SEISMIC EVALUATION AND CYCLIC TESTING OF BUCKLING RESTRAINED BRACES MANUFACTURED IN IRAN

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ABSTRACT :

Braced frames, as passive control systems of frame structures, are an efficient means of controlling lateral deformation of buildings. The common practice for achieving economy is to allow strategic elements of frames undergo plastic deformation in order to enhance the energy absorption of the system.. In regular braced frames the weak link is the brace element in compression. One way to remove this deficiency is to employ buckling restrained braces (BRB). Buckling prevention in BRBs is achieved by jacketing a core of a steel plate with concrete, which is in turn encased in a steel tube. This will restrain the buckling of the core plate. A coating material is used between the concrete and the core in order to prevent transmission of axial force upon the onset of plastic deformation in the plate. In this manner the compression behavior of the brace will be the same as that of its tension. This paper examines the cyclic behavior of BRBs constructed from the steel produced in Iran with other locally available materials. Some parameters, such as the width of the gap between the core and the encasing concrete, the cross-section of the core, … are varied in order to elicit their effects on the behavior of the brace. The experimental part of the study included 6 samples of the brace: 2 half scale and 4 of ¼ scale. These samples were tested under the same loading protocol and their results are compared and discussed.

KEYWORDS:
Buckling Restrained Brace (BRB), Experimental study, Cyclic Loading

1. INTRODUCTION

Throughout the years various design and construction technologies have been developed for enhancing the seismic performance of building structures. Moment frames usually undergo large levels of lateral deformations when subjected to strong ground motion or wind forces. Due to such deformations structural and nonstructural damage may result, compromising the integrity of the structures. The level of damage is also increased by the P-Delta action under large deformations. Various devices have been used in order to prevent harmful lateral deformations. One efficient way of counteracting large deformations of frames is the use of diagonal elements or braces that increase the lateral stiffness and energy dissipation capacity of the frame. In this way the inter-story deformations are controlled and protection is provided against damage.

A conventional brace is composed of a single steel member designed to sustain both tension and compression. The buckling load of such a member is dependent on the slenderness ratio of the element. The selection of the latter parameter is based on the level of the compressive force, and affects the stiffness of the member. Usually, it is necessary to specify large cross sections in order to avoid buckling failure. Flexural buckling, a failure mode in which the member loses its lateral stiffness and its load carrying capacity, is the most common problem associated with compression elements. When such a failure occurs, lateral stiffness drops and the frame stability decreases significantly, causing severe damage to the structural and non structural elements and in some cases leading to the collapse of the structure. Conventional braces have limited ductility and exhibit unsymmetrical hysteretic cycles, with marked strength deterioration when loaded in compression.

Buckling restrained braces (BRB) were developed to overcome the above mentioned problems. It was first constructed in Japan some thirty years ago. These braces are designed such that buckling is inhibited and the brace exhibits symmetrical hysteretic behavior under both tensile and compressive forces. Buckling restrained braces provide a more reliable and practical alternative to conventional braces for systems under earthquake. They can be

used for both new and retrofit of buildings and provide a substantial, repeatable, energy absorption capability. While frames with conventional braces present irregular patterns of deformation under earthquake excitations, with a tendency to concentrate large deformation levels in one or more stories, BRBs exhibit a more stable, symmetrical behavior. This does not necessarily mean that relative displacements will be smaller, but the response will be more uniform along the height of the structure.
In the two common buckling restrained braces the steel core, which sustains the lateral forces acting at the respective frame story, is surrounded by concrete which is encased either in a steel tube, or in a reinforced concrete panel. Figure 1 shows a typical cross section of a tube encased BRB.

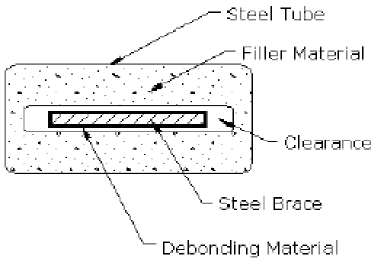

Figure 1. Typical cross section of a BRB

The gap between the core and the encasing concrete and debonding material (figure1), minimize the effect of frictional forces between the core and the surrounding member, allowing relative deformation between the two elements at the onset of yielding of the steel core. The term “Unbonded Brace”, some times used to denote a buckling restrained brace, indicates that there is a slip surface between the steel core and the surrounding concrete. Thus after yielding only the steel core resists axial loads, providing a ductile behavior. The material and geometry of the slip layer must be carefully selected to allow relative movement between the steel element and the concrete, while inhibiting in a buckling of the steel core as it yields in compression. In spite of the large number of research on and application of BRB's in Japan, US and some European countries, no significant study has been performed in Iran to allow its adaption with the existing materials and technologies.

2. EXPERIMENTAL PART OF THIS STUDY

To investigate the seismic performance and characteristic of buckling restrained braces, an experimental program was set up. 6 different specimens were manufactured and tested at the International Institute of Earthquake Engineering and Seismology (IIEES) in Iran for this study.

2.1. Specimens

4 quarter-scale specimens (S1 , S2 , S3 , S4) and 2 half-scale specimens (S5 and S6) were tested. Figures 2 and 3 show the overall geometry and setup of these specimens. all specimen was composed of a central core plate, confined in a concrete-filled square steel tube, except specimen S4 which had a cruciform core.

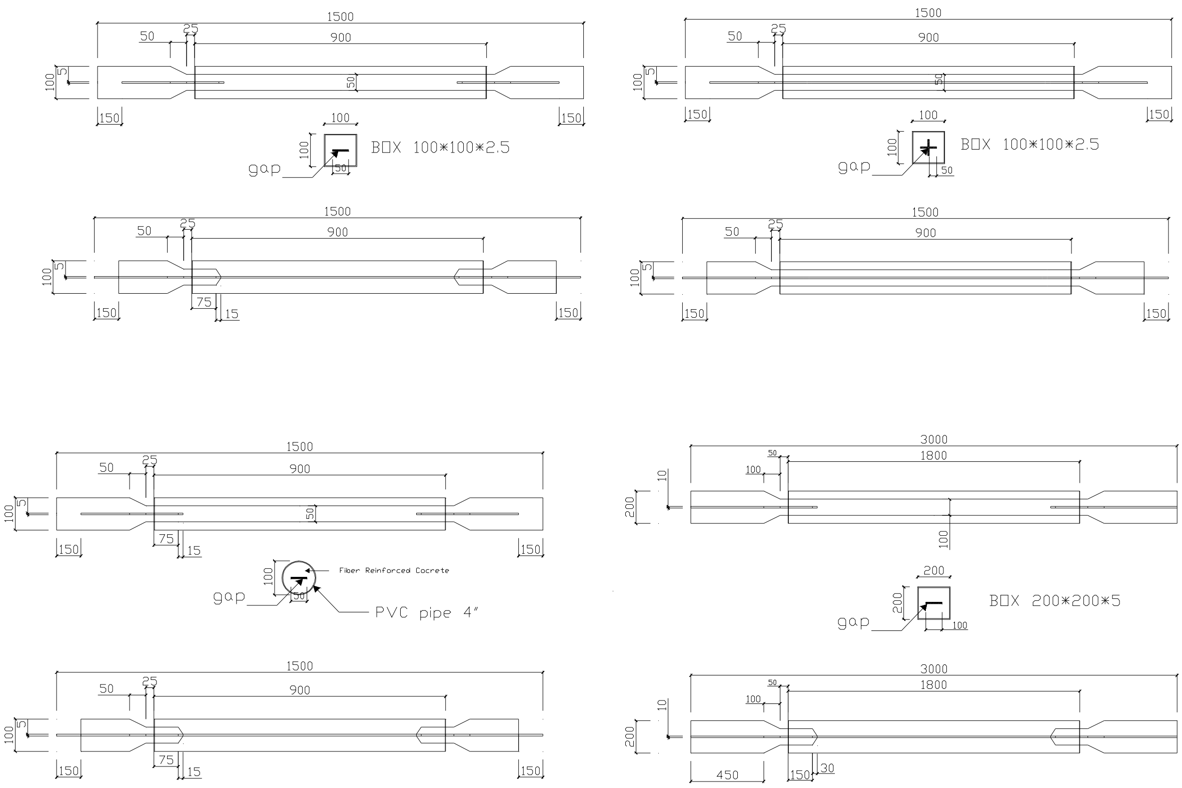

Figure 2. Set up for the test specimens, (top left) Specimens S1 & S2, (top right) Specimens S3, (bottom left) Specimens S4, (bottom right) Specimens S5 & S6

(a) (b)

Figure 3. Test setup for (a)quarter-scale, (b)half-scale

Table 1. Loading data

Specimen	D_{bm} (mm)	D_{by} (mm)	P_{ya} (Kg)	A_{sc} (cm^2)
S1	10	1.7	5875	2.5
S2	10	1.7	5875	2.5
S3	10	1.7	11163	4.75
S4	10	1.7	5875	2.25
S5	20	3.4	23500	10
S6	20	3.4	23500	10

In Table 1 , D_{bm} is the deformation corresponding to the designed story drift, D_{by} is the value of deformation quantity at first significant yield of test specimen, P_{ya} is the actual yield force of the core, F_{ya} is the actual yield strength of the core and A_{sc} is the area of yielding element.

2.2. Material properties

For the steel core ST37 steel is used, with nominal yield strength, F_{yn}, of 3700 Kg/cm^2 was used. The same type of steel was used for the encasing tube. All the specimens included gap elements. The specified concrete strength also was 410 Kg/cm^2.

2.3. Loading protocol

The loading history used is the protocol specified by the SEOAC-AISC standard with the additional requirements (Office of Statewide Health Planning and Development), OSHPD which shown in Figure 4.

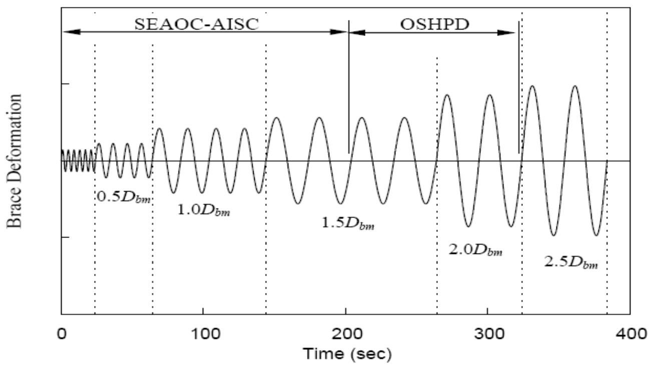

Figure 4. Standard Loading Sequence

The loading sequence requires two quantities: D_{by} and D_{bm}. D_{by} is defined as the axial deformation at the first significant yield of the specimen, and D_{bm} corresponds to the axial deformation of the specimen at the design story drift. These values were determined from the maximum values obtained by application of a number of major past Iranian earthquakes to a six story building specified by FEMA. Table 1 shows the details of the loading.

2.4. Data reduction

The SEAOC-AISC Recommendation requires that the tensile strength adjustment factor (*w*), the compression strength adjustment factor (β), and the cumulative inelastic axial deformation (η) be reported.

$$w = \frac{T_{\max}}{P_{yn}} = \frac{T_{\max}}{F_{yn} A_{sc}} \tag{1}$$

$$\beta = \frac{P_{\max}}{T_{\max}} \tag{2}$$

$$\eta = \frac{\Delta_p}{D_{by}} = \frac{E_h}{P_y^* D_{by}} \tag{3}$$

Where F_{yn} is the nominal yield strength, A_{sc} , the area of the yielding segment of the core plate P_{max} and T_{max} are the maximum compressive and maximum tension forces corresponding to a brace deformation of $1.5D_{bm}$. E_h is the hysteretic energy. ΔP is the total cumulative inelastic axial deformation.

3. EXPERIMENTAL RESULTS

The hysteretic loops for the specimens are shown in Figure 5. As can be seen the loops are quite stable. In specimens S1,S2,S5&S6 Figure 6 shows the plots of ω and β versus brace deformation for so called specimens.

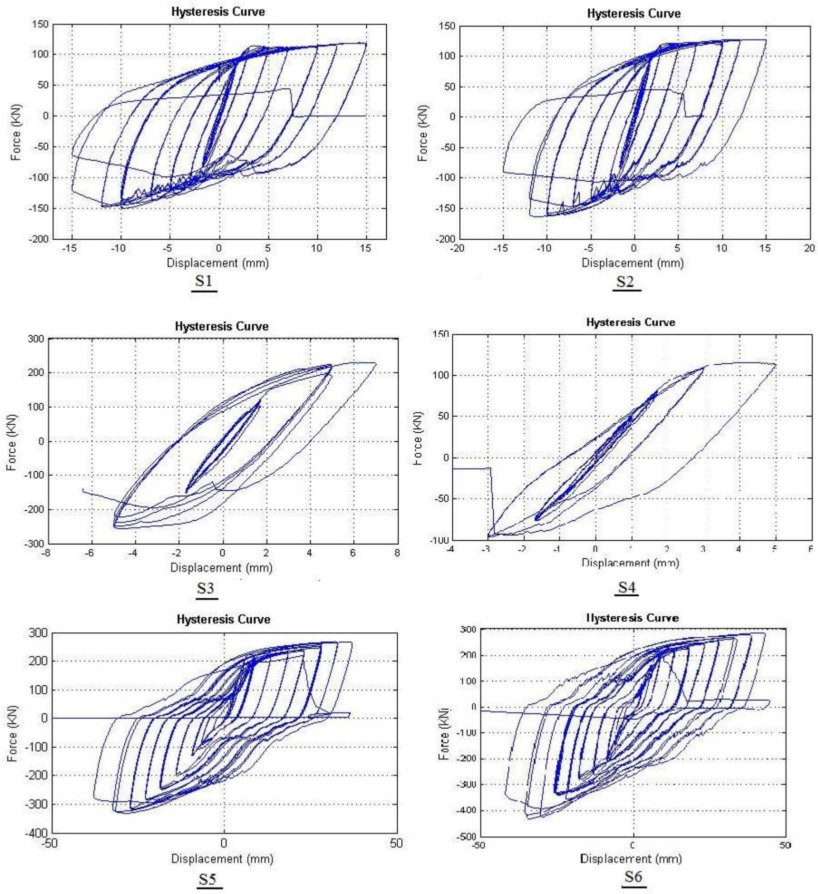

Figure 5. Hysteresis loop for specimens

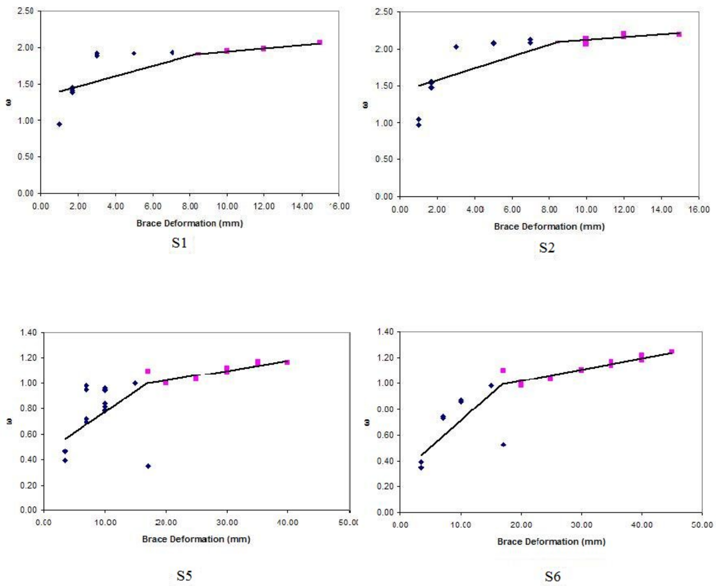

Figure 6. ω versus deformation level for S1 , S2 , S5 &S6

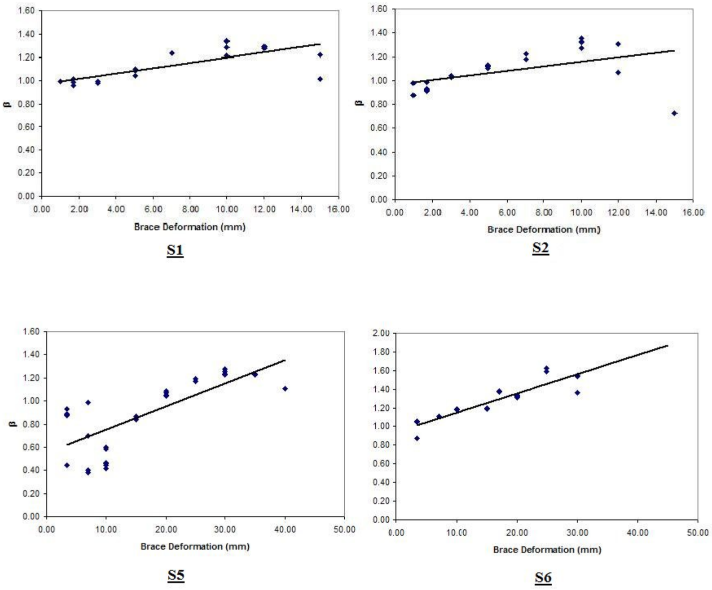

Figure7. β versus deformation level for S1 , S2 , S5 &S6

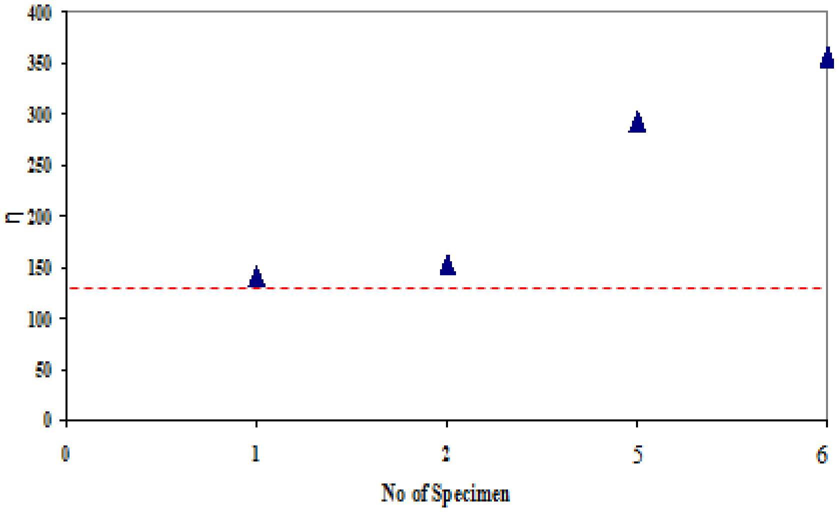

Figure 8. Maximum value of η for successful specimens tested

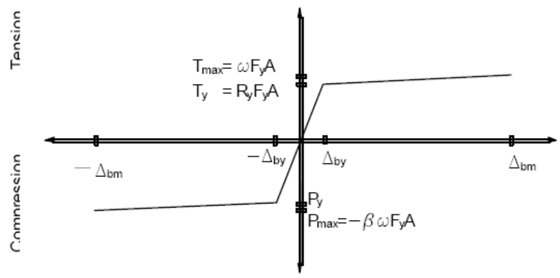

Figure 8. Diagram of brace force displacement

Table 2. Quantities at $1.5D_{bm}$

Specimens	βω	ω	β
S1	2.678	2.06	1.3
S2	2.769	2.215	1.25
S5	1.265	1.1	1.15
S6	1.441	1.1	1.31
Average	**2.03**	**1.62**	**1.252**

Based on the values obtained for η, two of the quarter scale specimens performed the best with an average of η= 150. Two other half scales Specimens S5 and S6 exhibited an average η of about 325. two specimens did not perform well because of inhibited deflection around the transition zone.The SEAOC Recommended Provisions (2001) uses the deformation level of $1.5D_{bm}$ ($=7.5D_{by}$) as a critical limit state for design. The values of *w*, β, and β*w* were calculated at this limit state by interpolation are listed in Table 2.

4.CONCLISIONS

Based on the test results in this study, the following conclusions can be drawn.

- Four of the specimens performed well under standard loading protocol, without fractures.
- The tension strength adjustment factor, *w*, as a function of the brace axial deformation, can be approximated by two straight lines, The average *w* at a deformation level of 1.5Dbm was 1.62 for the specimens tested.
- The compression strength adjustment factor, β, as a function of the brace axial deformation, can be approximated by a straight line. The average β value at a deformation of $1.5D_{bm}$ was 1.252. This value is smaller than the limiting value of 1.3 specified by SEAOC-AISC Provisions.
- The value of cumulative inelastic axial deformation ranged from 150 to 325 with an average value of about 238. This value is significantly higher than the 140 required by the SEAOC-AISC Provisions for uniaxial testing..
- Initial deflection deteriorated the performance of BRB. This deflection is usually due to manufacture's poor preparation.
- The transition zone (between end connection & concrete tube) is important in the performance of the brace. In this zone the section of the brace changes from rectangular to cruciform shape. In the experimentals yielding occurred more than in the core section. To avoid this, the transition zone should be stronger than the core.

5. References

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