Getting the Most Out of Buckling Restrained Braces

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Information to help you get what you design and design what you can get.

THE BUCKLING-RESTRAINED BRACE (BRB) was introduced in the United States in the late 1990s and since then has been used in more than 350 structures. Over the last 10 years, the technology has reached a significant level of maturity through research, codification and practice. The lateral-load resisting system in which it is an integral component, the buckling-restrained braced frame (BRBF), has been codified since 2005 and is covered by both the AISC *Seismic Provisions* (ANSI/AISC 341-05 and the upcoming release of 341-10) and ASCE/SEI 7-10.

The general level of awareness of BRBs and the BRBF in the engineering community has grown considerably in the last few years as evidenced by the significant number of research manuscripts, trade magazine articles and conference presentations covering the system. Yet even with all the information available many engineers still are unclear on the concept, particularly on how to design and specify the product.

Anatomy of a BRB

The main characteristic of a BRB is that it does not buckle. Its ability to yield both in compression and tension, dissipating seismic energy with nearly symmetric behavior, provides a significant advantage over conventional bracing systems.

BRBs have two main components, shown in Figure 1 on the opposite page, that perform distinct tasks while remaining uncoupled. The load-resisting component of a BRB is a steel core restrained against overall buckling by an outer casing filled with concrete. This casing is the stability component or buckling-restraining mechanism. Bonding of the steel core to the concrete is prevented in the manufacturing process to ensure that the BRB components remain separate to prevent composite action that would change the behavior.

The BRB is typically placed in a concentrically braced frame, forming a configuration referred to as a BRBF. This lateral-load resisting system is used most often for structures in seismic demand categories D, E or F, regardless of whether wind or seismic loads govern the design of the structure. BRBF systems provide cost savings over conventional bracing systems as the engineer is better able to estimate the seismic demands, and then size the connections and foundations accordingly. BRBF systems also have been explored for bridge, blast, and lower seismic applications where the highly-ductile, non-buckling attributes of the BRB might still provide a significant benefit.

BRBF systems exhibit robust cyclic performance and have large ductility capacity, which is reflected in the seismic response factors, R. When the beams in the lateral force resisting frame are moment connected to the columns, $R = 8$; when they are not (an option not permitted in the ASCE7-10 code) $R = 7$. Testing performed on BRBs to date has shown they are capable of withstanding multiple seismic events without failure or loss of strength.

Design and Specification

The design of a BRBF system is straightforward. Engineers typically use the Equivalent Lateral Force procedure provided in ASCE/SEI 7, unless a more rigorous analysis method is selected. The approximation of the structural period, T_a, should use C_r and x values from Appendix R of the *Seismic Provisions* or the methods of Section 12.8.2 of ASCE/SEI 7-10. A good reference on the methodology of designing with BRBs is "Seismic Design of Buckling-Restrained Braced Frames," the paper that earned authors Walterio López and Rafael Sabelli the 2008 AISC T.R. Higgins Lectureship award.

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One frequently asked question on BRBF projects is what information the structural engineer of record (SER) must include in the design drawings to obtain the intended performance. The SER should communicate design assumptions, acceptance criteria, and interpretation of the requirements of ANSI/AISC 341-05. That begins with the information necessary to ensure that BRBs can be accurately estimated, priced, designed, detailed, and erected, including BRB quantities, sizes, lengths and end connection types. However, additional information is necessary to ensure the BRBs provided meet the design intent and are adequate for the seismic response of the structure. This includes design factors and maximum allowable strength adjustment factors.

The following items should be included in the design drawings:

1. *Seismic design parameters and analysis procedure employed.* Include information such as the design story drift and the values of R, C_d, I, and ρ used in the design. In addition, the drawings should indicate what analysis procedure was conducted to obtain the design brace forces, which is important in accurately determining design brace strains and corresponding strength adjustment factors to be used in brace design.

2. *Permissible range of steel core yield strength, F_{ysc}.* A range of 38 ksi to 46 ksi is generally the accepted practice. However, discuss this with the BRB manufacturer.

3. *Permissible variability in BRB required strength.* There are two options for complying with the BRB strength requirements in AISC 341. One can maintain a constant steel core area and allow the core yield strength to vary (as in Item 2). Alternatively one can maintain a constant core yield strength and allow the steel core area to vary. The latter results in lower BRB overstrength but also results in a wider variation of BRB stiffnesses. BRBs with identical specified strengths may have stiffnesses that vary by as much as 20% due to differences in the overall length or the length of internal sections of the brace, which may result in unintentional system behavior.

4. *Permissible variability in BRB stiffness.* Specify either a minimum stiffness or both a minimum and a maximum stiffness. This can be given as a Stiffness Modification factor (*SM* factor) in the drawings, or as a K_{eff} value. Also provide guidance on how the BRB manufacturer should use the information given.

5. *Definition of methodology for determining BRB strains.* Calcu-

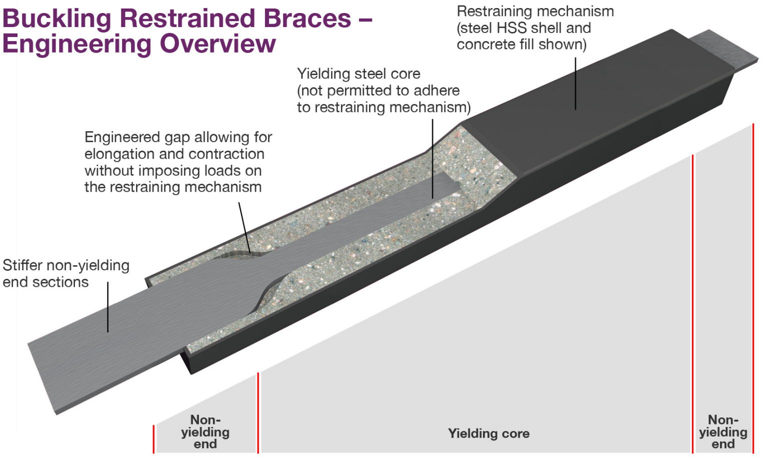

Fig. 1: Components of a buckling-restrained brace.

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Buckling-restrained braces (BRB) incorporated into a buckling-restrained braced frame (BRBF).

Buckling-restrained braces (BRB) anchored externally.

lated BRB strains should be smaller than those associated with successfully tested braces. As a result, the BRB manufacturer determines BRB strains to verify code compliance and should be required to submit proof of this compliance.

6. *Maximum permissible adjusted brace strength.* Frame beams, frame columns, and BRBF connections are checked using BRB-dependent strength adjustment factors ω, β, and ωβ. These factors can be obtained from BRB manufacturers early in the design of the structure.

7. *BRB connection details (even in skeleton format) that include work-point location and beam/column connection configuration.* If requested by the SER, BRB manufacturers will design and detail the connection of the brace to the gusset plate and may design and detail the entire gusset plate connection. Accomplishing that requires a minimum level of information on the design drawings. Connection limit states that include gravity and drag loads remain the responsibility of the engineer providing connection design for the structure.

Figure 2 provides an example of a BRB schedule that effectively communicates several of the items listed above, many with corresponding notes.

Although the process of designing and specifying BRBFs is generally straightforward, all parties can benefit from heeding the lessons of past projects to avoid re-learning those lessons at further expense. With that in mind, two recommendations are presented below.

Clearly state the force level for any forces given in the design drawings. The brace force specified on the drawings may be the brace *design axial strength*, P_{ysc}, the actual force level at which the engineer requires the brace to yield (as defined in AISC 341-05), a "P_u" value, or the actual load taken from the building model and perhaps rounded up to make fewer brace types. The design drawings should include both the design approach used (ASD vs. LRFD) and an equation showing the manufacturer how it is intended that the loads given are to be used.

It is important for the engineer to understand the interrelationship between stiffness, strength, and maximum adjusted brace strength and the fact that it is usually not possible to arbitrarily specify these three values. During the design phase, verify with the BRB manufacturer that BRB stiffnesses specified are feasible at the requested stength. **MSC**

This article is the basis of a presentation the authors will make at NASCC: The Steel Conference, May

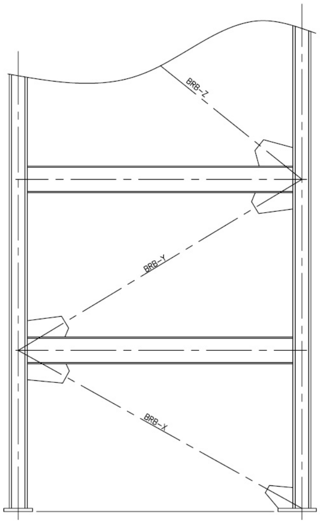

Fig. 2: Example of a buckling-restrained braced frame and schedule with notes.

Braced Frame	Brace Type	P_{ysc} or P_u (kips)	A_{sc} (in^2)	Stiffness Modifier (SM)
BF-1	BRB-X		X	
	BRB-Y		Y	
	BRB-Z		Z	

Notes

1. Buckling restrained braces are to be tested per the provisions of AISC 341-05. Supplier to submit proof of each brace's compliance with the qualified load and strain ranges.

2. P_{ysc} given is the design axial strength ($A_{sc}\ F_{ysc}$), or P_u given is the governing code level force in the brace, using LRFD force levels $P_u \leq 0.9\ A_{sc}\ F_{y\ min}$.

3. F_{ysc} is the actual yield stress of the steel core as determined by a coupon test. 38 ksi ≤ F_{ysc} ≤ 46 ksi. Charpy testing required when thickness of the core material exceeds 2 in.

4. Brace stiffness K_{eff} to be $SM \times (A_{sc}E/L)$ +/-10%, where the values for Stiffness Modification Factor (SM) and A_{sc} are taken from the table and L is the workpoint–workpoint length of the brace.

5. Brace strains to be calculated from design interstory drifts, or Brace strains to be calculated as $P_{service} / K_{eff}$, where $P_{service} = P_u / \rho I$ (ρ = code redundancy factor and I = code importance factor).

6. Maximum ωβ not to exceed X.XX. Maximum β not to exceed X.XX.