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TECHNICAL BULLETIN 5

Backbone Curve for DuraFuse Connections

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Abstract: A general backbone curve for the DuraFuse Frames connection was developed for use in nonlinear analysis. The general backbone curve was derived based on nine experimental specimens subjected to cyclic loading. The backbone curve is defined by eight points calibrated from the test data. This paper summarizes the backbone curve, describes its development, and compares the general curve with the experimental data.

Introduction

Many computer programs have the option to perform non-linear analysis of steel structures. To simulate non-linear behavior of joints, backbone curves for the joints are incorporated into the computer model of the building.

A general backbone curve for the DuraFuse Frames connection was developed for use in nonlinear analysis. The backbone curve is based on testing results of full-scale, one-sided DuraFuse (DF) bolted steel moment connections. This joint backbone curve can be implemented in structural analysis programs for non-linear analysis.

Backbone Curve Summary

The general backbone curve that was developed is shown in Fig. 1. The backbone is defined by eight points corresponding to different levels of inelastic rotation. The strength at each point is given in terms of the nominal plastic moment capacity of the beam (M_{pn}). The strength and rotation of each of the eight points is also summarized in Table 1.

The method for developing the general backbone curve and determining values for the points is described in the remainder of the paper.

DuraFuse Test Specimens

Four series of full-scale tests were performed to evaluate the DuraFuse Frames connection (E-, F-, G-, and H-series).

POINT	M/M_{pn}	Plastic Rotation
A	0.00	0.000
B	0.60	0.000
C	1.00	0.045
D	0.50	0.055
E	0.50	0.080
F	0.03	0.080
G	0.03	0.100
H	0.00	0.100

Table 1. *Backbone point coordinates*

Each series had a different beam-column combination (Table 2). Beam sizes that were considered ranged from W21×50 to W40×167.

The setup used for the experiments is shown in Fig. 2. Results from the test specimens included plots of plastic rotation versus normalized beam moment at column face (moment at column face divided by the nominal plastic moment capacity of the beam). Refer to UCSD TR-19/01 (Reynolds and Uang, 2019a) for more information on testing procedures, data, and DF plate dimensions.

Nine DF tests are described in the test reports. The first three series (E-, F-, and G-) each had two specimens. The first specimen in those series was just tested through 0.04 rad, and then the fuse plate was replaced. The second specimen in each series was tested beyond 0.04 rad, all the way to fuse failure. The H-series included

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three specimens, where the third specimen was loaded until the fuse plate fractured. After initial fuse failure, the connections still had significant strength, however most tests were stopped prior to deformations beyond 0.07 rad to prevent any damage to the testing equipment.

For the development of the general backbone curve, the second specimen of series E, F and G and the third specimen of series H were used to define the backbone curve beyond 0.045 rad plastic rotation.

A non-standard test was run for the F-series which evaluated the strength at the connection with no top plates or fuse plates installed. This data was used to judge the moment capacity of the connection for plastic rotations beyond 0.08 rad.

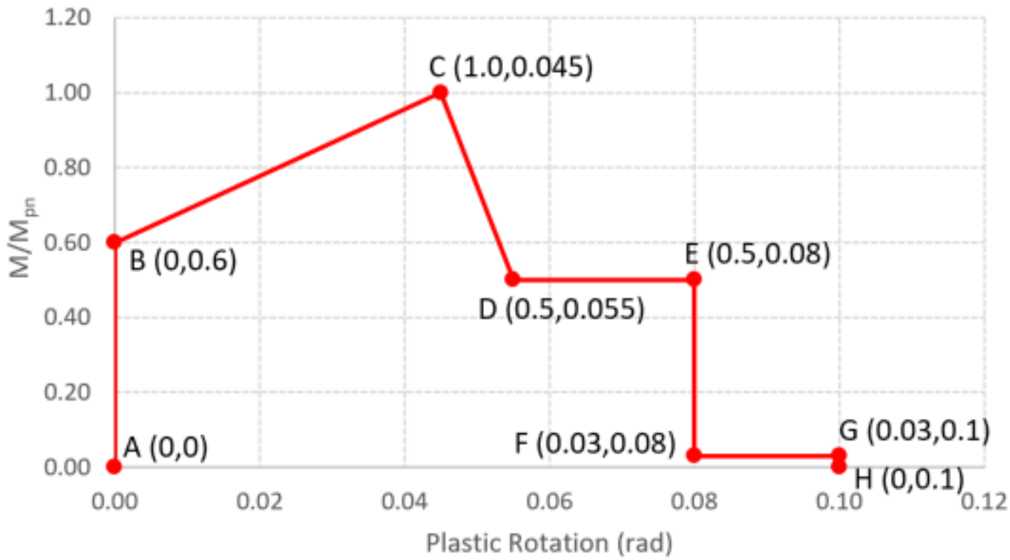

Fig. 1. *Backbone Curve Points*

Series	Member	d (in.)	t_w (in.)	b_f (in.)	t_f (in.)	Width-Thickness Ratio		$0.95 r_y E/(R_y F_y)$* (ft)
						h/t_w	$b_f/2t_f$	
E	Beam (W30×99)	29.7	0.52	10.5	0.67	51.9	7.80	8.8
	Column (W21×132)	21.8	0.65	12.4	1.04	28.9	6.01	-
F	Beam (W40×167)	38.6	0.65	11.8	1.03	52.6	5.76	10.0
	Column (W36×231)	36.5	0.76	16.5	1.26	42.2	6.54	-
G	Beam (W21×50)	20.8	0.38	6.53	0.535	49.4	6.10	5.4
	Column (W14×68)	14.0	0.415	10.0	0.72	27.5	6.97	-
H	Beam (W36×232)	37.1	0.87	12.1	1.57	37.3	3.86	10.9
	Column (BU Box	24.0	1.75	17.5	1.75	11.7	8.0	-

* Limited unbraced length for highly ductile beams per AISC 341-16

Table 2. *Member Cross-Sectional Dimensions [Reynolds, M., and Uang, C.M. (2019a)]*

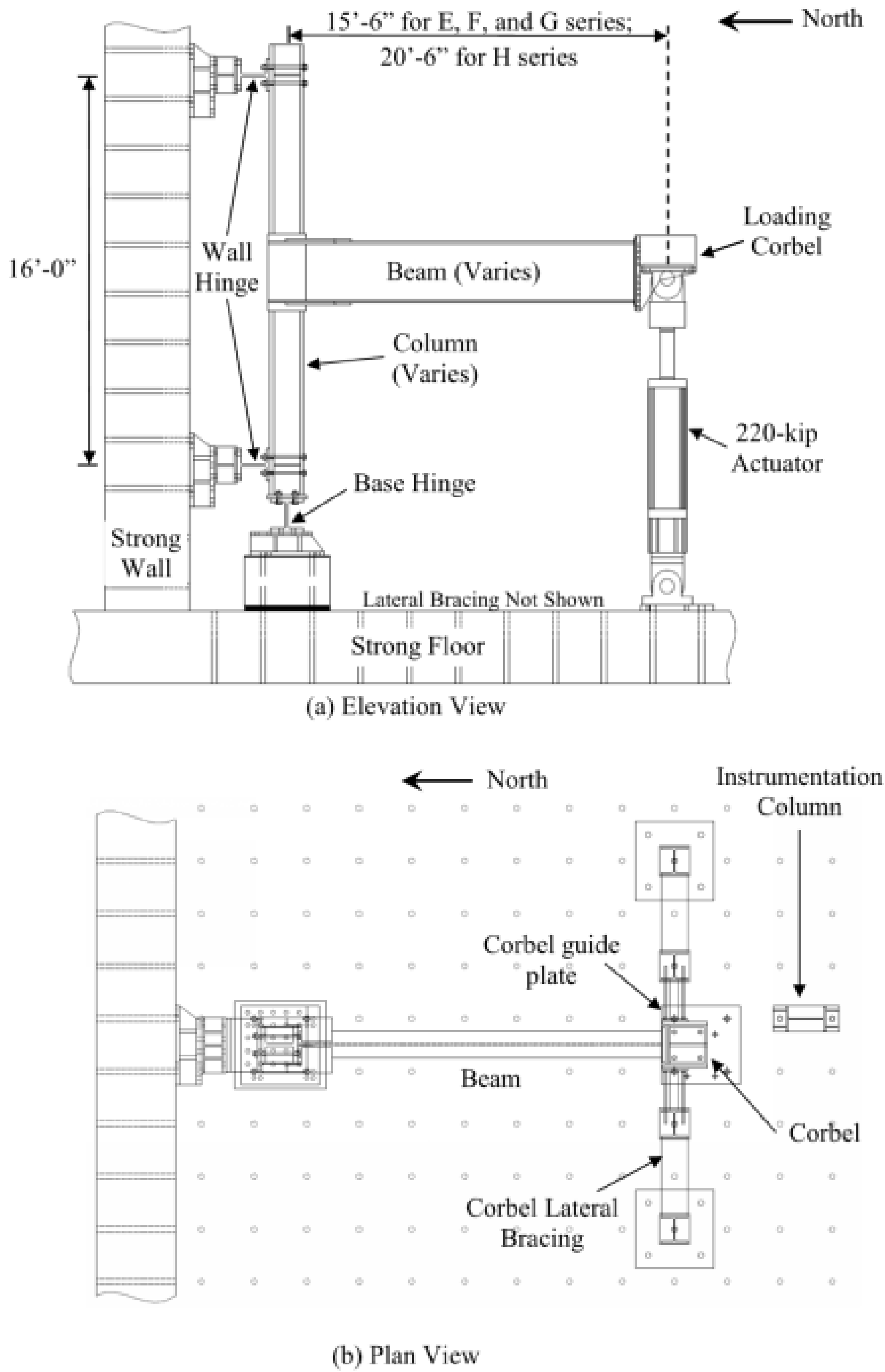

Figure 2.1 Overall Test Setup

Fig. 2. *Overall Test Setup [Reynolds, M., and Uang, C.M. (2019a)]*

Backbone Curve Derivation

Plastic rotation versus normalized moment plots for E1.2, F1.2, G1.2, H1.3, and F1.3 were used to develop the general backbone curve for DF moment frame connections (see Figs. 3 to 8).

Eight points make up the generalized backbone curve shown in Fig. 1. Strength and rotation values for points A through C were obtained from each of the test result plots (see Figs. 3 to 8). Table 3 summarizes strength and rotation values from each specimen. Specimens G1.2 and F1.3 were used to find reasonable values for points D through H. Each of the eight points will be discussed in this section.

Point A: Begin Testing: This was the start of testing at zero strength and zero plastic rotation.

Point B: Effective Yield Point: The elastic rotation had been removed from the test results, in order to show only the non-linear response. This made the slope between points A and B vertical. From the test results, the strength for point B corresponded to zero plastic rotation. For Specimen E1.2 from Fig. 3, for example, this value of M/M_{pn} was approximately 0.75. Values for point B for each specimen were summarized in Table 3. For the generalized backbone curve (Fig. 1, Table 1), a strength of $0.6M_{pn}$. was used, which was conservative as compared to the average of the four strengths ($0.65M_{pn}$).

Point C: Peak Strength: The peak strength was the maximum M/M_{pn} value from each test. For example, for Specimen E1.2, this value of M/M_{pn} was approximately 1.0 at a plastic rotation of approximately 0.047 rad. Values for point C for each specimen were summarized in Table 3. A strength of $1.0M_{pn}$ and a rotation of 0.045 rad for Point C were used for the generalized backbone curve (Fig. 1, Table 1), since these values were reasonable as compared to those in Table 3.

Point D: Strength Loss 1: This was the point where the connection lost strength due to fuse tearing. Specimen G1.2 in Fig. 5 represented the typical case and Fig. 6 explains the points where the connection lost strength and why. The test was stopped before the fuse plate tore through on the other side (Fig. 9). The strength and plastic rotation for the generalized backbone curve was based on Specimen G1.2, but was compared with results from the other tests (Figs. 3, 4, and 7).

Point E: Residual Strength. The plastic rotation for Point E was based on Specimen G1.2 (Fig. 5). Other tests were stopped at smaller deformations to protect laboratory equipment. For G1.2, connection strength of $0.5M_{pn}$ was maintained through 0.08 rad of inelastic deformation.

Point F: Strength Loss 2: None of the specimens were tested to the point of complete failure of both sides of the fuse plate. Since no specimens were tested beyond 0.08 rad, a significant drop in strength is assumed for the backbone curve at this point.

The magnitude of the residual strength after strength loss 2 was estimated based on a non-standard test, that had neither top plates nor fuse plates (Fig. 8). The residual strength value estimated from Fig. 8, was $0.03M_{pn}$ for deformations beyond 0.08 radians of inelastic deformation.

Points G/H: Ultimate Deformation: Values for these points in Fig. 1 and Table 1 were based on engineering judgement that the minimal strength of Point F could not be maintained indefinitely.

POINT			A		B		C	
SPECIMEN	BEAM	COLUMN	M/M_{pn}	Plastic Rotation	M/M_{pn}	Plastic Rotation	M/M_{pn}	Plastic Rotation
E1.2	W30X99	W21X132	0	0	0.75	0	1.00	0.047
F1.2	W40X167	W36X231	0	0	0.50	0	1.04	0.040
G1.2	W21X50	W14X68	0	0	0.65	0	1.07	0.040
H1.3	W36X232	BOX	0	0	0.70	0	1.10	0.045

Table 3. *Backbone curve points for each specimen [Reynolds, M., and Uang, C.M. (2019a)]*

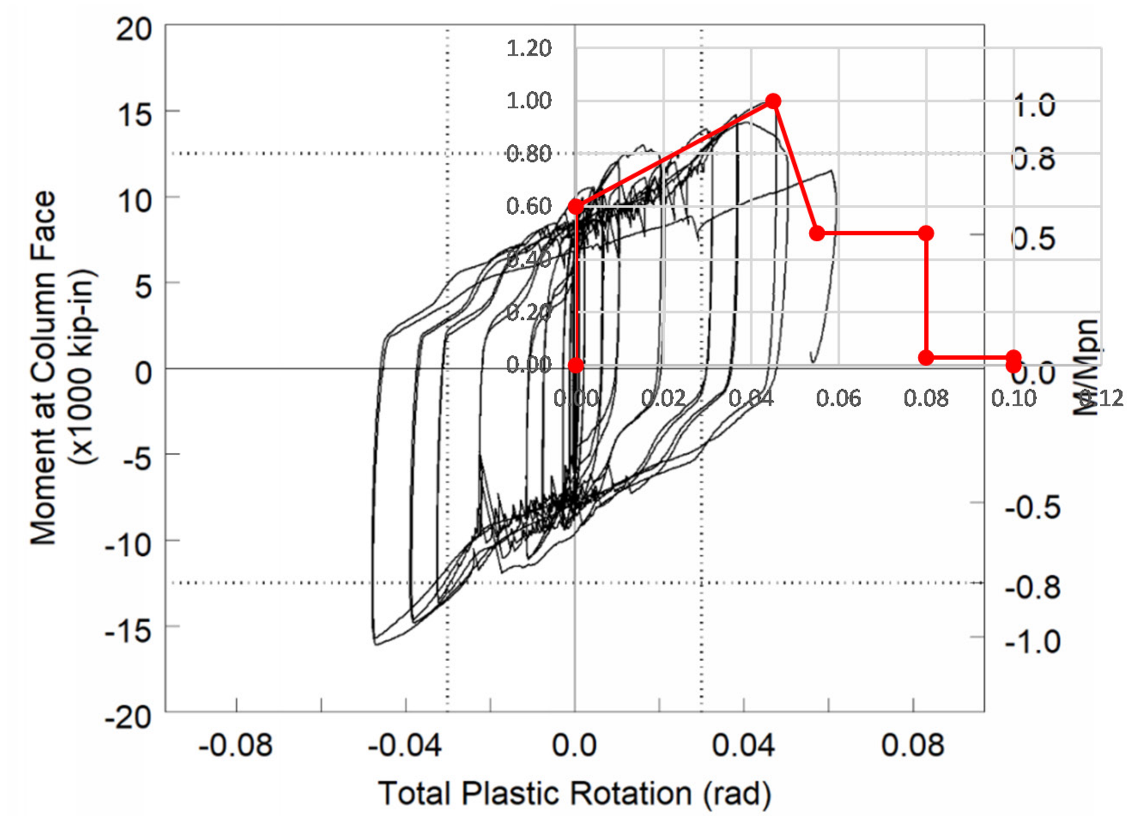

Fig. 3. *Specimen E1.2: Moment at Column Face versus Plastic Rotation [Reynolds, M., and Uang, C.M. (2019a)]*

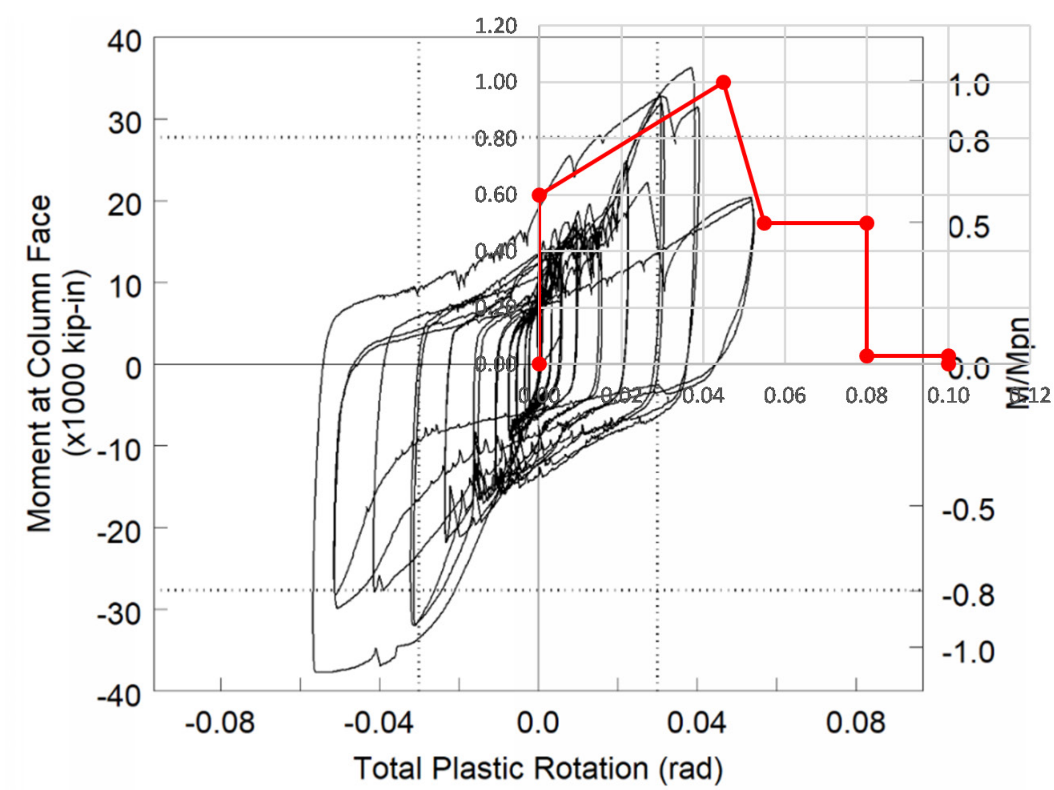

Fig. 4. *Specimen F1.2: Moment at Column Face versus Plastic Rotation [Reynolds, M., and Uang, C.M. (2019a)]*

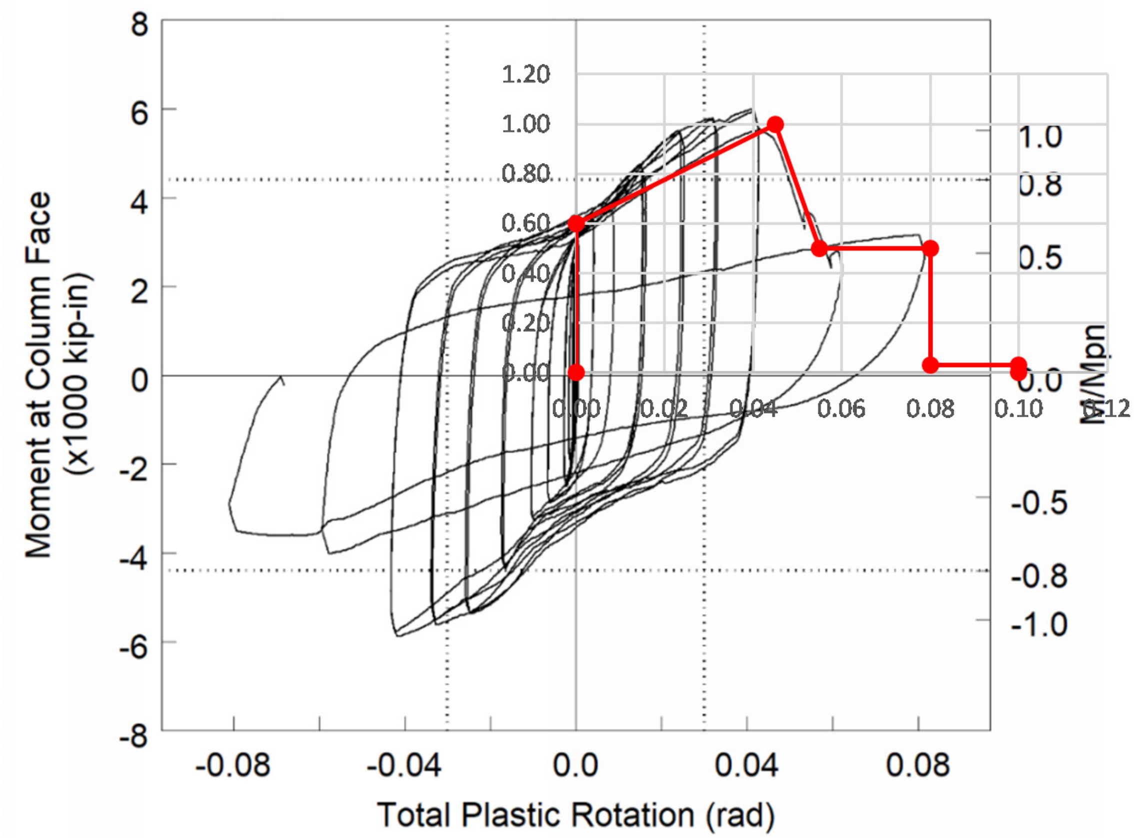

Fig. 5. *Specimen G1.2: Moment at Column Face versus Plastic Rotation [Reynolds, M., and Uang, C.M. (2019a)]*

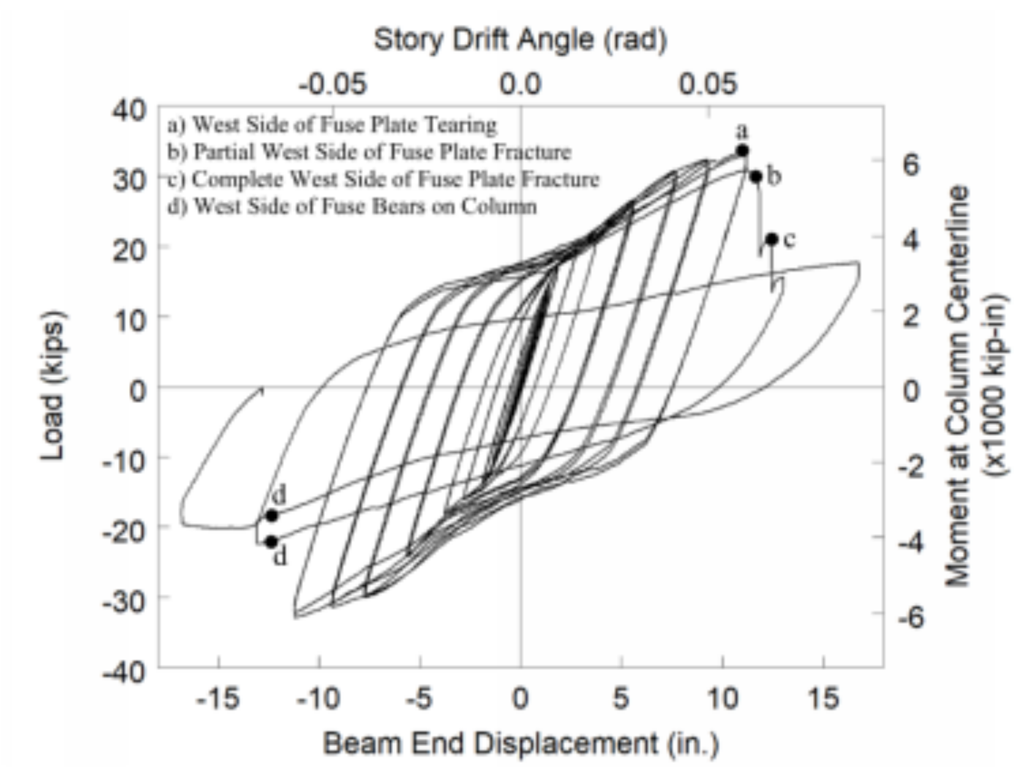

Fig. 6. *Specimen G1.2 Applied Load versus Beam End Displacement Response [Reynolds, M., and Uang, C.M. (2019a)]*

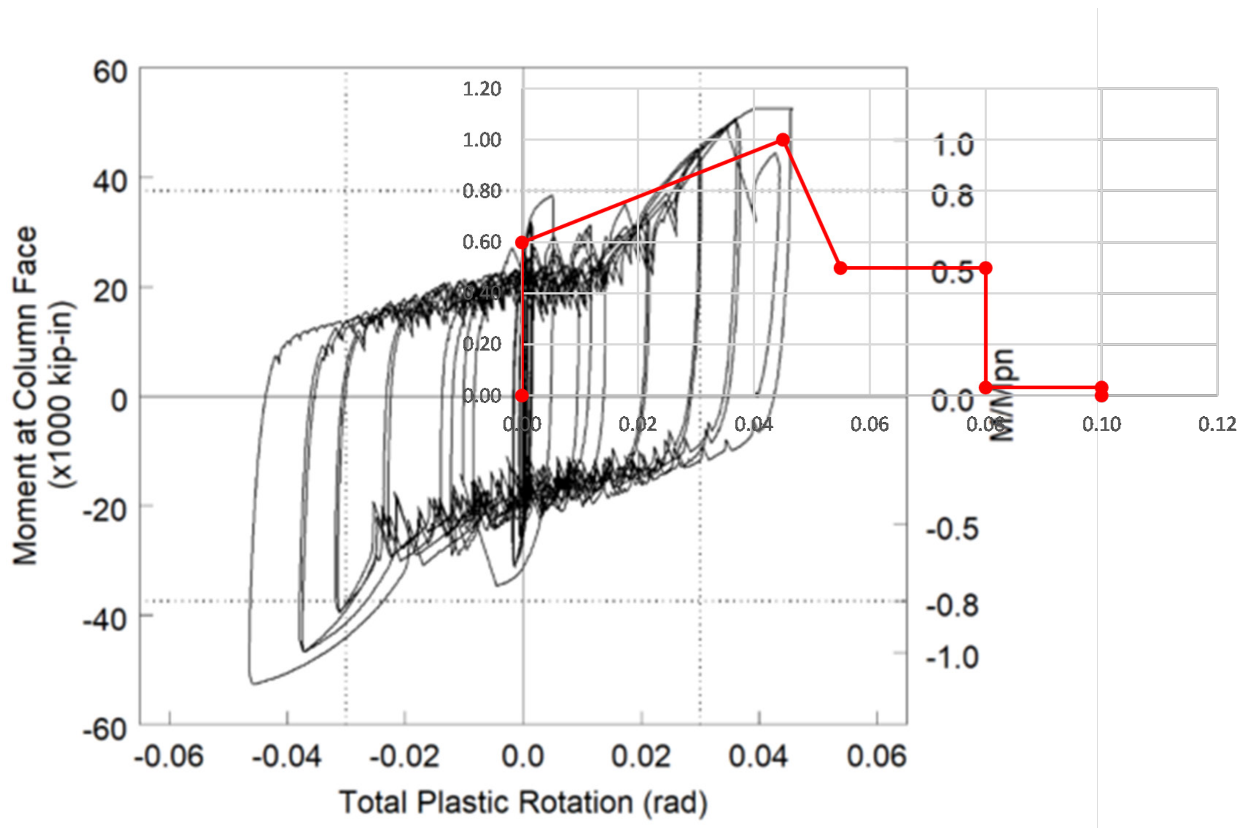

Fig. 7. *Specimen H1.2: Moment at Column Face versus Plastic Rotation [Reynolds, M., and Uang, C.M. (2019b)]*

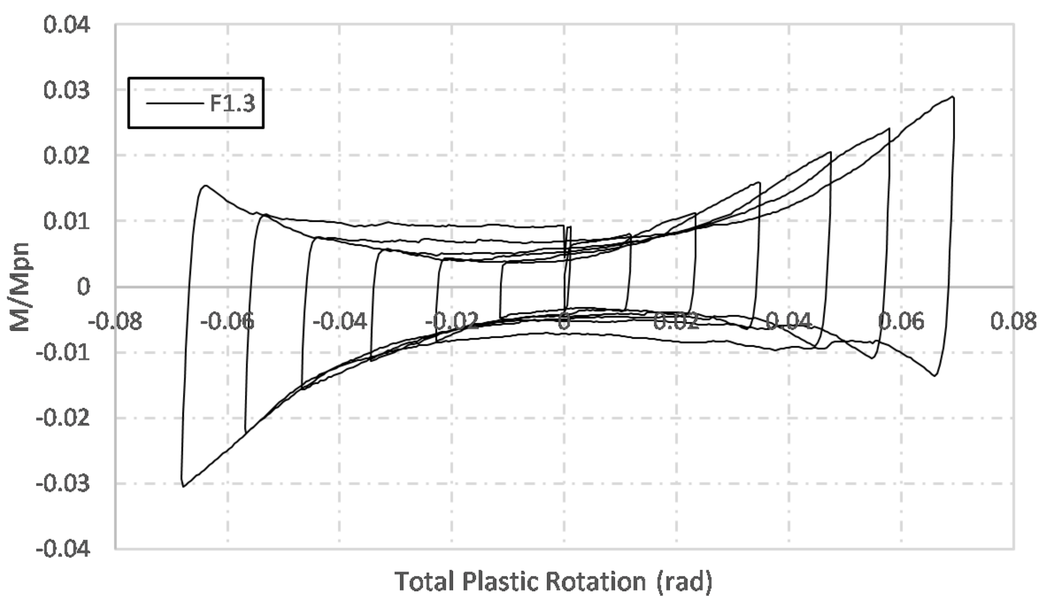

Fig. 8. *Specimen F1.3: Moment at Column Face versus Plastic Rotation*

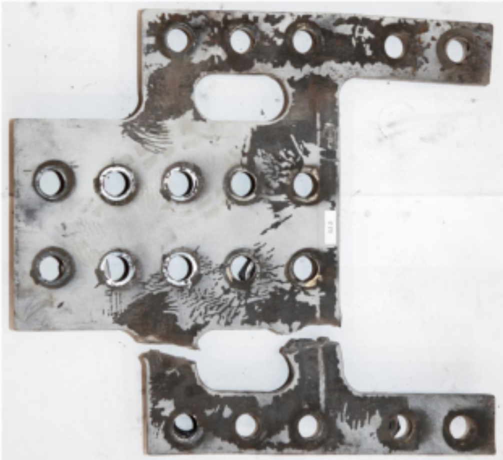

Fig. 9. *Specimen G1.2: Fuse Plate Tear [Reynolds, M., and Uang, C.M. (2019a)]*

Summary & Conclusions

A general backbone curve was developed based on the cyclic testing of full-scale, one-sided DuraFuse bolted steel moment connections. The general backbone curve was defined by eight points. Strength and rotation values for the eight points were calibrated from experimental results. The backbone curve can be used to define non-linear joint behavior in structural analysis programs.

References

Reynolds, M., and Uang, C.M. (2019a), *Cyclic Testing of DuraFuse (DF) Moment Frame Connections for SMF and IMF Applications: Series E, F, and G Specimens, Report No. TR-19/01*, Department of Structural Engineering University of California, San Diego La Jolla, CA.

Reynolds, M., and Uang, C.M. (2019b), *Cyclic Testing of DuraFuse (DF) Moment Frame Connections for SMF and IMF Applications: Series H Specimens, Report No. TR-19/02*, Department of Structural Engineering University of California, San Diego La Jolla, CA.

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