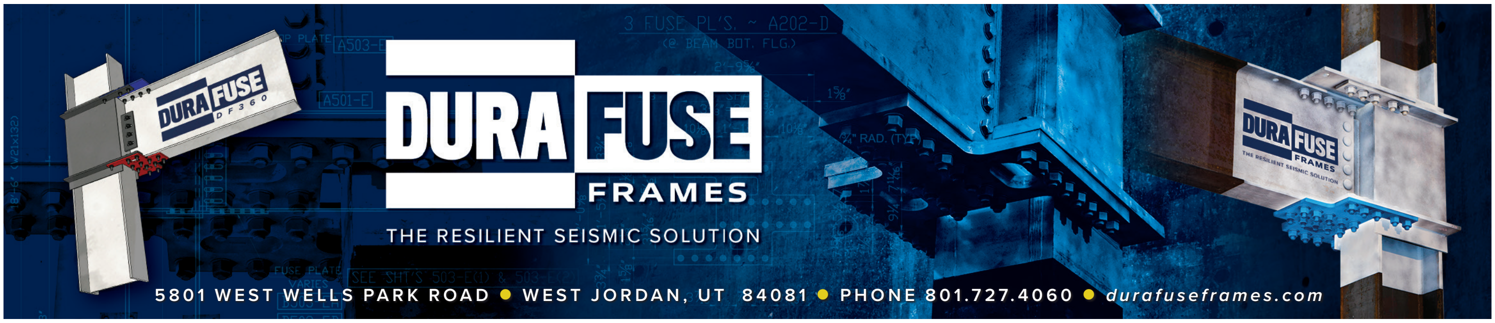

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TECHNICAL BULLETIN 16

Using BRBFs with Eccentric Configurations in Combination with DuraFuse Frames

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Abstract: One application of BRBFs that has been underappreciated is their use in eccentric configurations (BRBF-Es). Case studies were performed to compare the weight of BRBF-Es with SMFs in 1- and 3-story frames. BRBF-Es provided nearly the same amount of unobstructed bay space as SMFs with weight reductions of up to 58%. Another case study illustrates how some bays in an SMF can be converted to a BRBF-E, resulting in over 40% reduction in weight and elimination of grade beams without any architectural impact. The synergy of BRBF-E and SMF is maximized when DuraFuse Frames are used for the SMFs and CoreBrace braces are used for the BRBF-Es.

Background

This bulletin is about buckling-restrained braced frames (BRBFs) and special moment frames (SMFs), but it is helpful to begin with some background on eccentrically braced frames (EBFs). In the late 1970s and through the 1980s, there was concerted research effort to develop ductile braced frames for U.S. practice. Eccentrically braced frames were viewed as a way to combine the desirable stiffness of braced frames, with the desirable ductility and architectural flexibility of SMFs. Experimental and analytical studies at Berkeley investigated isolated EBF yielding links, sub-assemblies, and systems (Roeder and Popov, 1978; Hjelmstad and Popov, 1983; Malley and Popov, 1984; Kasai and Popov, 1986; Ricles and Popov, 1989; Engelhardt and Popov, 1992). Provisions for EBF design were included in the original LRFD seismic provisions (AISC, 1990) and were updated in subsequent provisions. ASCE 7 recognized the ductility of EBFs with an R of 8 (ASCE, 2016).

However, EBFs have remained a niche system because they are not perceived as cost competitive for most buildings. EBF design and detailing is complicated by the requirement to have stable yielding in the beam link while the rest of the beam and the braces remain essentially elastic. Numerous stiffeners are required in the links, relatively heavy braces are required to handle high moments and axial forces, and substantial connections are required at the brace ends. These issues and others hurt the economy of EBFs, such that their use is primarily driven by architectural considerations.

The development of buckling-restrained braced frames (BRBFs) also impacted the use of EBFs. BRBFs provide excellent stiffness and ductility (R=8), solving the main problem that EBFs were developed to address, with less complicated design and less steel weight.

One application of BRBFs that has been underappreciated is the use of BRBFs with eccentric configurations. BRBFs in eccentric configurations (BRBF-Es) are effective in accommodating architectural features (Prinz and Richards, 2012), and can be used in combination with DuraFuse Frames to dramatically reduce the cost of buildings that are currently designed as SMFs.

The purpose of this bulletin is to explain the benefits of BRBFs with eccentric configurations (BRBF-Es), explain how BRBF-Es are designed, and illustrate their powerful synergy with DuraFuse Frames.

BRBFs with Eccentric Configurations

Fig. 1 illustrates BRBF-Es, in the underformed state on the left and with significant lateral displacement on the right. In both configurations, the beam is designed to remain elastic and all inelasticity is confined to the brace, making them BRBFs and not EBFs.

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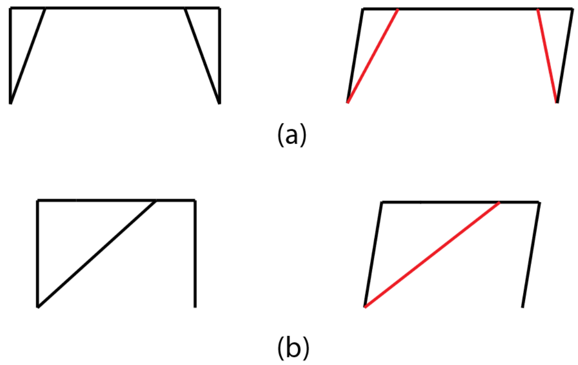

Fig. 1 *Buckling-restrained braced frames with eccentric configurations*

One advantage of BRBF-Es is the improved unobstructed bay space, as compared to traditional bracing. Fig. 2 shows a traditional BRBF, a special moment frame (SMF), and a BRBF-E for a bay that is 30 ft wide and 15 ft tall. The BRBF-E has almost the same unobstructed space below the finished ceiling as an SMF with deep columns (W27x) and requires much less steel to achieve the same stiffness.

Another advantage of BRBF-Es is easier detailing, as compared to EBFs. For example, the configuration shown in Fig. 1(b) is very easy to design as a BRBF-E, but has always been problematic structurally as an EBF. The EBF version of Fig. 1(b) has high inelastic deformation demands in the proximity of the link-to-column connection and no link-to-column connections are prequalified (AISC, 2016).

A unique feature of BRBF-Es is reduced stiffness, as compared to traditional BRBFs. This can be used to advantage because it facilitates the use of BRBF-Es in parallel with SMFs. It is challenging to use traditional BRBFs in parallel with SMFs because the BRBFs attract too much force because of their inherent stiffness relative to moment frames.

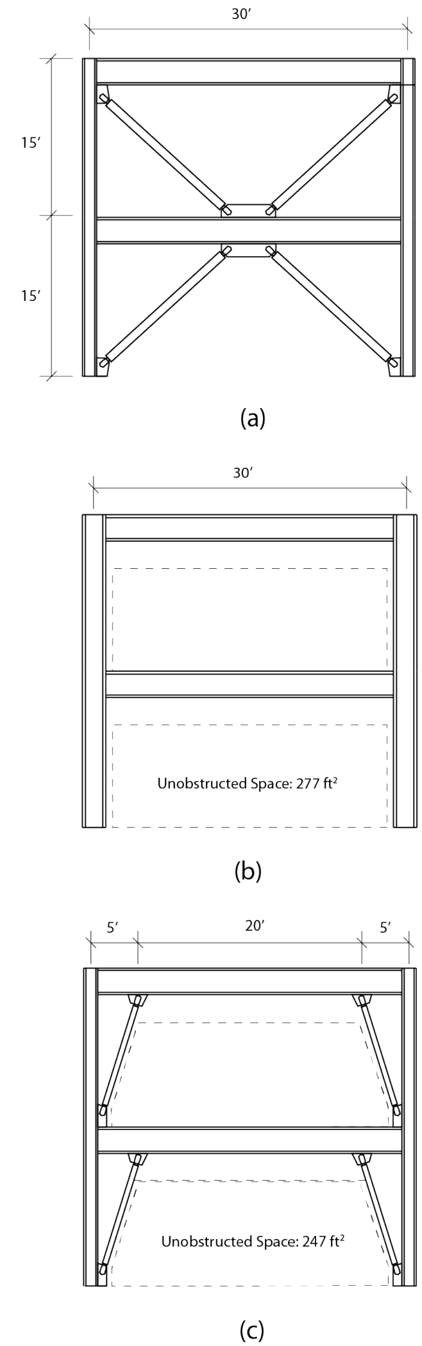

Fig. 2 *Comparing unobstructed space for different lateral force resisting systems: (a) traditional BRBF, (b) SMF, and (c) BRBF-E*

BRBF-E Design

The load effects in the beams of a BRBF-E are different than a BRBF, but are easy to calculate and manage in design. Fig. 3 shows a BRBF and a BRBF-E that have the same brace sizes (max tension 282 kips, max compression 309 kips). In both cases, the beam is designed for the maximum force that is delivered by the yielded braces in tension and compression, in combination with the gravity load effects. The moment diagrams in Fig. 3 just show seismic load effects for clarity:

BRBF-Es are less efficient than BRBFs for providing strength and stiffness because the load effects in the beam are much greater for BRBF-Es [Fig. 3(b)]. Similarly, the column load effects in multi-story frames will be higher for BRBF-Es because the brace angle is closer to vertical for the BRBF-Es. Beam and column weights for a BRBF-E will be higher than a BRBF for the same brace size.

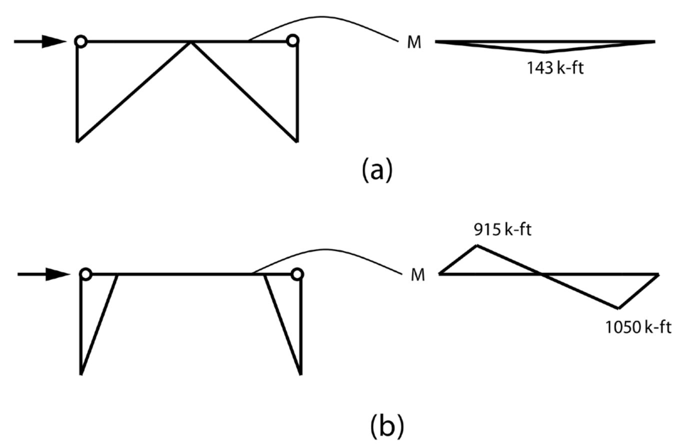

Fig. 3 *Beam load effects: (a) traditional BRBF, (b) BRBF-E*

While BRBF-Es are less efficient than BRBFs, BRBF-Es are still much more efficient than moment frames. In this bulletin, the focus is on how BRBF-Es may be used in place of a traditional moment frames in some contexts and in parallel with moment frame in other contexts.

Comparison Study

A comparison study for one-story and three-story frames was conducted to evaluate the relative weight of BRBF-Es and moment frames. All of the frames had a bay width of 30’ and a story height of 15’. Moment frames were considered with pinned bases and grade beams. The BRBF-E bases were always considered pinned. Connections at the BRBF-E beam to column joint were considered fixed, to reflect gusset plates that would be present for stories above.

Fig. 4 shows three frames that have essentially the same lateral stiffness of 190 k/in. Table 1 summarizes weights for the frames. The BRBF-E was half the weight of a pinned-base moment frame, and 30% lighter than the moment frame with grade beam. The weight advantages of the BRBF-E would be even greater if the moment frames were limited to a maximum column depth of W14 rather than W24.

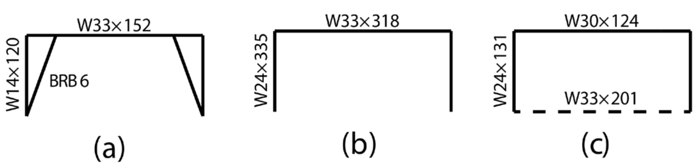

Fig. 4 *Three 1-story frames with same lateral stiffness: (a) BRBF-E; (b) SMF with pinned-base; (c) SMF with grade beam.*

Table 1 *Weight comparison of 1-story frames with same lateral stiffness*

	Weights (lbs)		
Component	**BRBF-E**	**SMF-Pinned**	**SMF-Grade Beam**
Grade Beam	0	0	6,033
Beam	4,583	9,565	3,726
Columns	3,603	10,035	3,940
Brace Cores	646	0	0
Brace Casings	905	0	0
Total	9,737	19,600	13,699

Fig. 5 shows three 3-story frames that have essentially the same lateral stiffness. Table 2 summarizes weights for the frames. The BRBF-E had 58% less steel weight than a pinned-base moment frame, and 36% less steel weight than a moment frame with grade beam. The weight advantages of the BRBF-E would be even greater if the moment frames were limited to maximum column depth of W14 rather than W24.

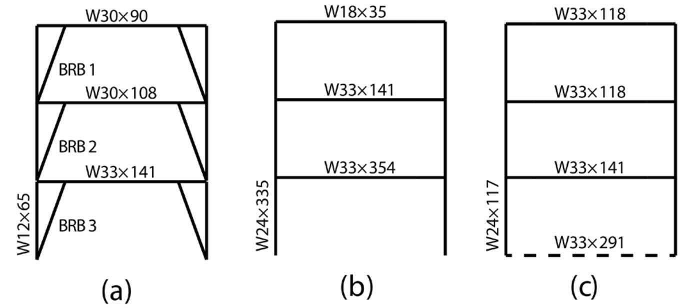

Fig. 5 *Three 3-story frames with same lateral stiffness: (a) BRBF-E; (b) SMF with pinned base; (c) SMF with grade beam*

Table 2 *Weight comparison of 3-story frames with same lateral stiffness*

	Weights (lbs)		
Component	**BRBF-E**	**SMF-Pinned**	**SMF-Grade Beam**
Grade Beam	0	0	8,738
Beam 1	4,236	10,616	4,236
Beam 2	3,236	4,236	3,542
Beam 3	2,685	1,051	3,542
Columns	5,849	30,104	10,536
Brace Cores	1,399	0	0
Brace Casings	2,102	0	0
Total	19,507	46,007	30,594

The conclusion from the 1- and 3-story comparison studies is that BRBF-Es are much more efficient than moment frames and should be used in place of moment frames where architecturally possible.

Multi-Bay Example

Fig. 6(a) shows a 3-story, 3-bay, SMF on the exterior of an example building. The beam and column sizes were governed by drift requirements. The light dashed lines in the figure indicate architectural finishes that could conceal eccentric bracing. The heavy dashed line at the base indicates a grade beam.

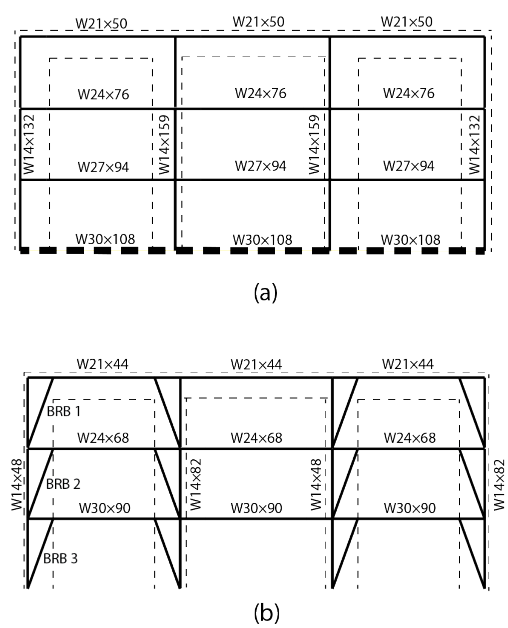

Fig. 6 *Two designs for a 3-bay moment frame with the same lateral stiffness: (a) SMF, (b) DuraFuse Frames + BRBF-E*

Fig. 6(b) shows an alternative design that uses BRBF-Es in bays where they can be concealed and a DuraFuse Frame SMF in the middle bay. Table 3 summarizes weights from the two frames. The alternative design results in a 41% reduction in steel weight, and the elimination of grade beams with no negative architectural impact.

Table 3 *Weight comparison of 3-story frames with same lateral stiffness*

	Weights (lbs)	
Components	**BRBF-E + SMF (Pinned)**	**SMF-Grade Beam**
Grade Beams	0	9,708
Beam 1s	8,054	8,452
Beam 2s	6,156	6,860
Beam 3s	3,981	4,502
Columns	11,668	26,184
Brace Cores	1,291	0
Brace Casings	1,440	0
Total	32,590	55,706

DuraCore (DuraFuse + CoreBrace)

The synergy between BRBF-Es and moment frames is maximized when DuraFuse Frames are used for the SMFs and CoreBrace braces are used for the BRBFs. DuraFuse Frames are the most resilient SMFs available because they incorporate fuse plates that prevent beam yielding during severe earthquakes. DuraFuse Frames are also the most efficient SMFs because they position connection plate material for greatest advantage. CoreBrace is the industry leader in providing BRBs with superior seismic performance. DuraFuse Frames, LLC, and CoreBrace, LLC, are sister-companies that are committed to providing the highest value and seismic performance.

Applications

There are many applications for BRBF-Es in combination with DuraFuse Frames. Many projects that are currently all-SMFs can actually accommodate BRBF-Es in some bays without negatively impacting architecture. For example, many steel buildings can accommodate eccentrically braced bays around stair cores and a few interior locations but cannot accommodate bracing around the perimeter. By using BRBF-E bays in some SMF bays, savings of 40 to 50% are possible.

Summary and Conclusions

Buckling-restrained braced frames are more efficient than special moment frames for providing strength and stiffness but can conflict with the architecture of a building. Eccentrically braced frames are more accommodating but are perceived as uneconomical, so special moment frames are generally used when BRBFs conflict with architecture.

BRBFs can be used in eccentric configurations (BRBF-Es) to great advantage. Case studies on 1- and 3-story frames were used to compare the weights of BRBF-Es with SMFs. BRBF-Es were 30 to 58 percent lighter than SMFs with the same stiffness. The BRBF-Es that were investigated had wide openings such that the unobstructed space in the bays was similar to that of a SMF with deep columns.

A final example illustrated how BRBF-Es can be used in parallel with DuraFuse Frames. Using BRBF-Es where architecturally feasible reduced steel tonnage by over 40% and eliminated the need for grade beams.

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