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Performance of BRBF System and Comparing it with the OCBF

E.Talebi and F.Zahmatkesh

***Abstract*—**Buckling-Restrained Braced Frame system(BRBFs) are a new type of steel seismic-load-resisting system that has found use in several countries because of its efficiency and its promise of seismic performance far superior to that of conventional braced frames. The system is addressed in the 2005 edition of the AISC Seismic Provisions for Structural Steel Buildings, also a set of design provisions has been developed by NEHRP. This report illustrates the seismic design of buckling restrained braced frames and compares the result of design in the application of earthquake load for ordinary bracing systems and buckling restrained bracing systems to see the advantage and disadvantages of this new type of seismic resisting system in comparison with the old Ordinary Concentric Braced Frame systems (OCBFs); they are defined by the provisions governing their design.

***Keywords*—**Buckling Restrained Braced Frame system (BRBFs), Ordinary Concentric Braced Frame systems (OCBFs).

I. INTRODUCTION

DURING an earthquake, seismic ground forces have the effect of applying lateral loads to buildings. If these loads are strong enough, they have the ability to damage the structure, leading to an economic loss for whoever owns the building or even worse the loss of human life. In order to prevent both of these from happening, it is crucial to have buildings that are able to withstand any foreseeable seismic loads they may be subjected to. A further type of diagonal brace, one that attempts to inhibit buckling under compression, is called a buckling-restrained brace (BRB). Structures fitted with BRBs are likely to absorb even more energy as both diagonal braces (in tension and compression) are resisting the lateral loads. How much more load a BRB can handle though is not always clear.

BRBF is the system characterized by the use of braces that yield inelastically both in tension and compression at their adjusted strengths. BRBs have full, balanced hysteresis loops as illustrated in Figure 1.1, with compression-yielding similar to tension-yielding behavior. They achieve this through the decoupling of the stress-resisting and flexural buckling resisting aspects of compression strength. Axial stresses are resisted by a shaped steel core, buckling resistance is provided to that core by a casing, which may be of steel, concrete, composite, or other construction. Because the steel core is restrained from buckling, it develops almost uniform axial strains.

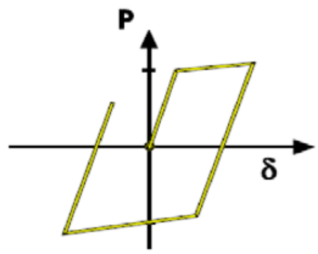

Fig. 1 Mechanics of a Buckling-Restrained Brace [1]

The concept of eliminating the compression buckling failure mode in intermediate for eliminating the buckling and slender of compressive elements as a long time has been a subject of discussion. The theoretical solution for eliminating the buckling failure mode is very simple: laterally brace a compression element, at close regular intervals, so that the compression element's un-braced length effectively approaches zero, as is shown in figure 2.

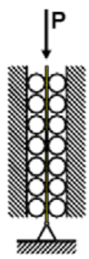

Fig. 2 Philosophy of a Buckling-Restrained Brace [1]

A buckling-restrained brace, or an unbonded brace, is a bracing member consisting of a steel core plate or another section encased in a concrete-filled steel tube over its length as shown in Figure 3. The term unbonded brace derives from the need to provide, prior to the casing of mortar, a slip or unbonding material layer between the steel core and the surrounding concrete, so that axial loads are taken only by the steel core. In addition, a small gap between the steel core and surrounding concrete has to be provided due to Poisson effect, which causes the steel to expand under compression.

E.Talebi is with the Sharif University Of Technology, International Campus, Kish Island, IRI (phone number: +98-912-5667509; fax: +98-764-4423581; e-mail: eln_tli@ yahoo.com).

F.Zahmatkesh is with the Sharif University Of Technology, International Campus, Kish Island, IRI (phone number: +98-912-2499902; fax: +98-764-4423581; e-mail: fa_zahmatkesh@ yahoo.com).

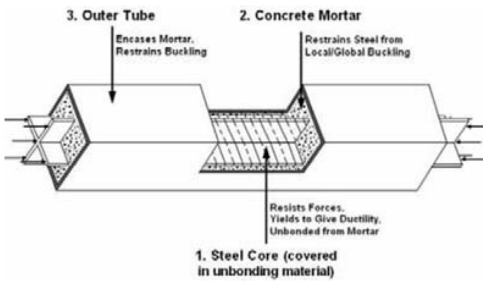

Fig. 3 Buckling-restrained brace cross section view [5]

II. BRBF SYSTEM CHARACTERISTICS

By contrast, buckling-restrained braces (BRBs) do not exhibit any unfavorable behavior characteristics of conventional braces. In order to accommodate the axial yielding of the steel core, and to prevent instability of the sleeve, the detailing of BRB end connections must be able to transmit forces to the core without permitting significant stress to develop in the sleeve. The end connections must also be designed to preclude modes of overall brace instability; they are therefore designed to have greater yield strength than the core within the sleeve so that yielding is confined to a limited length of the core. Because the length of the yielding zone changes when the BRB is subject to inelastic deformation, the ends of the sleeve are detailed so that this larger area of the core does not bear on it under expected deformations. In summary,

A. BRBs offer the following advantages:

- Ease of incorporating it into the structural system by means of a bolted or pinned connection to gusset plates.
- Stable hysteretic behavior without buckling with high energy dissipation capacity as illustrated in figure 4.
- Limited sensitivity to environmental condition changes.
- Ease of replacement when damaged after major earthquake.
- Does not usually require structural members and foundation strengthening.

B. BRBs offer the following disadvantages:

- Lack of recentering mechanism.
- Lack of criteria for checking and detecting damaged braces.
- Ductility properties strongly affected by the material type and geometry of the yielding steel core segment.
- Further studies regarding the reliability of brace connections to- the frame are required.

C. Comparison of BRBFs with the OCBFs

Conventional braced frames using typical bracing elements, offer a high lateral stiffness system for wind and low-level earthquake loads. However, these braces are expected to yield in tension and to buckle during a moderate or severe earthquake. When buckling occurs, the brace member loses its stiffness and part, if not most, of its load carrying capacity. These braces have limited ductility capacity, lowered energy absorption capability, and exhibit unsymmetrical hysteretic loops, with marked strength deterioration when loaded in compression (see fig.4). In contrast to the behavior of typical bracing elements, buckling-restrained braces (BRBs) are a reliable and practical alternative to conventional systems for enhancing the earthquake resistance of existing and new structures. They are capable of providing both the rigidity needed to satisfy structural drift limits, as well as a stable inelastic behavior and substantial energy absorption capability with similar hysteretic behavior both in tension and compression as shown in Figure 4. With these added energy dissipating members, damage due to yielding under a strong earthquake is expected to occur in the BRBs, while other structural members will be protected. These highly yielded devices are readily replaceable, and when replaced the resisting capacity of the structure remains intact.

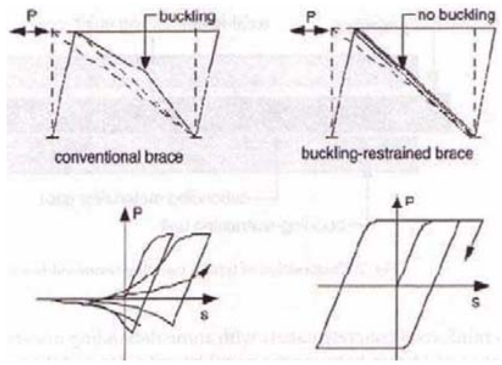

Fig. 4 Behavior of Conventional Brace and BRB [4]

D. Recommended provisions for BRBFs:

AISC 2005, Seismic Provisions For Structural Steel are presented for consideration only, and it is expected that the need for modifications or refinement will become clear as more engineers attempt to employ them, in conjunction with peer review, on actual design projects. According to AICS Seismic Provisions, 2005, the required axial strength of the steel core shall not exceed the design strength of the steel core, $\emptyset P_{ys}$,Where;

$\emptyset = 0.9$

$P_{ys} = F_y A_{sc}$

F_y =Specified minimum yield strength of steel core

A_{sc} =Net are of the steel core

To avoid buckling of BRB members, Watanabe et al. (1988), who performed experimental cyclic-loading tests on five BRB specimens with different P_{cr}/P_y ratios, suggested that the steel casing should be designed for adequate flexural stiffness so that;

$$P_{cr}/P_y \geq 1.5 \tag{1}$$

$$P_{cr} = \frac{\pi^2 E_S I_S}{(KL_{sc})^2} \tag{2}$$

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in which P_y is the yield strength in compression of the yielding steel core, P_{cr} , E_s and I_s are the elastic buckling strength, Young's modulus of elasticity, moment of inertia of the steel casing, respectively, K is equal to 1.4 for BRBFs. The contribution of concrete to the flexural stiffness of the steel casing is usually neglected. Chapter 16 in AISC Seismic Provisions for structural steel,2005 , and also Chapter 4 in FEMA 450 includes BRBF system factors R, C_d, $C_t(C_r)$, Ω_0 and x, allowing the BRB frame system to use an R of 8 for dual system and 7 for pinned connections.

III. SAMPLE PROJECT ANALYSIS AND DESIGN OF BRBF AND OCBF

In this report, the main goal is the use of a same building which is intended to provide a point of reference for comparison of different braced-frame systems. Figures 5 and 6 define the building and systems geometries.

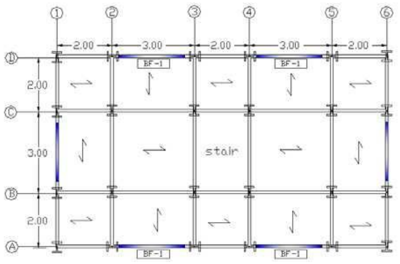


Fig. 5 Framing plan

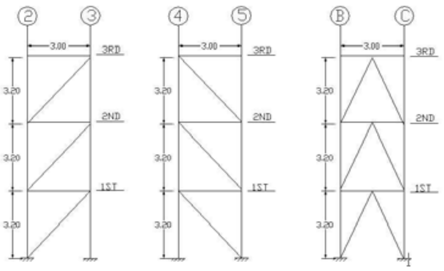


Fig. 6 Frame bracing geometry

A. *Sample structure characteristics:*

- Located in Tehran.
- 3 story steel structure.
- The soil profile type is III.
- Each story height is 3.2 meters.
- Structure system in X and Y direction is Steel concentric Braced Frames.

For linear manner, the equivalent static procedure is used for static linear manner, response spectrum used as dynamic linear manner and pushover method is used for nonlinear static manner. Response spectrum is derived from Iranian code and standard (no.2800-3rd edition) and for pushover procedure we use the coefficient method from FEMA 356. The seismic code which has been used in this report is, the 3rd Edition of Standard No. 2800 (Iranian Code of Practice for Seismic Resistant Design of Buildings), and for structural steel design, we use AISC-LRFD code. Because it is better to analyze and design the V and inverted V braces with UBC code in the software, so after designing the OCBF structure in AISC-LRFD code, we check the design with UBC code to become sure in our design.

B. *Structural materials:*

Materials that is used for W sections is ASTM A992 with F_y=450 MPa for BRB steel core we use ASTM A36 or JIS G3136 SN 400b with supplemental yield requirements of F_{ysc}=290 MPa($\pm$2.8 kN/m^2)), BRB Steel casing is used from ASTM A500 Grade B or JIS G 3466 STKR 400, Weld electrodes are used E70XX with notch toughness of 27 J at -18 degrees Celsius, Fill concrete is light weight concrete with $f_c' = 20\ MPa$. Since either bolts or a pin can be used to connect the brace to the gusset, specifications for both are provided High strength bolts (if used) ASTM A325 or A490 SC. Pins (if are used) is ASTM A354 Grade BC round stock. Design note: pin connections should comply with *AISC Load and Resistance Factor Design Manual of Steel Construction (AISC LRFD) (2001)* Specification D3.

C. *Design loads:*

In this section, for design loads using the loading demands prescribed in Topic sixth code and for the design checks utilizing the Section 8.6 of Chapter 8 of FEMA 450.

- Dead loads:
  - Roof mass = 0.07 kN/m^2
  - Floor mass = 0.06 kN/m^2
  - Exterior curtain wall weight = 0.06 kN/m^2
- Live loads:
  - Roof = 0.015 kN/m^2
  - Floor = 0.020 kN/m^2
- Siesmic loads:

Where; A=0.35, B=2.75, I=1 and R for BRBF=7 & for OCBF=6.

- For BRBFs: $C = (0.35 \times 2.75 \times 1)/7$
- For OCBFs: $C = (0.35 \times 2.75 \times 1)/6$

- Seismic weight, W:
  - Typical story weight = 486.02 (kN)
  - Roof story weight = 576.63 (kN)
  - Typical story live load = 164.75 (kN)
  - Roof story live load = 123.56 (kN)
  - Typical story wall weight = 223.59 (kN)
  - Typical story Seismic Weight = D.L + 0.2 L.L = 518.97 (kN)
  - Roof story Seismic Weight = D.L + 0.2 L.L = 601.34 (kN)

  Total Seismic Weight = 2418.38 (kN)

D. *Computer model description:*

- Braces are modeled as pin-ended.
- In order to provide a conservative brace design, the beams were assigned no rigid offset length at their connections.

- Floor diaphragms are modeled as rigid.
- Frame columns are modeled as fixed at their bases.
- As shown in Figure 7, the actual length of the steel core is smaller than the work-point-to-work-point length of the brace. As a result, the actual stiffness of the brace is greater than that computed using only the steel core area. For this example, the effective stiffness of the BRB is defined as 1.4 times the stiffness computed using only the steel core. This is consistent with many actual designs, [1].

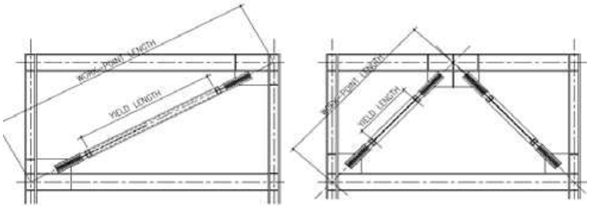


Fig. 7 Illustration of BRB yield lengths

E. Applicable load combinations:

- For LRFD designs, the load combinations in SEI/ASCE 7, Section 2.3 gives the following ten load combinations defining the required strengths of BRBs, frame beams, and frame columns associated with the seismic base shear.
  - LC1:1.4D
  - LC2:1.2D+1.6L
  - LC3:1.2D+0.5L+0.5EQX
  - LC4:1.2D+0.5L-EQX
  - LC5:1.2D+0.5L+0.5EQY
  - LC6:1.2D+0.5L-0.5EQY
  - LC7:0.9D+EQX
  - LC8:0.9D-EQX
  - LC9:0.9D+EQY
  - LC10:0.9D-EQY

F. Design control of steel core according to the AISC seismic provisions, 2005:

Following tables 3.1 to 3.2 summarized the design control results for the steel core of BRBFs according the AISC, 2005.

TABLE I
DESIGN CONTROL OF THE STEEL CORE FOR BF-1 FRAMES IN BRBFS

St.	Steel core sec. (mm)	A_{sc} (cm^2)	F_y (MPa)	Ø	P_{ysc} (kN)	P_{allow} (kN)	$P_{available}$ (kN)	$P_{allow} \geq P_{available}$
3rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
2rd	I-40×3	5.22	34.5	0.9	187	168.9	111.8	O.K
1st	I-40×3	5.22	34.5	0.9	187	168.9	94.1	O.K

TABLE II
DESIGN CONTROL OF THE STEEL CORE FOR BF-2 FRAMES IN BRBFS

St.	Steel core sec. (mm)	A_{sc} (cm^2)	F_y (MPa)	Ø	P_{ysc} (kN)	P_{allow} (kN)	$P_{available}$ (kN)	$P_{allow} \geq P_{available}$
3rd	I-80×3	7.0	34.5	0.9	242	218.0	112.3	O.K
2rd	I-100×3	11.7	34.5	0.9	403	362.7	179.6	O.K
1st	I-100×3	11.7	34.5	0.9	403	362.7	200.9	O.K

G. Design control of steel casing according to the AISC seismic provisions, 2005:

Following tables 3 and 4 summarize the design control results for the steel casing of BRBFs according the AISC, 2005.

TABLE III
DESIGN CONTROL OF THE STEEL CASING FOR BF-1 FRAMES IN BRBFS

St.	Box sec. (mm)	for box;b/t $\leq 1.4\sqrt{E/F_y}$	I_{sc} (cm^4)	L_{sc} (mm)	P_{cr} (kN)	P_y (kN)	$P_r/P_y \geq 1.5$
3rd	90×90×5	25≤33	205	439	108	68	O.K
2rd	100×100×6	16.7≤33	334	439	175	112	O.K
1st	100×100×6	16.7≤33	334	439	175	94	O.K

TABLE IV
DESIGN CONTROL OF THE STEEL CASING FOR BF-2 FRAMES IN BRBFS

St.	Box sec. (mm)	for box;b/t $\leq 1.4\sqrt{E/F_y}$	I_{sc} (cm^4)	L_{sc} (mm)	P_{cr} (kN)	P_y (kN)	$P_{cr}/P_y \geq 1.5$
3rd	100×100×4	25≤33	237	439	191	112	O.K
2rd	120×120×4	30≤33	417	439	336	179	O.K
1st	120×120×4	30≤33	417	439	336	201	O.K

IV. DESIGN RESULTS IN LINEAR PROCEDURE:

Following figure 8 to 9 show the section design results in the software for "A" axes of both structural systems.

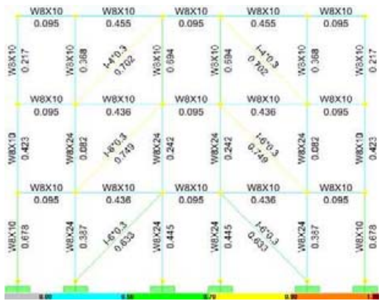


Fig. 8 BRBF designed sections at elevation "A "

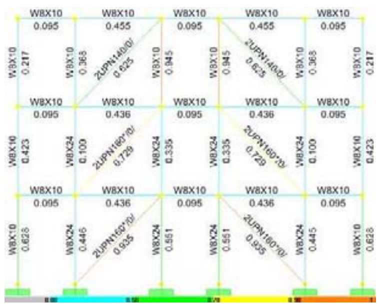


Fig. 9 OCBFs designed sections at elevation "A "

V. ANALYSIS RESULTS IN NONLINEAR STATIC PROCEDURE

A. Target displacement:

The values of target displacement and it's related parameters are summarized in Table 5 to 8.

TABLE V
VALUES OF TARGET DISPLACEMENT FOR BF-1 IN BRBFS

C_0	C_1	C_2	C_m	S_a	W (kN)	V_y (kN)	α	T_e (sec)	R	C_3	δ_t (mm)
1.3	1	1.1	0.9	0.96	2405	822	0.1	0.64	2.5	1.3	182

TABLE VI
VALUES OF TARGET DISPLACEMENT FOR BF-2 IN BRBFS

C_0	C_1	C_2	C_m	S_a	W (kN)	V_y (kN)	α	T_e (sec)	R	C_3	δ_t (mm)
1.3	1	1.1	0.9	0.96	2405	1004	0.2	0.7	2.1	1.3	167

TABLE VII
VALUES OF TARGET DISPLACEMENT FOR BF-1 IN OCBFS

C_0	C_1	C_2	C_m	S_a	W (kN)	V_y (kN)	α	T_e (sec)	R	C_3	δ_t (mm)
1.3	1	1.1	0.9	0.96	2438	1180	0.3	0.3	1.8	1.3	57

TABLE VIII
VALUES OF TARGET DISPLACEMENT FOR BF-2 IN OCBFS

C_0	C_1	C_2	C_m	S_a	W (kN)	V_y (kN)	α	T_e (sec)	R	C_3	δ_t (mm)
1.3	1	1.1	0.9	0.96	2438	1217	0.1	0.36	1.7	1.2	65

B. Hinge formation in structural systems:

After the application of target displacement according to FEMA 450, formations of the hinges in both structural systems are comparable from the hinges existences which are shown in figures 10 and 11. The important point is, when the structures are subjected to the seismic load, it is seen that all of the lateral force is suffered only by the braces for buckling restrained brace frame system where in the similar structure with ordinary concentric brace frame system, columns are suffering big part of the lateral force either than braces and as a result, by having focus on the figures, it is seen that hinges are formed only in braces in BRBFs where in OCBFs hinges are formed also in columns rather than braces. On the other hand, since the stiffness of the BRBFs is less than OCBFs, it has bigger relative story displacements than OCBFs. The similar manner is also seen in the other direction(Y-Direction).

VI. EFFECT OF HEIGHT IN THE COMPARISON OF BRBF WITH OCBF

To see the effect of height, the sample project analysis results are verified for 6, 9 and 12 story structures. All of the structural properties such as plan and bracing geometries and material properties are as the same as the sample three story structure. In order to summarize results of the increase of height, the tallest (12 story) structures for both structural systems are mentioned here.

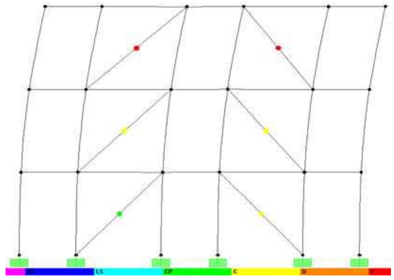


Fig. 10 Hinge formation at T.D for BRBFs in elevation "A "

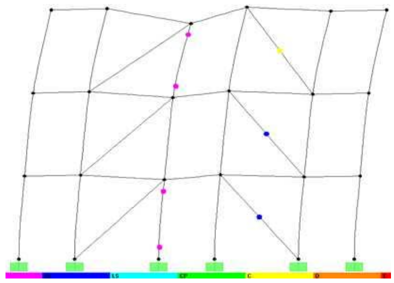


Fig. 11 Hinge formation at T.D for OCBFs in elevation "A "

A. Design control of steel core according to the AISC seismic provisions, 2005:

TABLE IX
DESIGN CONTROL OF THE STEEL CORE FOR BF-1 FRAMES IN BRBFS

St.	Steel core sec. (mm)	A_{sc} (cm^2)	F_y (MPa)	Ø	P_{ysc} (kN)	P_{allow} (kN)	$P_{available}$ (kN)	$P_{allow} \geq P_{available}$
12rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
11rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
10rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
9rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
8rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
7rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
6rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
5rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
4rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
3rd	I-40×3	3.42	34.5	0.9	118	106.1	67.6	O.K
2rd	I-40×3	5.22	34.5	0.9	187	168.9	111.8	O.K
1st	I-40×3	5.22	34.5	0.9	187	168.9	94.1	O.K

B. Design control of steel casing according to the AISC seismic provisions, 2005:

TABLE X
DESIGN CONTROL OF THE STEEL CASING FOR BF-1 FRAMES IN BRBFS

St.	Box sec. (mm)	for box;b/t $\leq 1.4\sqrt{E/F_y}$	I_{sc} (cm^4)	L_{sc} (mm)	P_{cr} (kN)	P_y (kN)	$P_r/P_y \geq 1.5$
12rd	90×90×5	25≤33	205	439	108	68	O.K
11rd	90×90×5	25≤33	205	439	108	68	O.K
10rd	90×90×5	25≤33	205	439	108	68	O.K
9rd	90×90×5	25≤33	205	439	108	68	O.K
8rd	90×90×5	25≤33	205	439	108	68	O.K
7rd	90×90×5	25≤33	205	439	108	68	O.K
6rd	90×90×5	25≤33	205	439	108	68	O.K
5rd	90×90×5	25≤33	205	439	108	68	O.K
4rd	90×90×5	25≤33	205	439	108	68	O.K
3rd	90×90×5	25≤33	205	439	108	68	O.K
2rd	100×100×6	16.7≤33	334	439	175	112	O.K
1th	100×100×6	16.7≤33	334	439	175	112	O.K

C. Design results in linear procedure:

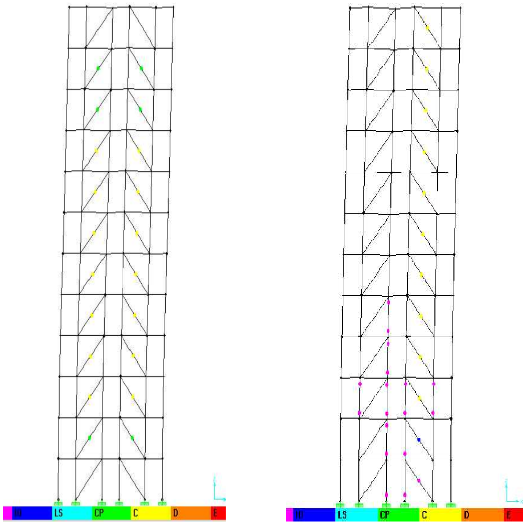
Section design results are shown in “A” axes for both structural systems in figure 12 "a" and "b".

(a)-for BRBFs (b)-for OCBFs

Fig. 12 Hinge formation at Target displacement in elevation “A “

D. Design results in nonlinear procedure:

When the target displacement is applied into both structural system, in the last step for the target displacement, it is seen that for BRBFs all of the horizontal force suffered by braces and hinges are formed only in the braces where in the similar manner it is seen that for OCBFs, hinges are formed both in columns and braces with T.D less than BRBF system’s, this fact is more obvious by comparing figure 13 "a" and "b" with each other.



(a)-for BRBFs (b)-for OCBFs

Fig. 13 Hinge formation at Target displacement in elevation “A “

As mentioned before, BRBF's manner in tension is similar in compression and this behavior helps this system to act more effective than ordinary systems in seismic energy dissipation. This fact can be seen in the hinge properties of both structural system which is shown in table 11 and 12.

TABLE XI
HINGE PROPERTIES IN BRBFS

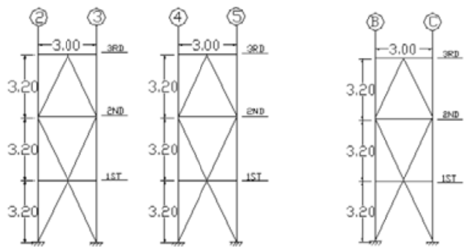
Hinge no.1	Force(kN)	Displacement(mm)
Positive	442.9	8.3
Negative	442.9	8.3

TABLE XII
HINGE PROPERTIES IN BRBFS

Hinge no.1	Force(kN)	Displacement(mm)
Positive	1939.3	8.3
Negative	313.7	1.3

VII. Effect of Bracing Geometry In the comparison of BRBF with OCBF:

In this part, we verify the effect of change in the bracing geometry, again to see the manner of BRBFs in comparison to the OCBFs. Figure 14 shows the bracing geometries for three story structure.



(a)-Typical BF-1 elevation (b)- BF-2 elevation

Fig. 14 Frame Bracing geometries

A. Design control of steel core according to the AISC seismic provisions, 2005:

TABLE XIII
DESIGN CONTROL OF THE STEEL CORE FOR BF-1 FRAMES IN BRBFS

St.	Steel core sec. (mm)	A_{sc} (cm^2)	F_y (MPa)	Ø	P_{ysc} (kN)	P_{allow} (kN)	$P_{available}$ (kN)	$P_{allow} \geq P_{available}$
3rd	I-40×3	3.42	34.5	0.9	118	106.1	68.2	O.K
2rd	I-40×3	5.22	34.5	0.9	187	168.9	85.6	O.K
1st	I-40×3	5.22	34.5	0.9	187	168.9	89.6	O.K

B. Design control of steel casing according to the AISC seismic provisions, 2005:

TABLE XIV
DESIGN CONTROL OF THE STEEL CASING FOR BF-1 FRAMES IN BRBFS

St.	Box sec. (mm)	for box;b/t	I_{sc} (cm^4)	L_{sc} (mm)	P_{cr} (kN)	P_y (kN)	$P_{cr}/P_y \geq 1.5$
3rd	90×90×5	18.0≤33	205	439	108	68	O.K
2rd	100×100×6	16.7≤33	334	439	175	86	O.K
1st	100×100×6	16.7≤33	334	439	175	90	O.K

C. Calculation of story drift:

TABLE XV
CONTROL OF STORY DRIFT FOR BRBFS

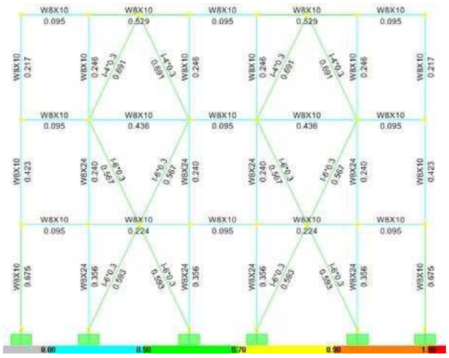
St.	St. Height (mm)	Design st. disp. (mm)	Design st. drift (mm)	Allow. st. drift (mm)
3rd	3200	8.4	46.2	48
2rd	3200	8.6	47.0	48
1st	3200	5.8	31.9	48

TABLE XVI
CONTROL OF STORY DRIFT FOR OCBFS

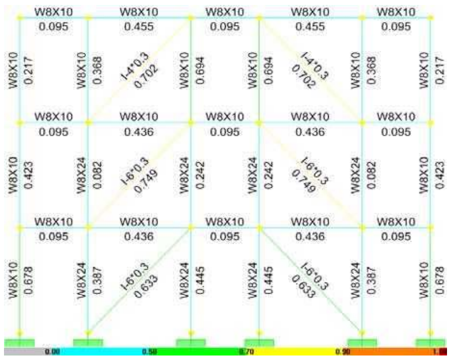
St.	St. Height (mm)	Design st. disp. (mm)	Design st. drift (mm)	Allow. st. drift (mm)
3rd	3200	6.9	9.5	48
2rd	3200	4.0	9.5	48
1st	3200	1.1	9.5	48

D. Verification of section ratios in the bracing geometry change for diagonal and cruciform form of bracing:

Following figure 15(a) & (b) to 16(a) & (b), shows the differences in section ratios for similar and no similar sections in both structural systems.



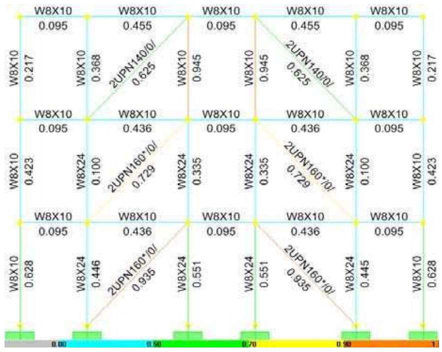
(a)- Cross-form Geometry



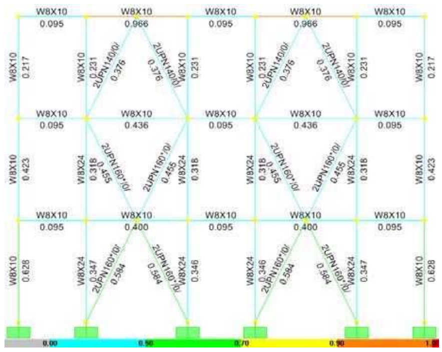
(b)- Diagonal Geometry

Fig. 15 Illustration of designed sections at (a) & (b) for BRBFs

By having focus in figure 16(a), (b) and 17(a), (b) it is seen than sections in cross-form behave stronger than in diagonal form. This means in similar sections for example in similar columns section ratios in cruciform is less than diagonal form of bracing geometry, but here is an important discussion, that because the sections have less stress ratios in cross form, so the whole stiffness of the structure is more than diagonal form so that the story drift of the structure in cross form is more than diagonal. As another comparison, in figure 16 and 17, it is seen than the net area in braces for BRBFs is about 10 times less than OCBFs (see the circled braces as an example of this fact). Also it is obvious that the stress ratio in braces for BRBFs with less net area section is less than stress ratio in OCBFs. For similar section areas in the columns this conclusion is also obvious. By having attention in mentioned figures it is seen the stress ratios in columns for BRBFs is less than the similar section in OCBFs. For the beams there are no any differences because the applied vertical loads in both systems are the same.



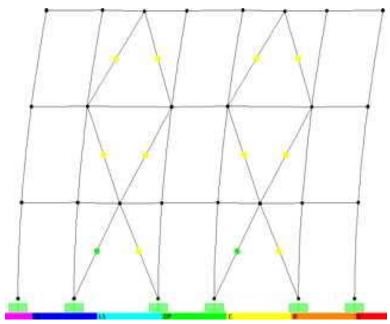
(a)- Cross-form Geometry



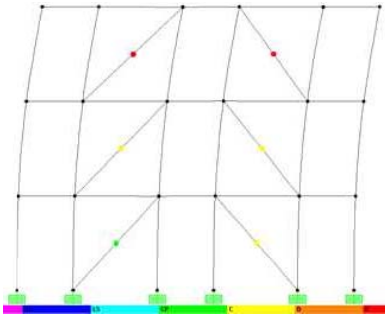
(b)- Diagonal Geometry

Fig. 16 Illustration of designed sections at (a) & (b) for OCBFs

E. Comparison of story hinge formation in the variety of bracing geometry for diagonal and cruciform form of bracing:

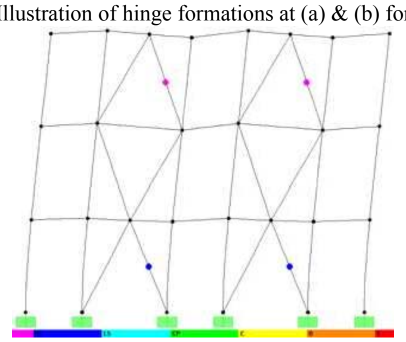


(a)- Cross-form Geometry

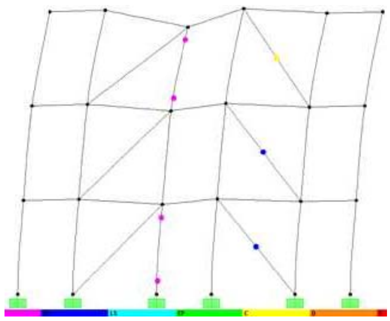


(b)- Diagonal Geometry

Fig. 17 Illustration of hinge formations at (a) & (b) for BRBFs



(a)- Cross-form Geometry



(b)- Diagonal Geometry

Fig. 18 Illustration of hinge formations at (a) & (b) for OCBFs

VIII. Conclusions

A. Effect of Height

By increasing the height of the structure, story drift increases but in BRBFs because the stiffness of whole of the structure is less than OCBFs and also because the AISC recommended the C_d more than OCBFs so story drift in BRBFs is more than OCBFs.

B. Effect of Geometry

In BRBFs, braces acts more effective in cross geometry than in diagonal form. Where in OCBFs, braces acts more effective in diagonal geometry than in cross form. So as the final conclusion, cross geometry acts more effective than diagonal form for BRBFs in contrast to OCBFs.

C. Section Aspects

For the same column sections, designed ratios in BRBF are less than OCBF system. Where for braces, section areas in OCBFs is more than BRBFs, this is where design ratios for braces in OCBFs is more than BRBF in this case.

D. Strength Aspects

In BRBFs, whole of the earthquake energy is dissipated by the braces so no hinge forms in any of the columns. In OCBFs energy dissipation is done by both braces and columns it means that after the formation of the preliminary hinges in the braces, next hinges forms in the columns.

E. Economic Aspects

BRBF systems do not usually require structural members and foundation strengthening as do conventional braced frame systems using traditional braces, thereby achieving more cost savings. Due to their better post yield behavior in both compression and tension and their energy dissipating characteristics, the installation of BRBs allows for a decrease in the cross sectional area of the steel structural frame, thus the weight of steel framing members used in the entire building can easily be reduced, that is a significant cost advantage in building construction.

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