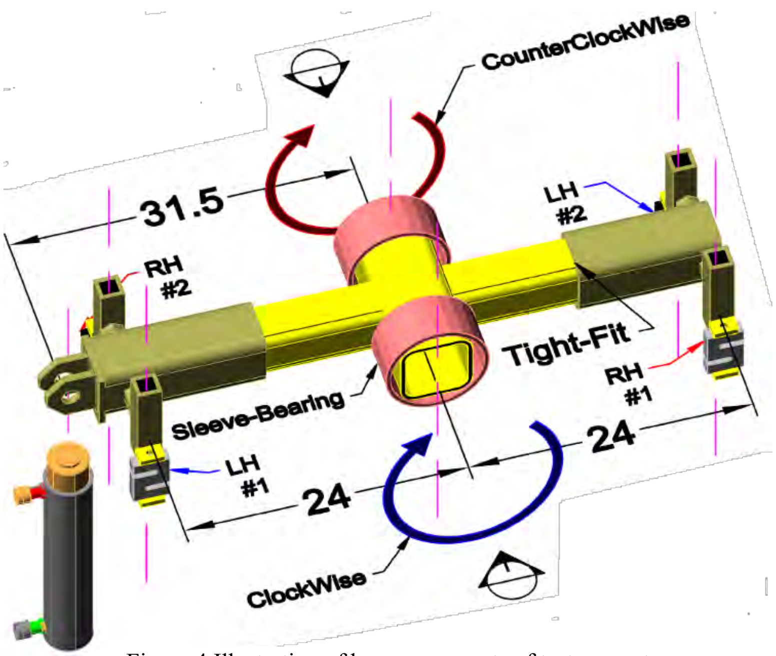


Figure 4 Illustration of key components of test apparatus

A double-acting hydraulic ram (Enerpac RR3014) connected to the end of ~~a~~ heavy member from a common center provided rotation for two test specimens at the front (#1) and rear (#2) -- see figure 4 for illustration.

A heavy member (I_x = 28.2 in^4) has negligible deflection, effectively providing equal displacements to all four arms. A displacement sensor for the test was conveniently located at 31_1/2" away from the common center provided equal beam-end displacements at 24.0" away.

Each arm is also equipped with a load cell at 24.0" away from the common center of rotation to register loads both in compression and in tension. Applied loads were measured using 10-Kip S-load cell installed between each of the arm and the beam-end clamp fixture.

In addition, the test apparatus is equipped with four small hydraulic cylinders providing the required simulated pallet load of approximately 1 kip to each arm engaging the connectors. A hydraulic pressure of 1000 psi was maintained via inter-connected hoses to each cylinder, having an effective area of 1 in^2 and an applied load of 1000 lbs at each cylinder (simulating a minimum pallet load to each arm). The cylinders are positioned at 4_1/4" away from the common center; this is far away enough to allow the connectors to freely bend during the test, accommodating up to 5-1/2" wide columns. The hydraulic pressure for simulated pallet load was adjusted at each end of a cycle to maintain 1000 psi of hydraulic pressure.

A program developed by SMHE provided a graphical output tracing the path of displacement and the corresponding loads throughout the entire test while a control of the displacement was achieved manually. Further analysis of the data was performed using a spreadsheet program in which a linear regression analysis was applied to the reduced and separated data set that was approximately below 85% of ultimate loads. The average of these slopes (representing the spring constant) was applied to the spring constant equation, which already accounted for the deflection from cantilever beams and the column.

3.0 TEST PROCEDURE

3.1 Test sample preparation

Test samples were supplied from JISE sent from China. The samples were received in single shipment(s) on 05/10/2023.

3.2 Locating the connector's neutral position.

After proper installation, the beam-end fixtures were clamped and tightened to minimizing profile warping. Top and bottom end-plates were welded to maintain the column profile and this is then clamped to restrain side-to-side movement. Approximately 10-kip were applied to each column via shared hydraulic cylinder. Then 1-kip each load was applied to each beam near the connection to simulate the pallet load via shared hydraulic cylinder. The initial horizontal-leveled setup is set as the neutral position (reference) for the entire test run.

3.3 Cyclic test procedures

The RMI states the following loading sequence:

(2) Loading Sequence for Storage-Rack Beam-to-Column Connections

Qualifying cyclic tests of storage-rack beam-to-column connections shall be conducted. By controlling the peak Drift Angle, θ, imposed on the Test Specimen as follows:

Load Step #	
(1)	3 cycles at θ = 0.025 radians
(2)	3 cycles at θ = 0.050 radians
(3)	3 cycles at θ = 0.075 radians
(4)	3 cycles at θ = 0.100 radians
(5)	2 cycles at θ = 0.150 radians
(6)	2 cycles at θ = 0.200 radians

Continue loading at increments of θ = 0.050 radians, with two cycles of loading at each step.

Beam end displacements and the number of test cycles at each stage are listed in the Table below.

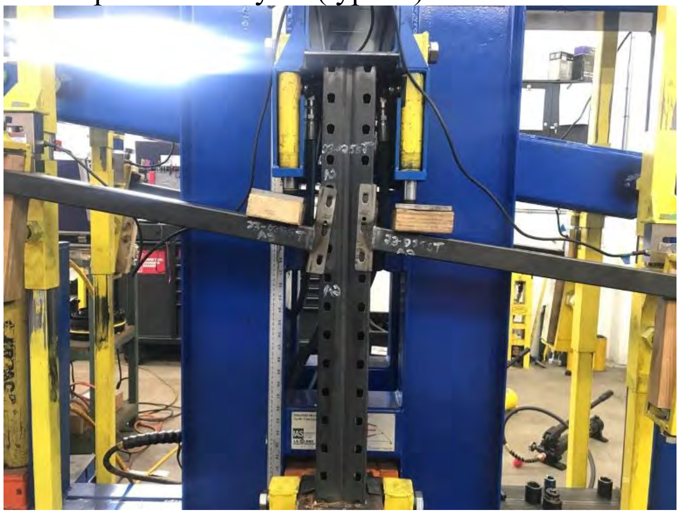
Table 1. Cycle Stages

Cycle Stage	Beam End Displacement [in] (@24.0" from common center)	Radians	Ram Displacement [in] (@31.5" from common center)
1	**+/- 0.60**	**+/- 0.025**	**+/- 0.7875**
2	**+/- 0.60**	**+/- 0.025**	**+/- 0.7875**
3	**+/- 0.60**	**+/- 0.025**	**+/- 0.7875**
4	**+/- 1.20**	**+/- 0.050**	**+/- 1.575**
5	**+/- 1.20**	**+/- 0.050**	**+/- 1.575**
6	**+/- 1.20**	**+/- 0.050**	**+/- 1.575**
7	**+/- 1.80**	**+/- 0.075**	**+/- 2.3625**
8	**+/- 1.80**	**+/- 0.075**	**+/- 2.3625**
9	**+/- 1.80**	**+/- 0.075**	**+/- 2.3625**
10	**+/- 2.40**	**+/- 0.100**	**+/- 3.15**
11	**+/- 2.40**	**+/- 0.100**	**+/- 3.15**
12	**+/- 2.40**	**+/- 0.100**	**+/- 3.15**
13	**+/- 3.60**	**+/- 0.150**	**+/- 4.725**
14	**+/- 3.60**	**+/- 0.150**	**+/- 4.725**
15	**+/- 4.80**	**+/- 0.200**	**+/- 6.3**
16	**+/- 4.80**	**+/- 0.200**	**+/- 6.3**

*RMI suggested loading sequences shown in bold.

After each cycle, the simulated pallet load on each beam was adjusted to ensure it was still 1-kip. The test was performed manually through all amplitude stages with an electric hydraulic pump until a clear failure has occurred.

4.0 Displacement Cycle (typical)



Stage 12 (-2.4”)

Stage 12 (+2.4”)

5.0 Results

ASTM A370, Standard Test Methods and Definition for Mechanical Testing of Steel Products										
Test ID	Ref. description of source component	Thk. [in]	Width [in]	Area [in^2]	Yield [lbs]	Ultimate [lbs]	2”/1” - Elong. [%]	F_y [ksi]	F_u [ksi]	F_u/F_y
TA1	T03805620 T 1-1/2 x 2-1/4 -14Ga	0.0801	0.5043	0.0404	2,473	2,754	17	61.2	68.2	1.11
TA2		0.0798	0.5012	0.0400	2,248	2,585	16	56.2	64.6	1.15
TC1	0.097 thk. 3-tab connector	0.1009	0.2510	0.0253	1,326	1,439	18	52.4	56.8	1.09
TC2		0.0990	0.2550	0.0252	1,371	1,562	16	54.3	61.9	1.14
TA1	O0900708020 3-1/2” x 2-3/4” x 3/16” - 0.079”	0.0794	0.504	0.0400	3,507	3,507	10	64.6	87.6	1.36
TA2		0.0788	0.505	0.0398	3,934	3,507	18	64.2	88.2	1.37

Beam-to-Column Connection (BCC) Test									
Specimen		Connector Description	F [in-kip/rad]	M_{cyclic}* [in-kip]	Specimen		Connector Description	F [in-kip/rad]	M_{cyclic}* [in-kip]
O0900708020 (3-1/2” x 2-3/4” x 3/16” - 0.079”)									
T03805620 T 1-1/2 x 2-1/4 -14Ga	A1	**3**-tab B-3” drop	110	8.9					
	A2		100	9.9					

Connection Description	F [in-kip/radians]		M [in-kip] *	
O0900708020/ T03805620 / 3-tabs B-3” drop	105	+/- 5.0 %	9.4	+/- 5.3 %

* per 2021 RMI/ANSI MH16.1-13.5, M cyclic is based on lowest peak moment recorded in CW and CCW

SMHE Inc.

Performed by

Prepared by:

Fady Herzalla

Eric Pearson

The tests were performed in general accordance with applicable test methods and standards at indoor ambient temperature environment. This report is exclusively for the use of the client as referenced in the report and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the lab or the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

Sample Result, A1:

O09007008020: 3-1/2 x 2-3/4 -14Ga / T03805620: T 1-1/2 x 2-1/4 -14Ga / 0.097 thk. 3-tab end-connector; B-3" drop
($I_{x,\,column}$ = 1.00 [in^4]; $I_{x,\,beam}$ = 0.19 [in^4])

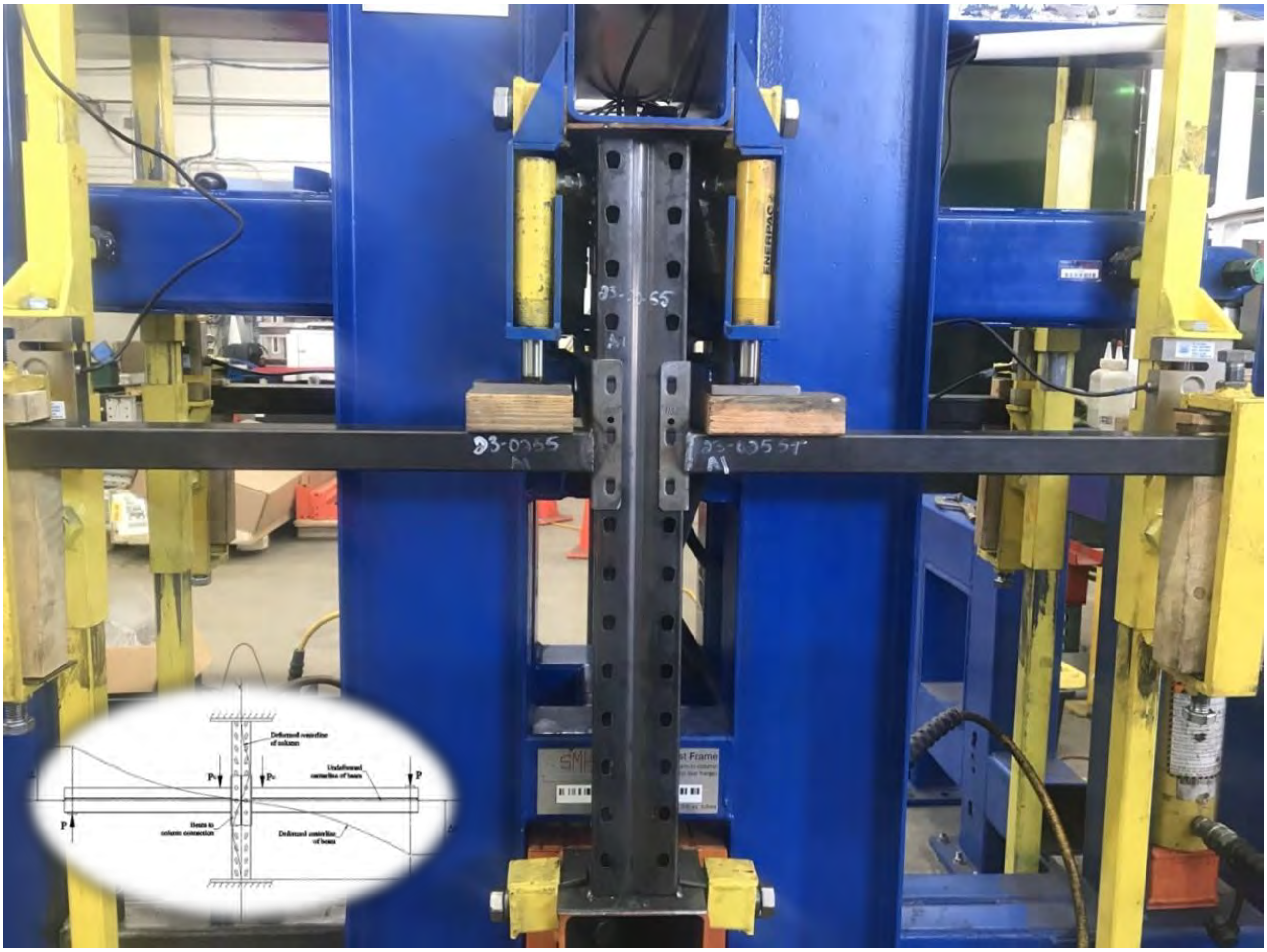
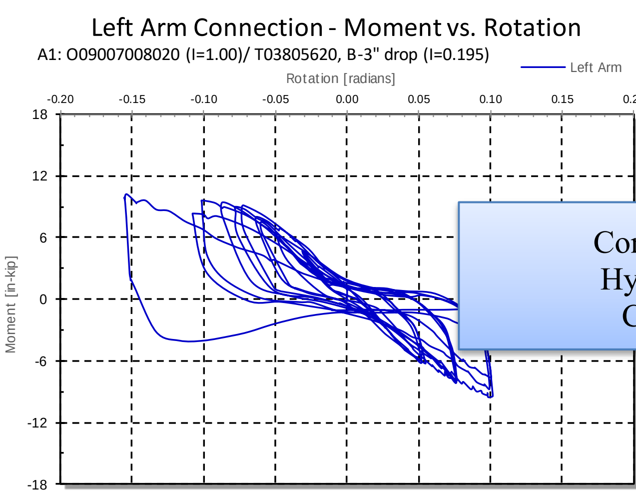


Figure A1-1: Specimen Setup (before test)



Connection Hysteresis Curves

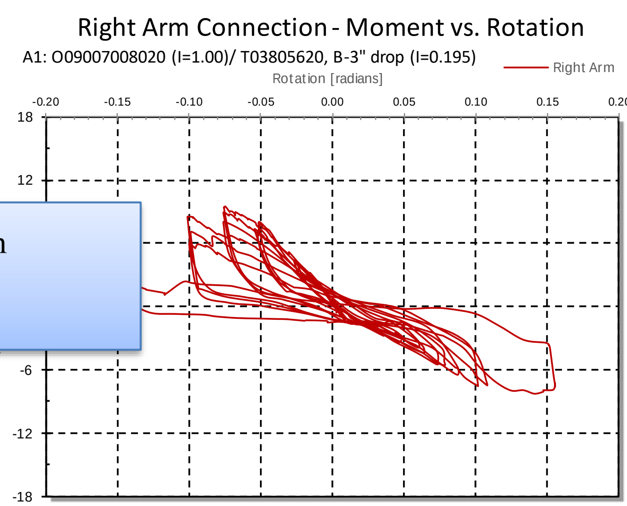


Figure A1-2a: Test plot (LH)

Figure A1-2b: Test plot (RH)

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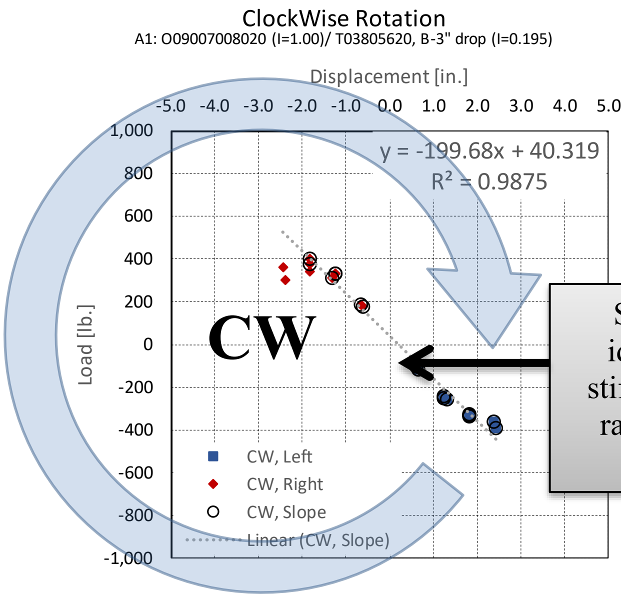


Figure A1-2c: Peak Loads in CW cycle

Slope represents idealized average stiffness ratio within range of allowable moment.

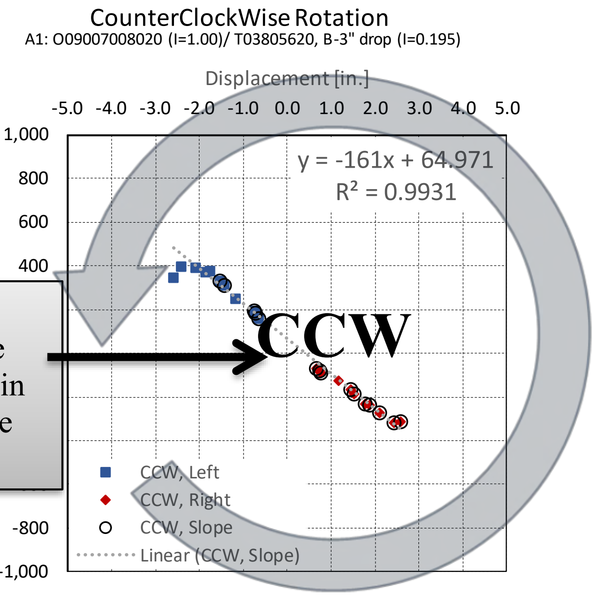
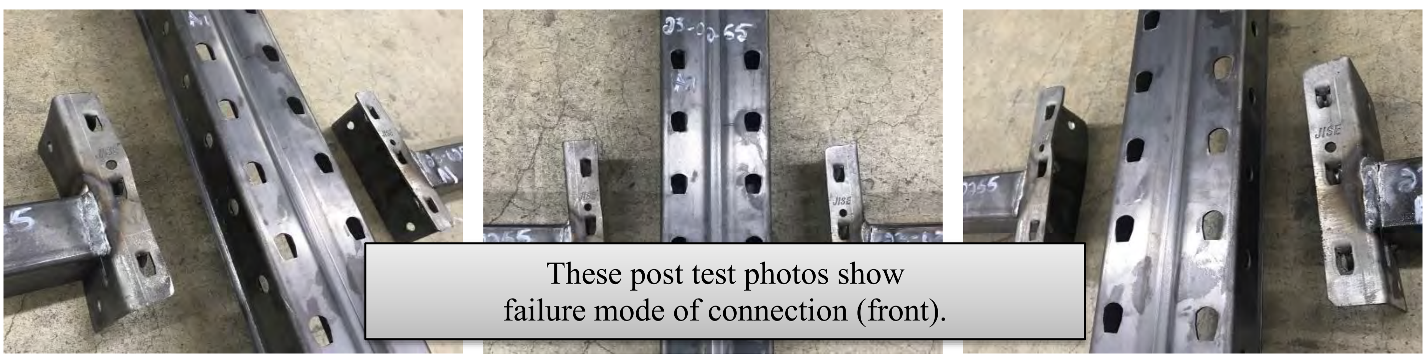
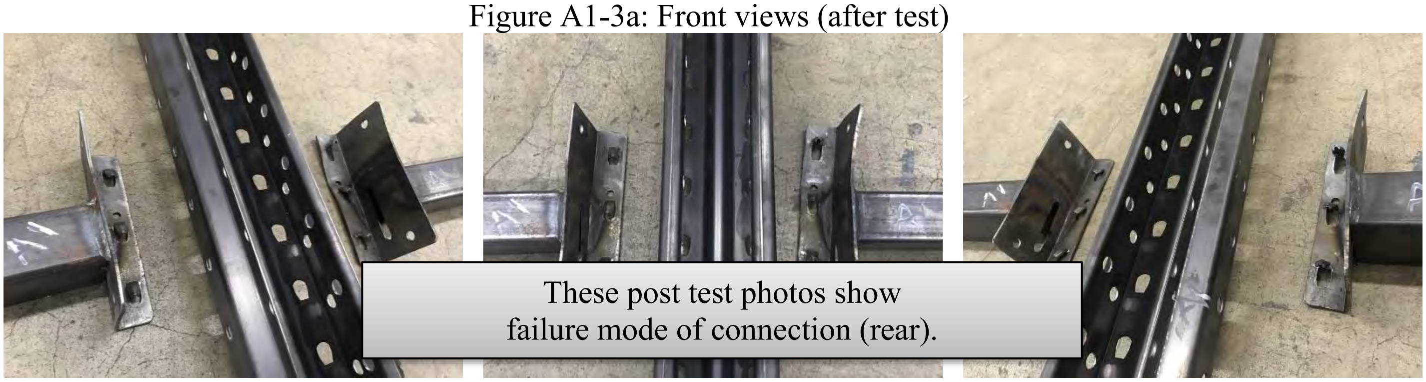


Figure A1-2d: Peak Loads in CCW cycle



Front (left oblique view) | Front (top view) | Front (right oblique view)

Figure A1-3a: Front views (after test)



Rear (left oblique view) | Rear (top view) | Rear (right oblique view)

Figure A1-3b: Rear views

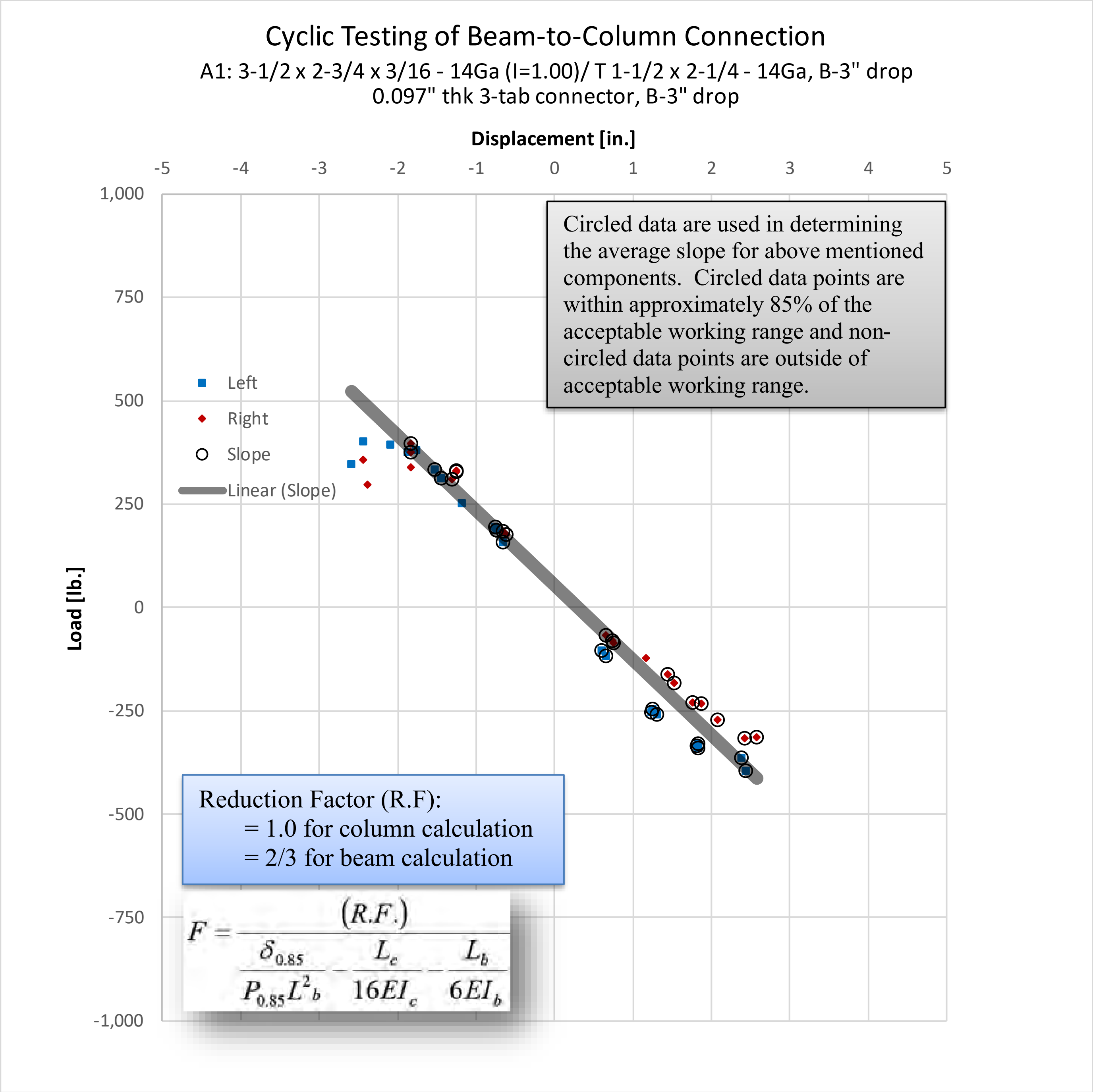


Figure A1-4: Resulting Data for Analysis (Slope = -200 [lbs. /in.], CW; -161 [lbs. /in.], CCW)

Spring Constant, F = 110 [in-kip/radians]
M_{cyclic} = 8.9 [in-kip]

Sample Calculation (specimen A1):

$$\left(\frac{P_{0.85}}{\delta_{0.85}}\right)_{CounterClockWise} = -200 \left[\frac{lbs.}{in}\right]$$

where, $$Slope = \frac{P_{0.85}L_b^2}{\delta_{0.85}}$$

$$\left(\frac{P_{0.85}}{\delta_{0.85}}\right)_{ClockWise} = -161 \left[\frac{lbs.}{in}\right]$$

and $$Slope_{average} = \left\{\left(\frac{P_{0.85}L_b^2}{\delta_{0.85}}\right)_{CW} + \left(\frac{P_{0.85}L_b^2}{\delta_{0.85}}\right)_{CCW}\right\}\Big/ 2$$

thus, $Slope_{average}$ = (-200 + -161) / 2 = -180 [lbs. /in.]

Note: check if sign need be changed at this point.

$$F = \frac{(R.F.)}{\frac{\delta_{0.85}}{P_{0.85}L_b^2} - \frac{L_c}{16EI_c} - \frac{L_b}{6EI_b}}$$

$$F_{columns} = \frac{1.0}{\frac{1}{180} - \frac{30}{16(29{,}500{,}000)(1.00)} - \frac{24}{6(29{,}500{,}000)(0.19)}} = 110 \left[\frac{in-kip}{radians}\right],$$

where (R.F.) = 1.0 for column calculation

$$F_{beams} = \frac{(2/3)}{\frac{1}{180} - \frac{30}{16(29{,}500{,}000)(1.00)} - \frac{24}{6(29{,}500{,}000)(0.19)}} = 73 \left[\frac{in-kip}{radians}\right],$$

where (R.F.) = 2/3 for beam calculation

Appendix

Figures/Test Plots

Specimen A1:

O09007008020: 3-1/2 x 2-3/4 -14Ga / T03805620: T 1-1/2 x 2-1/4 -14Ga / 0.097 thk. 3-tab end-connector; B-3" drop
($I_{x,\,column}$ = 1.00 [in^4]; $I_{x,\,beam}$ = 0.19 [in^4])

Figure A1-1: Specimen Setup (before test)

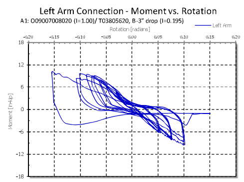


Figure A1-2a: Test plot (LH)

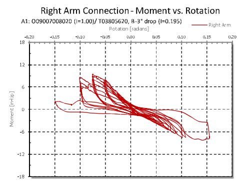


Figure A1-2b: Test plot (RH)

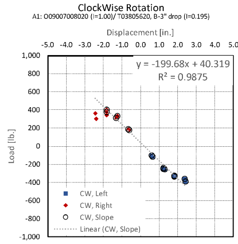


Figure A1-2c: Peak Loads in CW cycle

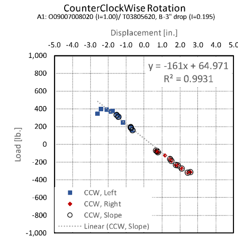


Figure A1-2d: Peak Loads in CCW cycle

Front (left oblique view) Front (top view) Front (right oblique view)

Figure A1-3a: Front views (after test)

Rear (left oblique view) Rear (top view) Rear (right oblique view)

Figure A1-3b: Rear views (after test)

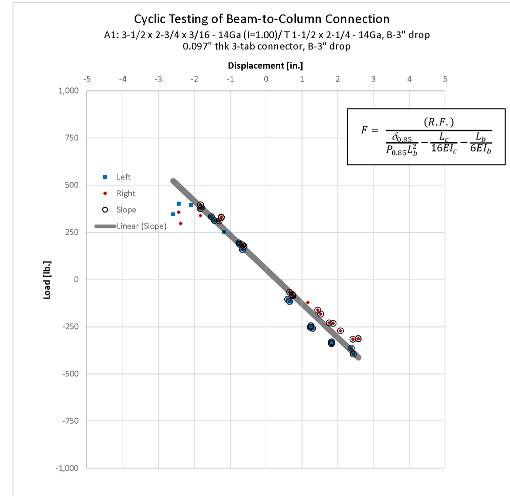


Figure A1-4: Resulting Data for Analysis (Slope = -200 [lb/in], CW: -161 [lb/in], CCW)

Spring Constant, F = 110 [in-kip/rad]

M $_{max,\ cyclic}$ = 8.9 [in-kip]

Specimen A2:

O09007008020: 3-1/2 x 2-3/4 -14Ga / T03805620: T 1-1/2 x 2-1/4 -14Ga / 0.097 thk. 3-tab end-connector; B-3" drop
($I_{x,\,column}$ = 1.00 [in^4]; $I_{x,\,beam}$ = 0.19 [in^4])

Figure A2-1: Specimen Setup (before test)

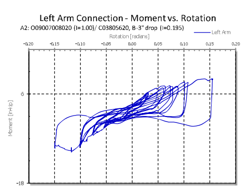


Figure A2-2a: Test plot (LH)

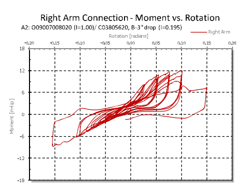


Figure A2-2b: Test plot (RH)

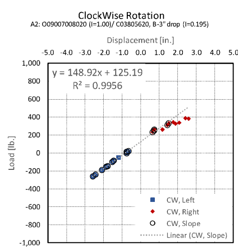


Figure A2-2c: Peak Loads in CW cycle

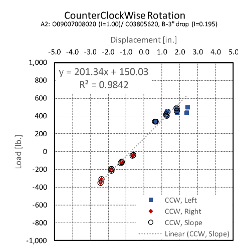
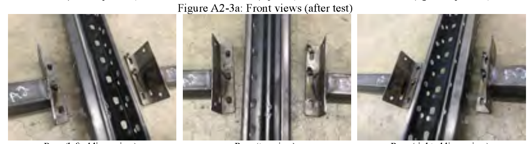


Figure A2-2d: Peak Loads in CCW cycle

Front (left oblique view) Front (top view) Front (right oblique view)

Figure A2-3a: Front views (after test)



Rear (left oblique view) Rear (top view) Rear (right oblique view)

Figure A2-3b: Rear views (after test)

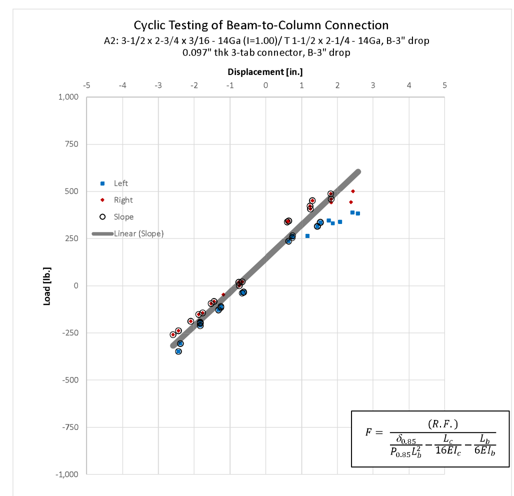


Figure A2-4: Resulting Data for Analysis (Slope = 149 [lb/in], CW: 201 [lb/in], CCW)

Spring Constant, F = 100 [in-kip/rad]

M $_{max,\ cyclic}$ = 9.9 [in-kip]