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# TECHNICAL BULLETIN 19

## Beam Lateral Bracing for DuraFuse Frames

Michael Reynolds, EIT<sup>1</sup> and Paul Richards, PhD, PE<sup>2</sup>

**Abstract:** Traditional Special Moment Frame (SMF) beams are designed to form plastic hinges under seismic loading. AISC 341-16 specifies prescriptive beam lateral bracing requirements for those beams to mitigate instability caused by the plastic hinges. In contrast, DuraFuse Frames systems have fuse plates that eliminate plastic hinge formation in the beams. DuraFuse Frames systems have been tested without lateral bracing and are prequalified through ER-610 for use without bracing per AISC 341-16 D1.2b and E3.4b. To mitigate lateral torsional buckling unrelated to plastic hinges, DuraFuse Frames systems use beam lateral bracing per AISC 360 based on the maximum moment that can develop in the beam. This prequalified approach results in around 70% fewer beam lateral brace points than other SMF systems, saving time and money on projects. Case studies are presented that illustrate the savings on lateral bracing costs by using DuraFuse Frames.

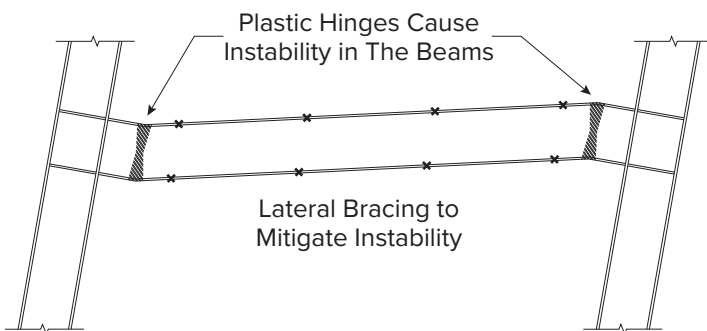
### Introduction

Traditional Special Moment Frame (SMF) systems are designed so that, under severe seismic loading, the beams will form plastic hinges near the beam ends (see Figure 1). Beam plastic hinge formation introduces instability to the beams (Nakashima et al., 2002), so bracing is added to SMF beams to mitigate lateral torsional buckling. AISC 341-16 D1.2b and E3.4b give prescriptive beam lateral bracing requirements for moment frames that form plastic hinges in the beams (AISC, 2016a). The prescriptive requirements limit the maximum brace spacing to  $L_b \leq 0.095r_yE/(R_yF_y)$  and require braces at plastic hinges, concentrated forces, and changes in cross section. These requirements result in a greater number of brace points than the beam lateral bracing requirements of AISC 360 (2016b).

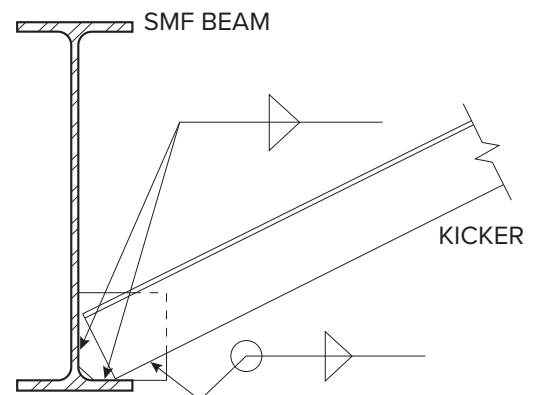
A consequence of the prescriptive bracing requirements of AISC 341 is that the lightest and most efficient beams require the most brace points. For example, a W24X55 beam requires 4 brace points for a 27 ft span (see Appendix A). Designers must provide the required brace points or upsize the moment frame beam.

### Typical SMF Beam Bracing

Brace points are typically provided through kickers when SMF beams are parallel to gravity framing. Figure 2 shows a typical detail with kicker angles welded to plates attached to the bottom of the SMF beam. This detail introduces extra parts and additional shop and field welding.



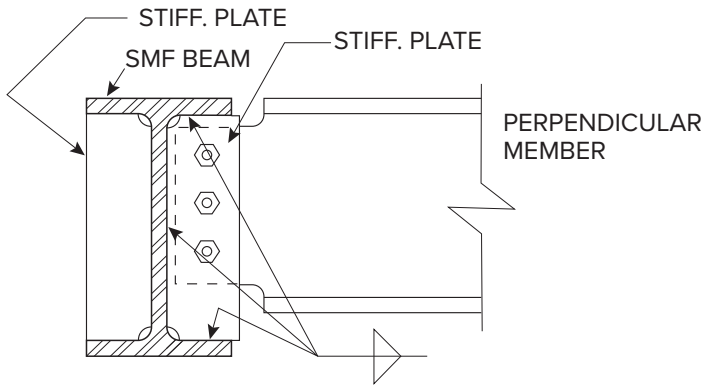
**Fig. 1** Plastic Hinges in SMF Beams



**Fig. 2** Typical Kicker Detail for Brace Points on SMF Beams Parallel to Gravity Framing

1 Project Engineer, DuraFuse Frames, 5801 West Wells Park Road, West Jordan, UT 84081. Email: [michael.reynolds@durafuseframes.com](mailto:michael.reynolds@durafuseframes.com)  
 2 Vice President, DuraFuse Frames, 5801 West Wells Park Road, West Jordan, UT 84081. Email: [paul.richards@durafuseframes.com](mailto:paul.richards@durafuseframes.com)

When SMF beams are perpendicular to gravity framing, SMF beam brace points are typically provided through special detailing at the gravity beam connections (see Figure 3). Full depth stiffener plates are provided on both sides of the SMF beam and the bottom flanges of the gravity beams are coped. The extra components and labor increase fabrication costs.



**Fig. 3** Typical Beam Brace Detail for SMF Beams Perpendicular to Gravity Framing

## DuraFuse Frames Beam Bracing Requirements

DuraFuse Frames systems have shear fuses that yield to prevent plastic hinges in the beam. Since the shear fuses prevent plastic hinges from forming in the beam, DuraFuse Frames systems do not have the stability problems of traditional SMFs. DuraFuse Frames systems have been tested without lateral bracing and are prequalified through ER-610 for use without bracing per AISC 341-16 D1.2b and E3.4b (UES, 2019).

One of the DuraFuse Frames system qualification tests is shown below in Figure 4. A W21X50 beam with a 15.5 ft unbraced span was used for this test, where bracing every 5.4 ft would have been required for the beam with a traditional SMF connection (per AISC 341-16 D1.2b and E3.4b). This experiment, and others without lateral bracing per AISC 341-16 D1.2b and E3.4b, demonstrated excellent rotation capacity, well beyond that required for prequalification.



**Fig. 4** Experimental Test Without Lateral Bracing (W21X50 shown)

DuraFuse Frames systems are braced according to AISC 360. DuraFuse Frames beams are braced so that the nominal beam flexural strength is at least as high as the probable maximum moment in the beam ( $\Phi_d M_n \geq M_{pr}$ ). Below is a design example for a W24X55 beam with a 27 ft span.

Beam Properties:

$$\begin{array}{lll} Z_x = 134 \text{ in}^3 & S_x = 114 \text{ in}^3 & L_p = 4.7 \text{ in} \\ L_r = 13.9 \text{ in} & F_y = 50 \text{ ksi} & \Phi_d = 1.0 \end{array}$$

First, the probable maximum moment in the beam is determined. Fuse plates are proportioned so that the probable maximum moment is no greater than the  $M_{pr}$  of the beam.

$$M_{pr} \leq F_y Z_x = (50)(134) = 6700 \text{ k-in} = 558.3 \text{ k-ft}$$

Next, calculate  $\Phi_d M_n$  assuming no brace points and compare with  $M_{pr}$ .

$$\begin{aligned} \Phi_d M_n &= \Phi_d C_b \left[ M_{pr} - (M_{pr} - 0.7 F_y S_x) \left( \frac{L_b - L_p}{L_r - L_p} \right) \right] \leq \Phi_d M_p \\ &= (1.0)(2.27) \left[ 558 - (558 - 0.7((50)(114)/12)) \left( \frac{27 - 4.7}{13.9 - 4.7} \right) \right] \\ &= 259.7 \text{ k-ft} < M_{pr} \rightarrow \text{not enough bracing.} \end{aligned}$$

Since  $\Phi_d M_n$  was too low with no brace points, calculate  $\Phi_d M_n$  with 1 brace point and compare with  $M_{pr}$ .

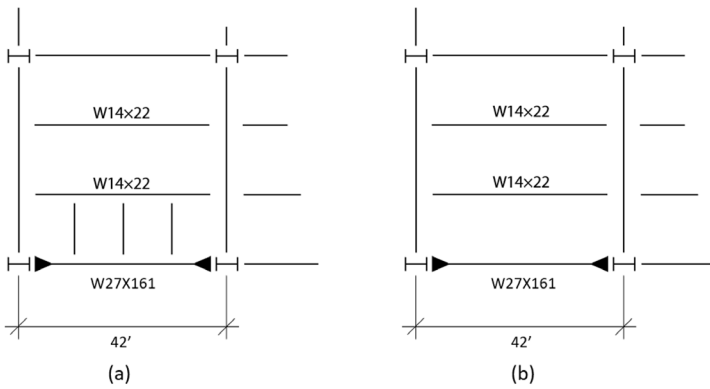
$$\begin{aligned} \Phi_d M_n &= \Phi_d C_b \left[ M_{pr} - (M_{pr} - 0.7 F_y S_x) \left( \frac{L_b - L_p}{L_r - L_p} \right) \right] \leq \Phi_d M_p \\ &= (1.0)(1.67) \left[ 558 - (558 - 0.7((50)(114)/12)) \left( \frac{13.5 - 4.7}{13.9 - 4.7} \right) \right] \\ &= 570.4 \text{ k-ft} > M_{pr} \rightarrow 1 \text{ brace point OK} \end{aligned}$$

$\Phi_d M_n > M_{pr}$ , thus only one brace point is required for the beam.

A W24X55 beam with a 27 ft span would require one brace point with DuraFuse Frames systems. The same beam would require four brace points with a traditional SMF (see Appendix A).

## Example of Reduced Bracing (SMF Beam Parallel to Gravity Framing)

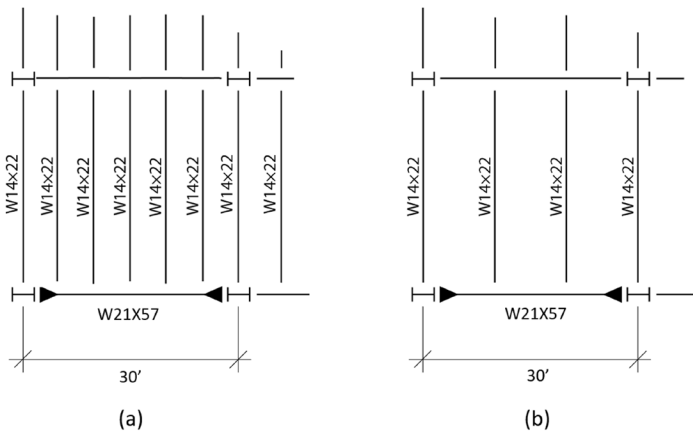
Another example illustrates the benefits of DuraFuse Frames systems when gravity framing is parallel to moment frames. Figure 5(a) shows a W27X161 beam that is 42 ft long and is parallel to the gravity framing. This beam would require three brace points under the prescriptive requirements of AISC 341-16 D1.2b and E3.4b. With DuraFuse Frames systems, however, no brace points would be required for a 42 ft long W27X161 beam [see Figure 5(b) and Appendix B].



**Fig. 5** Elimination of Kickers: (a) traditional moment frames, (b) DuraFuse Frames

### Example of Reduced Bracing (SMF Beam Perpendicular to Gravity Framing)

Another example illustrates the benefits of DuraFuse Frames systems when gravity framing is perpendicular to moment frames. Figure 6(a) shows a W21X57 SMF beam that is 30 ft long and perpendicular to the gravity framing. Per the prescriptive requirements (AISC 341-16 D1.2b, E3.4b), this example beam would require five brace points. Typical gravity framing for a 30 ft bay would be beams at 10 ft on center. In order to provide five brace points, three additional beams would be added, with the special bracing detail (Figure 3) on each one. The same SMF beam used with DuraFuse Frames systems would only require two brace points [see Figure 6(b) and Appendix C]. The DuraFuse Frames system design results in a 60% reduction in beam lateral brace points and elimination of the three additional gravity beams.



**Fig. 6** Elimination of Additional Gravity Beams: (a) traditional moment frames, (b) DuraFuse Frames

### Example of When Bracing Cannot be Provided

A final example illustrates the benefits of DuraFuse Frames systems when it is not possible to provide any lateral bracing. Consider a W24X55 beam with a 32 ft span for which lateral bracing cannot be provided. With a traditional SMF, the best option would be to box out the beam with plates welded to both sides because no standard wide flange shape can meet the requirements of AISC 341-16 D1.2b and E3.4b with a 32 ft unbraced span.

With DuraFuse Frames systems, this beam could just be changed to a W18X76 (See Appendix D), to avoid welding additional plates along the length of the beam.

### Cost Savings from Reduced Lateral Bracing

DuraFuse Frames systems have fewer required brace points, which reduces material costs, labor costs, and construction time. Cost savings are seen regardless of the direction of gravity framing members. Table 1 shows the estimated cost of braces for a particular 9-story medical office building in a high seismic area. A standard SMF option required 420 beam brace points, but the DuraFuse Frames system design only required 122 beam brace points, which was a 71% decrease. Assuming an average cost of \$350/brace point, over \$100,000 was saved on the project.

**Table 1** Estimated Cost of Bracing

	# Brace Points	Cost
Standard SMF	420	\$147,000
DuraFuse Frames	122	\$ 42,700
Difference	298	\$104,300

\*Assuming average cost of \$350/brace point

### Conclusions

Traditional SMF beams will form plastic hinges during severe earthquake loading and require close lateral bracing to mitigate instability. The prescriptive beam lateral bracing requirements of AISC 341-16 D1.2b and E3.4b result in numerous brace points for SMF beams. DuraFuse Frames systems use an innovative technology that eliminates plastic hinge formation in the beams and have been tested without prescriptive beam lateral bracing. DuraFuse Frames systems are prequalified through ER-610 for use without bracing per AISC 341-16 D1.2b and E3.4b. DuraFuse Frames system beams are braced per AISC 360 so the beam flexural strength is greater than the probable maximum moment in the beam. DuraFuse Frames systems eliminate about 70% of the beam brace points, reducing material and labor costs on projects and improving project schedules.

### References

American Institute of Steel Construction (2016a). "Seismic Provisions for Structural Steel Buildings," AISC 341, Chicago, IL.

American Institute of Steel Construction (2016b). "Specification for Structural Steel Buildings," AISC 360, Chicago, IL.

Nakashima, Masayoshi & Kanao, Lori & Liu, Dawei. (2002). Lateral Instability and Lateral Bracing of Steel Beams Subjected to Cyclic Loading. Journal of Structural Engineering. 128. 10.1061/(ASCE)0733-9445(2002)128:10(1308).

UES (2019), "DuraFuse Frame Technology," Uniform Evaluation Service ER-610, Uniform Evaluation Service, Ontario, CA.

## Appendix A

### Other Moment Frames Bracing

W24X55 – 27 ft long

$$L_b \leq 0.095r_y E / (R_y F_y) \\ = 0.095(1.34)(29000) / ((1.1)(50)) \\ = 67.1 \text{ in.} = 5.59 \text{ ft.}$$

$$n_b \geq (\text{Span}) / (\text{Max } L_b) - 1 \\ = 27 / 5.59 - 1 = \underline{4 \text{ brace points}}$$

## Appendix B

### Other Moment Frames Bracing

W27X161 – 42 ft long

$$L_b \leq 0.095r_y E / (R_y F_y) \\ = 0.095(3.23)(29000) / ((1.1)(50)) \\ = 161.8 \text{ in.} = 13.5 \text{ ft.}$$

$$n_b \geq (\text{Span}) / (\text{Max } L_b) - 1 \\ = 42 / 13.5 - 1 = \underline{3 \text{ brace points}}$$

### DuraFuse Frames Bracing

W27X161 – 42 ft long

Provide bracing such that  $\Phi_d M_n \geq M_{pr}$

$$M_{pr} = F_y Z_x = (50)(515) = 25750 \text{ k-in} = 2145.8 \text{ k-ft}$$

Check for case where no brace points provided:

$$\Phi_d M_n = F_{cr} S_x \leq \Phi_d M_p \quad (L_b > L_r) \\ = (1.0)(60.7)(458) / 12 \\ = 2315.7 \text{ k-ft} > M_{pr} \rightarrow \underline{\text{OK with no braces}}$$

## Appendix C

### Other Moment Frames Bracing

W21X57 – 30 ft long

$$L_b \leq 0.095r_y E / (R_y F_y) \\ = 0.095(1.35)(29000) / ((1.1)(50)) \\ = 67.6 \text{ in.} = 5.64 \text{ ft.}$$

$$n_b \geq (\text{Span}) / (\text{Max } L_b) - 1 \\ = 30 / 5.64 - 1 = \underline{5 \text{ brace points}}$$

### DuraFuse Frames Bracing

W21X57 – 30 ft long

Provide bracing such that  $\Phi_d M_n \geq M_{pr}$

$$M_{pr} = F_y Z_x = (50)(129) = 6450 \text{ k-in} = 537.5 \text{ k-ft}$$

Check for case where 2 brace points provided:

$$\Phi_d M_n = \Phi_d C_b [M_{pr} - (M_{pr} - 0.7F_y S_x) \left( \frac{L_b - L_p}{L_r - L_p} \right)] \leq \Phi_d M_p \\ = (1.0)(1.36)[538 - (538 - 0.7(463)) \left( \frac{10 - 4.8}{14.3 - 4.8} \right)] \\ = 573.1 \text{ k-ft} > M_{pr} \rightarrow \underline{2 \text{ brace points OK}}$$

## Appendix D

### Other Moment Frames Bracing

32 ft unbraced length

$$L_b \leq 0.095r_y E / (R_y F_y) \\ r_y \geq L_b R_y F_y / (0.095 E) \\ \geq (32 \times 12) (1.1) (50) / (0.095 \times 29000) \\ \geq 7.67 \text{ in.}$$

There is no wide flange shape with  $r_y \geq 7.67$ .

### DuraFuse Frames Bracing

W18X76 – 32 ft long

Provide bracing such that  $\Phi_d M_n \geq M_{pr}$

$$M_{pr} = F_y Z_x = (50)(163) = 8150 \text{ k-in} = 679.2 \text{ k-ft}$$

Check for case where no brace points provided:

$$\Phi_d M_n = F_{cr} S_x \leq \Phi_d M_p \quad (L_b > L_r) \\ = (1.0)(62.4)(146) / 12 \\ = 758.7 \text{ k-ft} > M_{pr} \rightarrow \underline{\text{OK with no braces}}$$



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