

## PART VI

### Appendix R

### Qualifying Cyclic Tests of Buckling-restrained Braces

#### R.1 Scope

This Appendix includes requirements for qualifying cyclic tests of individual buckling-restrained braces and buckling-restrained brace subassemblages, when required in these provisions. The purpose of the testing of individual braces is to provide evidence that a buckling-restrained brace satisfies the requirements for strength and inelastic deformation by these provisions; it also permits the determination of maximum brace forces for design of adjoining elements. The purpose of testing of the brace subassemblage is to provide evidence that the brace-design can satisfactorily accommodate the deformation and rotational demands associated with the design. Further, the subassemblage test is intended to demonstrate that the hysteretic behavior of the brace in the subassemblage is consistent with that of the individual brace elements tested uniaxially.

Alternative testing requirements are permitted when approved by the engineer of record and the authority having jurisdiction. This Appendix provides only minimum recommendations for simplified test conditions.

#### R.2 Symbols

The numbers in parentheses after the definition of a symbol refers to the Section number in which the symbol is first used.

- $\Delta_b$  Deformation quantity used to control loading of the test specimen (total brace end rotation for the subassemblage test specimen; total brace axial deformation for the brace test specimen) (Section R.6).
- $\Delta_{b,m}$  Value of deformation quantity,  $\Delta_b$ , corresponding to the design story drift (Section R.6).
- $\Delta_{b,y}$  Value of deformation quantity,  $\Delta_b$ , at first significant yield of test specimen (Section R.6).

#### R.3 Definitions

|                     |                                                                                                                                                                                        |
|---------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BRACE TEST SPECIMEN | A single buckling-restrained brace element used for laboratory testing intended to model the brace in the Prototype.                                                                   |
| DESIGN METHODOLOGY  | A set of step-by-step procedures, based on calculation or experiment, used to determine sizes, lengths, and details in the design of buckling-restrained braces and their connections. |

|                             |                                                                                                                                                                               |
|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| INELASTIC DEFORMATION       | The permanent or plastic portion of the axial displacement in a buckling-restrained brace.                                                                                    |
| PROTOTYPE                   | The brace, connections, members, steel properties, and other design, detailing, and construction features to be used in the actual building frame.                            |
| SUBASSEMBLAGE TEST SPECIMEN | The combination of the brace, the connections and testing apparatus that replicate as closely as practical the axial and flexural deformations of the brace in the prototype. |
| TEST SPECIMEN               | Brace test specimen or subassembly test specimen.                                                                                                                             |

#### R.4 Subassembly Test Specimen

The subassembly test specimen shall satisfy the following requirements :

- (1) The mechanism for accommodating inelastic rotation in the subassembly test specimen brace shall be the same as that of the prototype. The rotational deformation demands on the subassembly test specimen brace shall be equal to or greater than those of the prototype.
- (2) The axial yield strength of the steel core,  $F_{yc}$ , of the brace in the subassembly test specimen shall not be less than that of the prototype where both strengths are based on the core area,  $A_{gc}$ , multiplied by the yield strength as determined from a coupon test.
- (3) The cross-sectional shape and orientation of the steel core projection of the subassembly test specimen brace shall be the same as that of the brace in the prototype.
- (4) The same documented design methodology shall be used for design of the subassembly as used for the prototype, to allow comparison of the rotational deformation demands on the subassembly brace to the prototype. In stability calculations, beams, columns, and gussets connecting the core shall be considered parts of this system.
- (5) The calculated margins of safety for the prototype connection design, steel core projection stability, overall buckling and other relevant subassembly test specimen brace construction details, excluding the gusset plate, for the prototype, shall equal or exceed those of the subassembly test specimen construction.
- (6) Lateral bracing of the subassembly test specimen shall replicate the lateral bracing in the prototype.
- (7) The brace test specimen and the prototype shall be manufactured in accordance with the same quality control and assurance processes and procedures.

Extrapolation beyond the limitations stated in this section shall be permitted subject to qualified peer review and approval by the authority having jurisdiction.

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**R.5 Brace Test Specimen**

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The brace test specimen shall replicate as closely as is practical the pertinent design, detailing, construction features, and material properties of the prototype.

**R.5.1 Design of Brace Test Specimen**

The same documented design methodology shall be used for the brace test specimen and the prototype. The design calculations shall demonstrate, at a minimum, the following requirements :

- (1) The calculated margin of safety for stability against overall buckling for the prototype shall equal or exceed that of the brace test specimen.
- (2) The calculated margins of safety for the brace test specimen and the prototype shall account for differences in material properties, including yield and ultimate stress, ultimate elongation, and toughness.

**R.5.2 Manufacture of Brace Test Specimen**

The brace test specimen and the prototype shall be manufactured in accordance with the same quality control and assurance processes and procedures.

**R.5.3 Similarity of Brace Test Specimen and Prototype**

The brace test specimen shall meet the following requirements:

- (1) The cross-sectional shape and orientation of the steel core shall be the same as that of the prototype.
- (2) The axial yield strength of the steel core,  $P_{JSC}$ , of the brace test specimen shall not vary by more than 50 percent from that of the prototype where both strengths are based on the core area,  $A_{SC}$ , multiplied by the yield strength as determined from a coupon test.
- (3) The material for, and method of, separation between the steel core and the buckling restraining mechanism in the brace test specimen shall be the same as that in the prototype.

Extrapolation beyond the limitations stated in this section shall be permitted subject to qualified peer review and approval by the authority having jurisdiction.

**R.5.4 Connection Details**

The connection details used in the brace test specimen shall represent the prototype connection details as closely as practical.

**R.5.5 Materials**

- (1) Steel core: The following requirements shall be satisfied for the steel core of the brace test specimen:
  - (a) The specified minimum yield stress of the brace test specimen steel core shall be the same as that of the prototype.

- (b) The measured yield stress of the material of the steel core in the brace test specimen shall be at least 90 percent of that of the prototype as determined from coupon tests.
- (c) The specified minimum ultimate stress and strain of the brace test specimen steel core shall not exceed those of the prototype.

(2) Buckling-restraining mechanism

Materials used in the buckling-restraining mechanism of the brace test specimen shall be the same as those used in the prototype.

### **R.5.6 Connections**

The welded, bolted, and pinned joints on the test specimen shall replicate those on the prototype as close as practical.

## **R.6 Loading History**

### **R.6.1 General Requirements**

The test specimen shall be subjected to cyclic loads according to the requirements prescribed in Sections R.6.2 and R.6.3. Additional increments of loading beyond those described in Section R.6.3 are permitted. Each cycle shall include a full tension and full compression excursion to the prescribed deformation.

### **R.6.2 Test Control**

The test shall be conducted by controlling the level of axial or rotational deformation,  $\Delta_b$ , imposed on the test specimen. As an alternate, the maximum rotational deformation may be applied and maintained as the protocol is followed for axial deformation.

### **R.6.3 Loading Sequence**

Loads shall be applied to the test specimen to produce the following deformations, where the deformation is the steel core axial deformation for the test specimen and the rotational deformation demand for the subassembly test specimen brace:

- (1) 2 cycles of loading at the deformation corresponding to  $\Delta_b = \Delta_{by}$
- (2) 2 cycles of loading at the deformation corresponding to  $\Delta_b = 0.5\Delta_{bm}$
- (3) 2 cycles of loading at the deformation corresponding to  $\Delta_b = 1.0\Delta_{bm}$
- (4) 2 cycles of loading at the deformation corresponding to  $\Delta_b = 1.5\Delta_{bm}$
- (5) 2 cycles of loading at the deformation corresponding to  $\Delta_b = 2.0\Delta_{bm}$
- (6) Additional complete cycles of loading at the deformation corresponding to  $\Delta_b = 1.5\Delta_{bm}$  as required for the brace test specimen to achieve a cumulative inelastic axial deformation of at least 200 times the yield deformation (not required for the subassembly test specimen).

The design story drift shall not be taken as less than 0.01 times the story height for the purposes of calculating  $\Delta_{bm}$ . Other loading sequences are permitted to be used to qualify the test specimen when they are demonstrated to be of equal or greater severity in terms of maximum and cumulative inelastic deformation.

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**R.7 Instrumentation**

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Sufficient instrumentation shall be provided on the *test specimen* to permit measurement or calculation of the quantities listed in Section R.9.

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**R.8 Materials Testing Requirements**

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**R.8.1 Tension Testing Requirements**

Tension testing shall be conducted on samples of steel taken from the same material as that used to manufacture the steel core. Tension test results from certified mill test reports shall be reported but are not permitted to be used in place of specimen testing for the purposes of this Section. Tension-test results shall be based upon testing that is conducted in accordance with Section R.8.2.

**R.8.2 Methods of Tension Testing**

Tension testing shall be conducted in accordance with ASTM A6, ASTM A370, and ASTM E8, with the following exceptions:

- (1) The yield stress that is reported from the test shall be based upon the yield strength definition in ASTM A370, using the offset method of 0.002 strain.
- (2) The loading rate for the tension test shall replicate, as closely as is practical, the loading rate used for the test specimen.
- (3) The coupon shall be machined so that its longitudinal axis is parallel to the longitudinal axis of the steel core.

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**R.9 Test Reporting Requirements**

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For each test specimen, a written test report meeting the requirements of this Section shall be prepared. The report shall thoroughly document all key features and results of the test. The report shall include the following information:

- (1) A drawing or clear description of the test specimen, including key dimensions, boundary conditions at loading and reaction points, and location of lateral bracing, if any.
- (2) A drawing of the connection details showing member sizes, grades of steel, the sizes of all connection elements, welding details including filler metal, the size and location of bolt or pin holes, the size and grade of connectors, and all other pertinent details of the connections.

- (3) A listing of all other essential variables as listed in Section R.4 or R.5, as appropriate.
- (4) A listing or plot showing the applied load or displacement history.
- (5) A plot of the applied load versus the deformation,  $\Delta_b$ . The method used to determine the deformations shall be clearly shown. The locations on the test specimen where the loads and deformations were measured shall be clearly identified.
- (6) A chronological listing of significant test observations, including observations of yielding, slip, instability, transverse displacement along the test specimen and fracture of any portion of the test specimen and connections, as applicable.
- (7) The results of the material tests specified in Section R.8.
- (8) The manufacturing quality control and quality assurance plans used for the fabrication of the test specimen. These shall be included with the welding procedure specifications and welding inspection reports.

Additional drawings, data, and discussion of the test specimen or test results are permitted to be included in the report.

#### **R.10 Acceptance Criteria**

At least one subassembly test that satisfies the requirements of Section R.4 shall be performed. At least one brace test that satisfies the requirements of Section R.5, shall be performed. Within the required protocol range all tests shall satisfy the following requirements:

- (1) The plot showing the applied load vs. displacement history shall exhibit stable, repeatable behavior with positive incremental stiffness.
- (2) There shall be no fracture, brace instability or brace end connection failure.
- (3) For brace tests, each cycle to a deformation greater than  $\Delta_{by}$  the maximum.
- (4) tension and compression forces shall not be less than the nominal strength of the core.
- (5) For brace tests, each cycle to a deformation greater than  $\Delta_{by}$  the ratio of the maximum compression force to the maximum tension force shall not exceed 1.3.

Other acceptance criteria may be adopted for the brace test specimen or subassembly test specimen subject to qualified peer review and approval by the authority having jurisdiction.

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**PART VI**  
**Appendix S**  
**Welding Provisions**

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**S.1 Scope**

This Appendix provides additional details regarding welding and welding inspection, and is included on an interim basis pending adoption of such criteria by AWS or other accredited organization.

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**S.2 STRUCTURAL DESIGN DRAWINGS AND SPECIFICATIONS,  
SHOP DRAWINGS, AND ERECTION DRAWINGS**

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**S.2.1 Structural Design Drawings and Specifications**

Structural design drawings and specifications shall include, as a minimum, the following information:

- (1) Locations where backup bars are required to be removed.
- (2) Locations where supplemental fillet welds are required when backing is permitted to remain.
- (3) Locations where fillet welds are used to reinforce groove welds or to improve connection geometry.
- (4) Locations where weld tabs are required to be removed.
- (5) Splice locations where tapered transitions are required.
- (6) The shape of weld access holes, if a special shape is required.
- (7) Joints or groups of joints in which a specific assembly order, welding sequence, welding technique or other special precautions are required.

**S.2.2 Shop Drawings**

Shop drawings shall include, as a minimum, the following information:

- (1) Access hole dimensions, surface profile and finish requirements.
- (2) Locations where backing bars are to be removed.
- (3) Locations where weld tabs are to be removed.
- (4) NDT to be performed by the fabricator, if any.

**S.2.3 Erection Drawings**

Erection drawings shall include, as a minimum, the following information:

- (1) Locations where backing bars to be removed.
- (2) Locations where supplemental fillets are required when backing is permitted to remain.
- (3) Locations where weld tabs are to be removed.
- (4) Those joints or groups of joints in which a specific assembly order, welding sequence, welding technique or other special precautions are required.