On Designing with Buckling-Restrained Braced Frames

By Walterio A. López, S.E.

Engineers designing structures assigned to, or required to be detailed to, the requirements of Seismic Design Categories D, E, and F are more frequently specifying buckling-restrained braced frames (BRBFs) as the Seismic Load Resisting System (SLRS) when the program allows for the use of concentric braced frames. Technical journals, construction industry publications, and leading national conferences feature articles and keynote speeches on BRBFs. It is no wonder, then, that one may be intrigued just a bit and ask: What are these BRBFs? How are they treated by codes? And how are they specified?

Definition

BRBFs are a special class of concentric braced frames in which overall brace buckling is precluded at the required axial strengths associated with the Seismic Base Shear. Numerous analytical and experimental studies have been conducted on BRBFs, and those studies have helped qualify some of BRBF's characteristics including positive post-yield stiffness and large repeatable hysteretic loops.

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The main component of BRBFs is the brace, which is known as a buckling-restrained brace (BRB). The idea behind a BRB is simple; to provide a buckling-restraining mechanism separate from the load-resisting portion of the brace (the steel core) such that buckling of the core is limited to very small amplitudes. By limiting the buckling of the core to very small amplitudes, the core is able to yield in compression, and even sustain compressive strains well in excess of its yield strain.

Brief History

The first U.S. application of a BRBF as the SLRS was in 1999 for a University of California Davis new laboratory building. Nine years later many more applications in both new construction and seismic retrofit have followed, with one estimate placing the number of structures utilizing BRBFs at about 150 and the number of BRBs used at about 20,000. Proprietary BRBs used in U.S. construction projects to date include those manufactured by Nippon Steel Corporation, Star Seismic, and CoreBrace.

BRBFs and Applicable Codes

A structural engineer specifying a BRBF for the first time needs to know that the system is covered both by the *Minimum Design Loads for Building and Other Structures* (ASCE 7-05) and the *SEISMIC PROVISIONS For Structural Steel Buildings* (ANSI/AISC 341-05) and, thus, adopted by reference in the *2006 International Building Code* (2006 IBC). Because of a mishap, Table 12.8-2 of ASCE7-05 omitted C_t and x values for BRBF, which are identical to those for eccentrically braced frames. The 2010 printing of ASCE 7 will include the omitted parameters. In the meantime, design engineers and plan reviewers involved in BRBF projects are encouraged to refer to Appendix R of ANSI/AISC 341-05 for C_t and x values. Other design parameters are found on Table 12.2-1 of ASCE 7-05. Lastly, the increase in building height limit defined in Section 12.2.5.4 of ASCE7-05 is interpreted to apply to all steel braced frames and, therefore, to BRBFs as well.

Structural engineers utilizing BRBFs for the first time ask whether they will need to perform complex calculations, submit their design for peer review approval in addition to approval by the Authority Having Jurisdiction, and conduct project specific testing of the BRB sizes chosen. These are all valid questions whose answers are found in codes. The same as for any other codified system, the appropriate method of analysis to be used in a BRBF project is dictated by Table 12.6-1 of ASCE 7-05. Therefore, complicated analytical procedures are not system-dependent but

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Seismic Design Category dependent. The criterion to evaluate the adequacy of a BRBF design is compliance with the appropriate chapters of ASCE 7-05 and ANSI/AISC 341-05. Some Authorities Having Jurisdiction are not yet familiar with those chapters and delegate the seismic review of a BRBF project to a third party peer reviewer. However, in those instances, the approval by a peer reviewer supplements and does not duplicate that by the Authority Having Jurisdiction. The expectation is that as Authorities Having Jurisdiction become more familiar with the system, and as long as a BRBF design does not take exception to code requirements, the need for a third party peer review will diminish. As far as testing is concerned, ANSI/AISC 341-05 requires that BRBF designs be based on the results of qualifying cyclic tests. This requirement ensures that only successful BRB concepts are used, limits the use of BRBs to within their proven range of deformation capacity, and forces both the brace manufacturer and design engineer to define the similarities between project braces and successfully tested braces. As long as the design engineer does not specify BRBs with sizes or deformations larger than those successfully tested, project-specific testing is not required. The state of the practice is for the design engineer to contact BRB manufacturers to obtain their test data to know the limitations in size and deformation for a given BRB type.

Analysis, Design, Specification, and Gusset Connections

Proper design of BRBFs starts with appropriate analysis assumptions. It is appropriate to account for the effective stiffness of the BRB as opposed to modeling only the work point to work point stiffness based solely on the area of the steel core, A_{sc}. It is also appropriate to account for the fixity provided by the gusset connections and model beam-to-column joints as fixed. In reality, a non-moment-resisting beam to column connection is difficult to achieve. Just as important as the analysis assumptions is the proper specification of the steel core material. Steel normally specified for core material has a wide variability in its actual yield strengths from its specified nominal values and that's undesirable from a behavior standpoint. As a result, current state of the practice is to specify a steel core material with a narrow range of yield strengths (F_{ysc} = 42 ksi, ± 4 ksi, for example), allowing the manufacturer to procure the steel core material based on Mill Test Reports, but requiring coupon tests prior to BRB fabrication. BRB sizes are chosen using the smallest F_{ysc} specified and the surrounding frame and connections are designed using adjusted BRB strengths based on the largest F_{ysc} specified. The detailing of gusset plate connections is as critical to the adequate seismic behavior of BRBFs as any other single component. The structural engineer needs to spend enough time following best practices in detailing gusset configurations or risk that at large interstory drifts some gusset connections may become the limit state in adequate BRBF seismic performance.▪

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