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Seismic evaluation of all-steel buckling restrained braces using finite element analysis

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A R T I C L E I N F O

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A B S T R A C T

All-steel buckling restrained braces (BRBs) are a newly developed variation of ordinary BRBs with enhanced characteristics in terms of weight and curing of the mortar core. Finite element (FE) models of all-steel BRBs with varied geometries were subjected to cyclic analyses in this study. The satisfactory brace geometries that minimized instability of the core section while maximizing energy dissipation capacity were then identified. Bilinear FE-derived back-bone curves of the selected BRBs were subsequently used in the representative truss elements to retrofit three 4-, 8-, and 12-story frames. The advantages of these braces were highlighted by drawing performance comparisons against ordinary braces. Nonlinear static and dynamic responses of the frames with all-steel BRBs were also assessed in terms of parameters such as maximum inelastic deformation demand.

1. Introduction

Buckling restrained braces are the new generation of concentric braced frames (CBFs) which solved the buckling problem and enhanced the ductility and stiffness of their frames. Conventional configuration of these braces consists of a central core plate encased in a mortar-filled tube, which restrains the core plate form buckling in compression. Compressional behavior of the core plate is dominated by yielding, rather than buckling, which is similar to tensional loading procedure [1], and results in a stable hysteretic curve accompanied by enhanced ductility. Qiang [3] investigated the practical application of these braces in Asian buildings [3]. Component testing was carried out by Black et al. [2] that revealed a symmetric and stable hysteretic curve for these braces. Investigation of the seismic performance of BRBs was widely conducted by Sabelli et al. [5] and design criteria of BRBs were provided in AISC 341-10 (Seismic Provisions for Steel Structures) [6]. Wakabayashi et al. [4] introduced the panel BRB which consisted of one or two steel core plates embedded in a reinforced concrete panel. Fahnestock et al. also conducted the pseudo-dynamic numerical analyses of large-scale BRBs [7]. Optimization studies on steel core lengths for damper BRBs were carried out by Mirtaheri et al. [8] that showed the significance of low cycle fatigue, at which short brace lengths were used. They also uttered that materials with considerable work hardening, such as stainless steel, might be appropriate alternatives, instead of ordinary carbon steel. Prasad [9] claimed that BRBs require smaller beam sections than conventional CBFs with chevron bracing configuration. Takeuchi et al. [10] studied the local buckling of core plate and discussed the restrainer thickness and its effect on the local (global) buckling of BRBs. They also declared that, due to the fact that BRBs will experience large inelastic deformations during strong ground motions, it is not logical to study their behavior in the elastic range. Performance-based design (e.g. following FEMA 440 [11]) should be used instead, as a reliable way for obtaining a design capable of achieving the intended performance goals.

Conventional configuration of BRBs suffers from the heavy weight and curing problem of the mortar core. To address these inefficiencies, a new type of BRBs, called all-steel BRBs [1], is introduced. The concept behind the new configuration is the same; but, the unbounding agent is not mandatory in this type; i.e. the core plate will be encased in a steel tube without any mortar and unbounding material surrounding it, which causes all-steel BRBs to be lighter, easier and faster to fabricate without needing mortar. Thus, this type becomes more economic and practical than the conventional BRBs. In addition, the proposed BRBs can be easily inspected after earthquakes by disassembling. The hysteretic behavior of all-steel BRBs was experimentally investigated by Tremblay et al. [12]. An important factor which affects the buckling behavior of all-steel BRBs is the ratio of Euler buckling load, P_e, to the yield strength of the core, P_y. Effect of P_e/P_y ratio was first noted by Wananabe et al. [13] and was suggested to be considered greater than unity in order to protect the brace from global (local) buckling. However, the P_e/P_y ratio of 1.5 was proposed for design purposes [14].

$$\frac{P_e}{P_y} \geq 1.0 \tag{1}$$

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Table 1
BRB specimen properties.

No	Model name	Restrainer dimensions (mm)	Core plate section	Core plate area (mm^2)	Gap (mm)	Ir (mm^4)	P_e (KN)	P_{yc} (KN)	Pe/Py Ratio
1	U1G0	90 × 80 × 10	2UNP60	1416	–	3,085,000	724.21	487.15	1.49
2	U1G5	100 × 80 × 10	2UNP60	1416	5	3,145,000	738.29	487.15	1.52
3	U1G10	110 × 80 × 10	2UNP60	1416	10	5,228,300	1227.35	487.15	2.52
4	U1G20	130 × 80 × 10	2UNP60	1416	20	7,992,000	1876.13	487.15	3.85
5	U1G40	170 × 180 × 10	2UNP60	1416	40	15,878,300	3727.45	487.15	7.65
6	U2G0	120 × 100 × 10	2UNP80	2368	–	7,733,300	1815.4	831.27	2.18
7	U2G5	130 × 100 × 10	2UNP80	2368	5	9,435,000	2214.88	831.27	2.66
8	U2G10	140 × 100 × 10	2UNP80	2368	10	11,346,700	2663.65	831.27	3.20
9	U2G20	160 × 100 × 10	2UNP80	2368	20	15,840,000	3718.46	831.27	4.47
10	U2G40	200 × 100 × 10	2UNP80	2368	40	27,786,700	6522.957	831.27	7.85

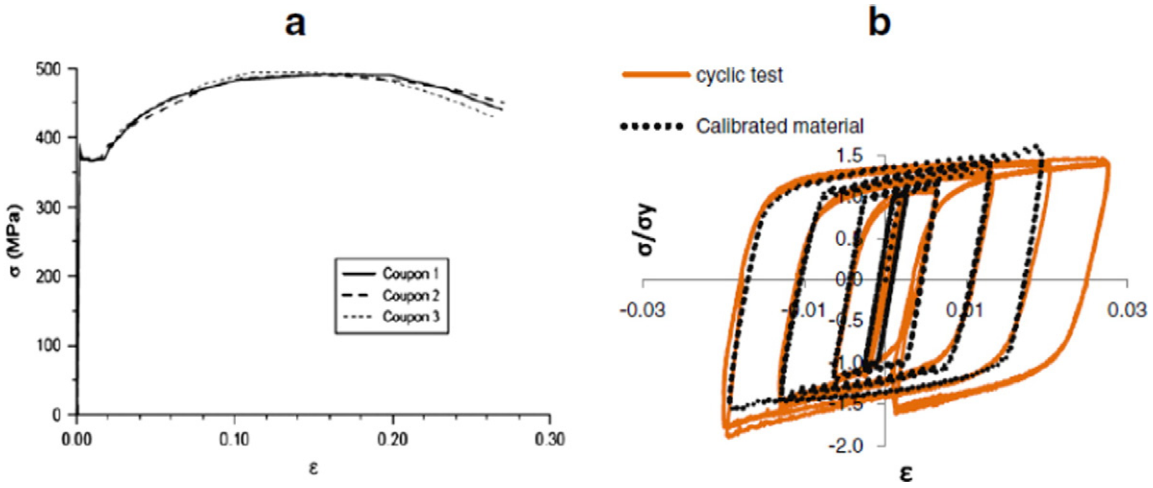

Fig. 1. a) Monotonic experimental stress–strain curve, b) cyclic experimental stress–strain curve and calibrated hysteretic response of the steel material.

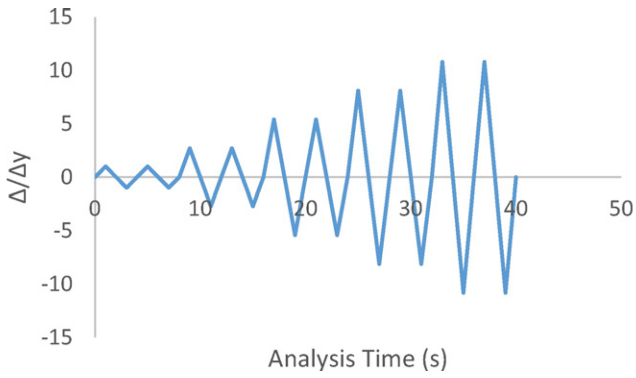

Fig. 2. Loading protocol of the BRB models according to AISC Seismic. Provisions.

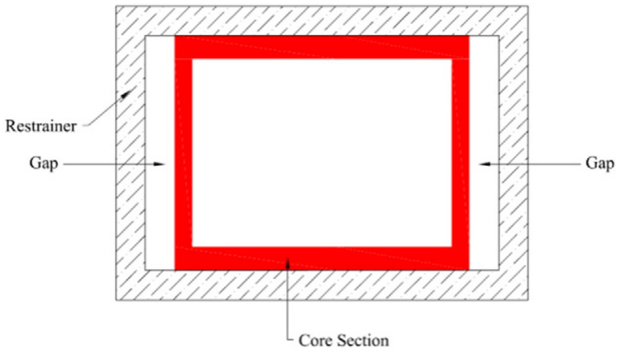

Fig. 3. Typical cross section of proposed BRB.

$$P_e = \frac{\pi^2 E I_{sc}}{L_{sc}^2} \tag{2}$$

In these equations, I_{sc} shows the moment of inertia of the restrainer tube and L_{sc} is the clear length of the brace. By considering the hardening effect in Eq. (1), yield strength of the brace will increase by 30%. This value, when combined with the strength factor (φ) of 0.85, will lead to the following equations:

$$\frac{\varphi P_e}{1.3 P_y} \geq 1.0 \tag{3}$$

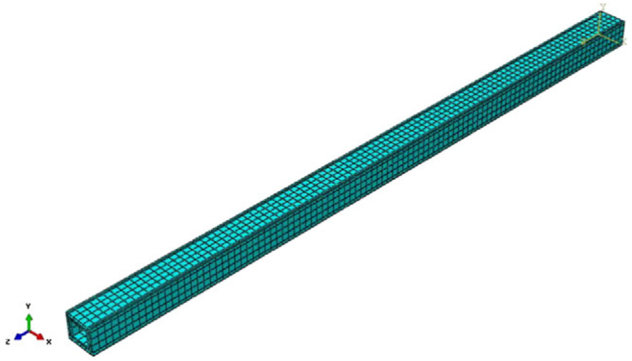

Fig. 4. Finite element model of proposed BRB.