KPU International Journal of Engineering & Technology
Volume 2, Issue1, March 2022
e-ISSN:2790-0819, p-ISSN:2790-0800
Date Received: 2022-02-23
Date Accepted: 2022-03-18
Date Published: 2022-03-30
Original Research

Effectiveness of the Buckling Restrained Brace in Steel Moment Frames in Afghanistan

MOHAMMAD NASER AMIN*
Assistant Professor, Department of Building Construction Management, Kabul Polytechnic University, Kart-e-Mamorin, Kabul, Afghanistan, Tel: +93766828165
Email: naser.amin@kpu.edu.af / naser1amin@yahoo.com

Abstract

This paper studies the seismic response behavior and seismic performance of unbraced Steel Moment Frame Structure designed for seismicity of Kabul province and then it is assumed that same design is subjected to the seismicity of Badakhshan province of Afghanistan by Time History Analysis method. The validity of the concept of eliminating the compression buckling failure mode of Buckling Restrained Brace by encasing it over its length in a steel tube filled with concrete leading to similar performance under compression and tension is investigated from the result of Nonlinear Dynamic Time History Response Analysis. Recent developments have caused population growth concentrated in major cities of Afghanistan, building owners and engineers have no option other than going for vertical building structures. As Afghanistan is located in a seismically active zone, these structures are subjected to collapse or large lateral displacements due to strong earthquake ground motions. Afghanistan has newly adopted standards for the design of steel structures, but there is no steel building designed with a BRB system yet in the country. Therefore, in this research, an unbraced steel office building is designed for Kabul city by Afghan Structural Code (ASC), and also it is assumed to be constructed in Badakhshan province with the highest seismic hazard in the country. Two patterns of BRBs with varying core cross-section areas have been used in order to find the optimum cross-section area. Dynamic Eugene value analysis and nonlinear dynamic response analysis are carried out to determine the dynamic characteristics and seismic performance. For response analysis, artificially simulated ground accelerations of Badakhshan and Kabul provinces, which have the phases of recorded Seismic waves of (El Centro NS) are adopted to the response spectrum prescribed by Afghan Structural Code. From the result of response analysis, it is concluded that the response of the special moment frame structure in terms of maximum story drift angle is within the code limitation in Kabul province and more than the code limitation for Badakhshan province. With employing Buckling Restrained Braces in Badakhshan province, the energy dissipation and damage prevention capacity of unbraced frame is greatly improved and the response of the frame braced with-BRB is mostly within the allowable range of the Afghan Structural Code.

Keywords: Buckling Restrained Brace, Nonlinear Dynamic Analysis, Ductility, Ground Motion

* Corresponding Author

1. Introduction

Seismic events are of great concern all over the world, particularly for those parts that are located in active seismic zones. Since Afghanistan is located in the geologically active part of the world it is laced with faults [1]. Know faults are large enough and most likely to slip rapidly and generate earthquakes. Afghanistan's seismicity is driven by the relative northward moment of the Arabian plate past western Afghanistan at 33mm/year and of the Indian plate past eastern Afghanistan at 39 mm/year both plates sub-duct under Eurasian plate [1]. Central and western Afghanistan is seismically less active but the northeastern part of the country is more seismically active as the effects of the collision of Indian and Eurasian plates are most pronounced there [1]. Based on historical earthquakes and tectonic mapping of Afghanistan the country has four large faults such as Chaman Fault (CHF), Herat fault (HF), Central Badakhshan fault (CBF), Darvaz fault (DF), and other middle faults such as Gardez, Mokure, Kunar, Panjsher-Jabarlsarage, Paghman- Surobi, and Talas-Forghana fault [1]. A large number of small to medium earthquakes hit Afghanistan annually and every few years a powerful earthquake hits and causes significant damage and fatalities. Only in the last 10 years, earthquakes have killed more than 7000 people, including the Nahrin earthquake in May 1998 that killed an estimated 4000 people [2]. Strong earthquake ground shaking could cause damage to structures and trigger landslides, improved seismic regulations, construction standards, and techniques, guided by scientific estimates of seismic hazard could significantly reduce the loss of life and property [2]. In some cities of the country, many buildings have been built waywardly, without consideration of international structural engineering norms and seismic design regulations which can create serious dangers and disasters when subjected to strong earthquake ground motions. During a seismic event, often the poor quality of building design and construction are widely documented as the main reasons for large lateral displacements which causes human fatalities and property loss. In order to control and limit damage and lateral displacement of steel structures, one of many ways is to provide ductility to the structure [3]. Based on nonlinear dynamic analysis with earthquake ground motions, this research discusses the effectiveness of the introduction of Buckling Restrained Braces (BRBs) as a passive device in high seismic hazard areas in Afghanistan. The stable hysteretic behavior of a BRB device has the ability to control strength, stiffness, and yield displacement.

2. Buckling Restrained Braces (BRBs) Overview

Buckling restrained braces are widely used around the world to strengthen structures against seismic loads. They were first implemented in Japan in late 20^{th} century [4]. The concept Buckling Restrained Braces (BRBs) is a relatively new development in Afghanistan. It is an alternative to replace the conventional braced frames which surpass their ductility and energy dissipation capacity [5]. Unlike the conventional steel bracing element which shows unsymmetrical behavior under cyclic loading as it's shown in figure 1, the Buckling restrained brace has proven its high ductility in tension due to ductile yielding material properties and its performance is

governed by buckling under compression [3]. Considerable plastic deformations can be developed after yielding and before failure for both load directions that lead to highly ductile behavior. It yields in compression and tension and absorb energy. The fundamental aim of the construction of BRB is to prevent the buckling of the steel core by encasing it over its length in a steel tube filled with concrete with or without concrete or mortar as shown in Figure [5].

Buckling Restrained Braces are made of inner steel core and outer casing filled with concrete and a bound preventing layer/ slip surface (gap) between concrete and steel core. The layer is constructed to allow relative moment between steel core and concrete [6]. Figure 3 shows that removal of lateral buckling failure under compression leads to similar performance under compression and tension. Concrete and steel tube encasement provides sufficient flexural strength and stiffness to prevent global buckling of the brace, allowing the core to undergo fully reversed axial yield cycles without loss of stiffness or strength. The steel casing filled with concrete also prevents the local buckling of the core under compression thus; the steel core is to resist the full axial force designed in bracing [7], [3] and the external cement filled steel tube opposes buckling stresses. To ensure stable and consistent behavior, the steel core needs continues and support.

The core of the brace is divided into three parts along its length; the middle so-called yielding length and the rigid non-yielding parts on both ends as shown in figure 4. The increased cross-section area of the non-yielding part ensures that it remains elastic and therefore, the plasticity or yielding is concentrated only in the middle part of the steel core. This configuration provides high confidence in the prediction of the element behavior and failure [5]. Figures 5 and 6 show the typical Buckling Restrained Brace and its cross-section.

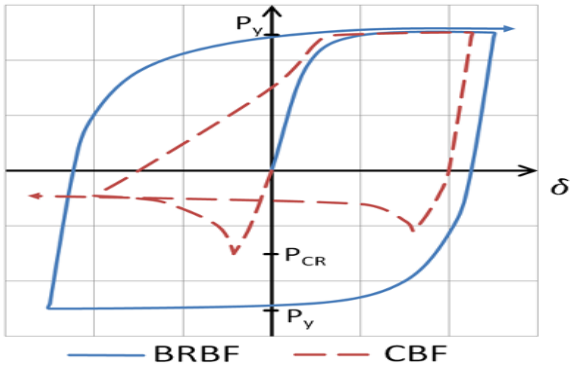


Figure 1. BRBF & CBF behavior (Source: [3])

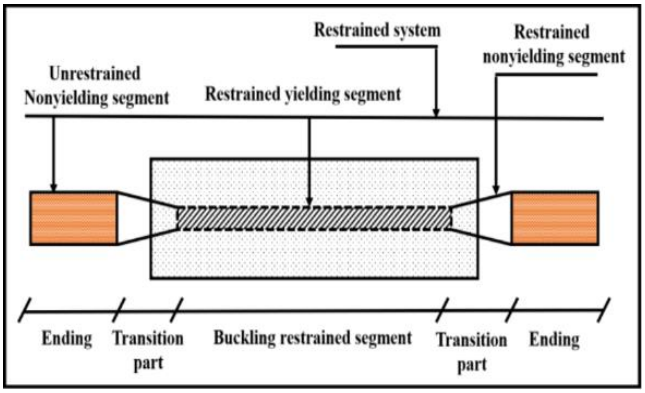


Figure 2. BRB Concept. (Source: [5])

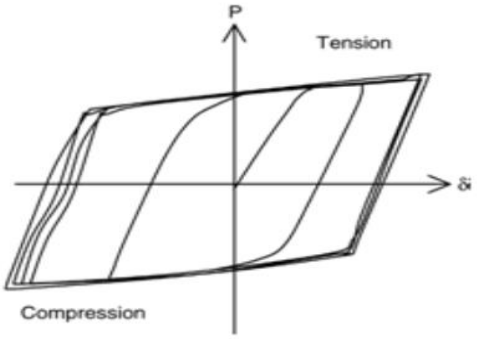


Figure 3. BRB in tension & compression. (Source: [3]).

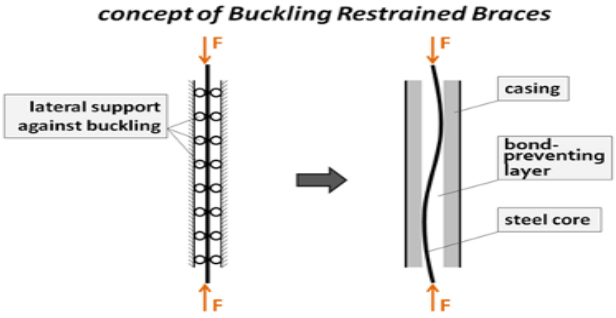


Figure 4. Main parts of BRB. (Source: [7])

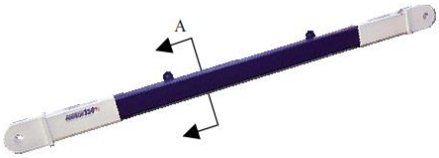


Figure 5. Typical BRB. (Source: [7])

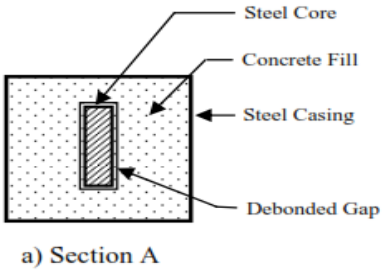


Figure 6. BRB cross section. (Source: [7])

3. Numerical model

The targeted building is 12 story steel office building designed for Kabul, a 2D frame model from the middle of the 12 story office building in the X direction has been chosen and analyzed. The first story is 533 cm tall and the upper stories dimensions are set, respectively, at 419cm. The building has a span of 914cm in the X direction and 610cm in the Y direction. In the structural, analysis the floor load is 5.71 kN/m^2 for the roof and 8.64kN/m^2 for floors [8]. ASTM A572 Grade 50 steel has been used as steel material for beams and columns with a minimum yield stress of F_Y=34.5kN/cm^2 and module of elasticity of E=20500kN/cm^2. The finite element method is used to obtain the required strength beams and columns. According to the Afghan Structural Code (ASC), steel structures are designed either by allowable stress design ASD or by Load and Resistance Factored Design method LRFD [9], [10]. In this research, the LFRD method is adopted and members are designed for the maximum combination of loads. Table 1 lists the profiles sections used in beams and columns. Figures 7 and 8 shows the analysis model and plan of the building, respectively.

Table 1. Frame Cross Sections

No.	*Level*	*Beam X direction*	*Columns*
1	Level 1 to 4	IPE600 (600x200x12x19)	H400x678 (448x427x82x50.5)
2	Level 5 to 12	IPE600 (600x200x12x19)	H400x340 (406x403x42.9x26.5)

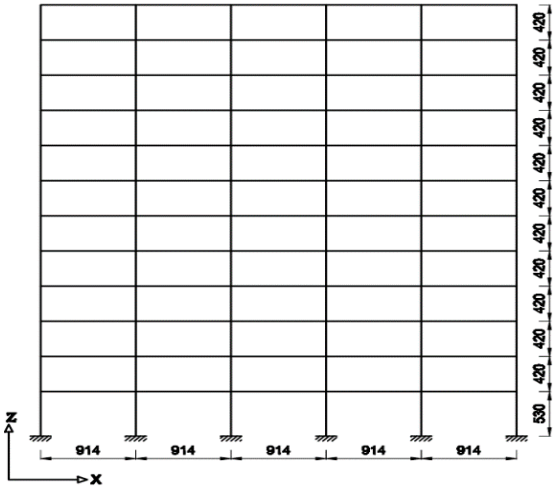


Figure 7. Numerical model of the building. (Source: Author)

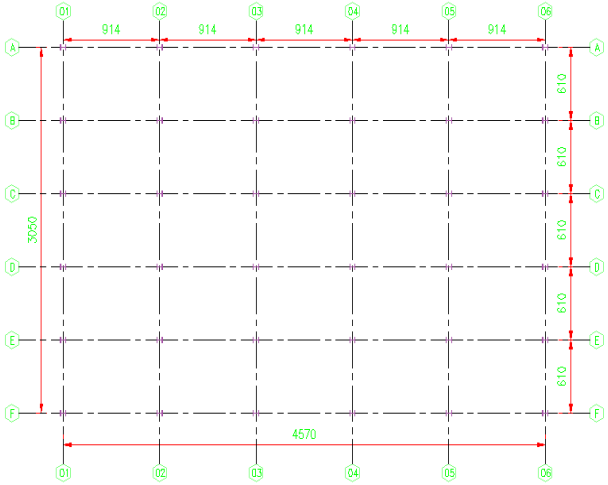


Figure 8. Plan of the building. (Source: Author)

4. Input Ground Acceleration

Design base earthquake (DBE) for the targeted building is the target spectrum of Kabul that corresponds to an extremely rare earthquake with a return period of 2500 years. Besides that, it is assumed that mentioned building is built in Badakhshan province of Afghanistan where it is subjected to the highest seismic intensity ground acceleration of 763cm/s^2. The Afghan Structural Code (ASC) design response spectrum is expressed as follow:

$$S_a(T,h)\begin{cases} S_{DS}(0.4+0.6\,T/T_0 & \dots \quad T \le T_0 \\ S_{DS} & \dots \quad T_0 < T \le T_S \\ S_{D1}/T & \dots \quad T_S < T \end{cases}$$

$$T_0 = 0.2 S_{D1} / S_{DS}$$
$$T_S = S_{D1} / S_{DS}$$

T is the natural period, and *h* is the damping factor of the structure. For Kabul province the spectral acceleration at a short period of 0.2 second S_S=1.28g and spectral acceleration at a period of 1 second S_1=0.51g. The design earthquake spectral response acceleration parameter at 0.2 second is $S_{DS} = 2/3 * S_{MS} = 2/3 * 1.28 = 0.8533g$ and design earthquake spectral response acceleration parameter at a period of 1 second is $S_{D1} = 2/3 * S_{M1} = 2/3 * 0.765 = 0.51g$. Afghan Structural Code (ASC) Target response acceleration spectrum with 5% damping is illustrated in Figure 9. For Badakhshan province the spectral acceleration at short a period of 0.2 second S_S=2.4g and spectral acceleration at a period of 1 second S_1=1.2g. The design earthquake spectral response acceleration parameter at 0.2 second is $S_{DS} = 2/3 * S_{MS} = 2/3 * 2.4 = 1.6g$ and earthquake spectral response acceleration parameter at a period of 1 second is $S_{D1} = 2/3 * S_{M1} = 2/3 * 1.8 = 1.2g$. Afghan Structural Code (ASC) target response acceleration spectrum for Badakhshan province with 5% damping is illustrated in Figures 10. To perform the nonlinear dynamic time-history seismic response analysis, simulated seismic ground motion matching the response spectrum of Kabul and Badakhshan are created. The response spectra of the simulated ground motion are consistent with the corresponding target spectrum. Artificially generated ground motion has phase wave characteristics of recorded ground motion of (El Centro NS). The absolute response acceleration spectra of simulated ground motions for Kabul and Badakhshan with 2% and 5% damping factors are illustrated in figures 9 and 10 respectively.

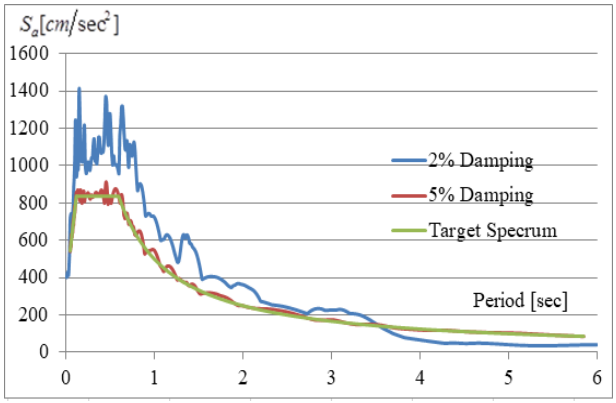


Figure 9 Response spectrum for Kabul province. (Source: Author)

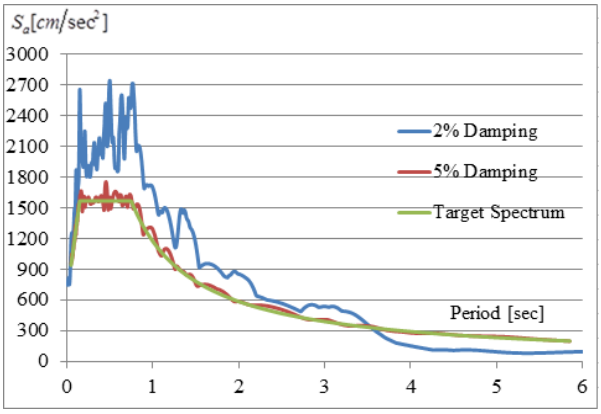
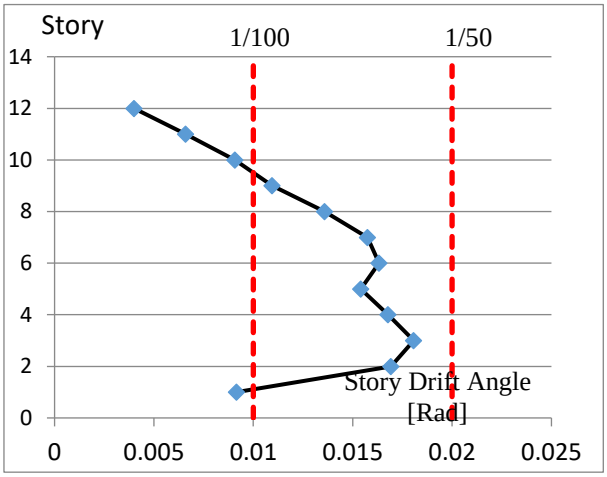


Figure 10. Response spectrum for Badakhshan province. (Source: Author)

5. Results of Nonlinear Time History Responses Analysis of Unbraced Frame Structure

In this research, input ground motion is considered in the X-direction. A Newmark-β *scheme w*ith β=1/4 is used for numerical integration, and the time interval for response calculation (Δt) is 0.002 seconds. The duration time is 50 seconds. The Raleigh damping matrix is adopted with a damping factor of 2%. Nonlinear dynamic response analysis has been carried out for Kabul and Badakhshan provinces by DYNAT 2 program. Figure 11 and 12 illustrates the distribution of the maximum story drift angle of each story over the height of the building for Kabul and Badakhshan province. The peak response of the frame structure in Kabul province in terms of maximum story drift angle is smaller than the maximum allowable limit for all floors of the structure. However, the response of the structure in Badakhshan province from second floor up to ninth floor is more than the allowable range. The story drift angle

for each story is the story drift of each story divided by height of each story. Since



steel is a soft material, the allowable range for steel structures is one divided by 50.

Figure 11. Story vs. story drift angle, Kabul province. (Source: Author)

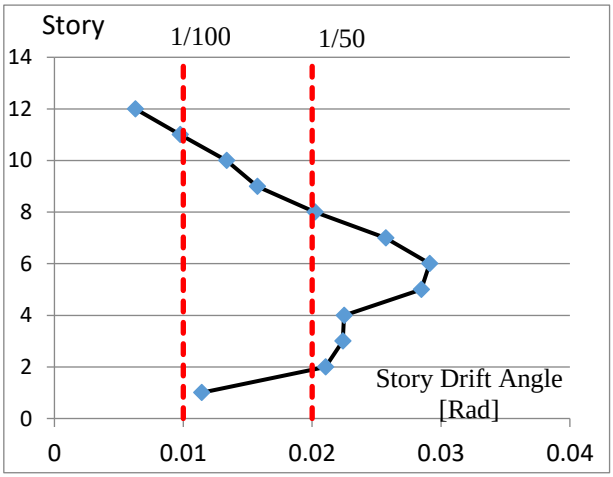
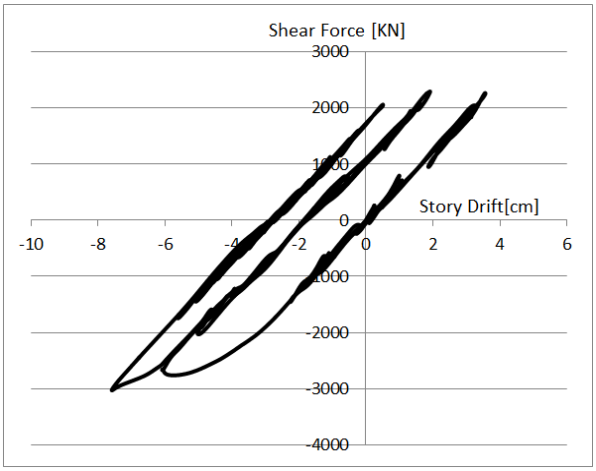


Figure 12. Story vs. story drift angle, Badakhshan province. (Source: Author)

Figure 13 illustrates the time history of the relationship between shear force and story drift of the third story which has the maximum story drift in Kabul province. Although the intensity of ground motions in Kabul province is medium, yet the relationship between shear force and story drift is nonlinear. Figure 14 illustrates the time history of the relationship between shear force and story drift of the 6th story which has the maximum story drift in Badakhshan province. As the intensity of ground motion in



Badakhshan province is high, therefore, the relationship between shear force and story drift is nonlinear and the structure yields.

Figure 13. Shear force vs. story drift, Kabul province. (Source: Author)

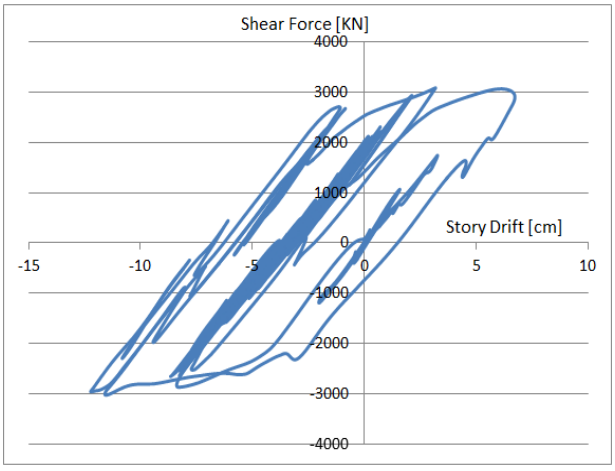


Figure 14. Shear force vs. story drift, Kabul province. (Source: Author)

To determine natural period, Eigenvalue analysis of the frame structure is carried out. Table 2 and table 3 lists a natural period T_s, a damping factor h_s, a participation factor $\beta_{s,}$ and an effective mass ratio ρ_s of each mode s in the X direction for Kabul and Badakhshan provinces respectively. The first natural period of the structure is 2.65 seconds.

Tables 4 and 5 list the maximum results of nonlinear dynamic response of the structure in terms of weight W_i, story height H_i, maximum story drift δ_{max}, maximum story drift

angle γ_{max}, maximum shear force Q_i, and maximum shear coefficient V_i for each story for Kabul and Badakhshan provinces respectively.

Table 2. Eigen values in Kabul Province

s	*T_S [sec]*	*h_s*	*β_s*	*ρ_s*
1	2.649	0.0200	3.991	0.8021
2	0.866	0.0200	1.419	0.1014
3	0.499	0.0290	0.874	0.0385
4	0.336	0.0408	-0.628	0.0198
5	0.246	0.0545	-0.506	0.0129

Table 3. Eigen values in Badakhshan Province

s	*T_S [sec]*	*h_s*	*β_s*	*ρ_s*
1	2.649	0.0200	3.991	0.8021
2	0.866	0.0200	1.419	0.1014
3	0.499	0.0290	0.874	0.0385
4	0.336	0.0408	-0.628	0.0198
5	0.246	0.0545	-0.506	0.0129

Table 4. Maximum responses in Kabul Province.

i	W_i [kN]	H_i [cm]	δ_{max} [cm]	γ_{max} [rad]	Q_i [kN]	V_i
1	19094	*530*	4.856	0.009162	3475	0.1820
2	17484	*420*	7.104	0.016914	3323	0.1901
3	15874	420	7.59	0.018071	3032	0.1910
4	14264	420	7.045	0.016774	2561	0.1795
5	12654	420	6.471	0.015407	2343	0.1852
6	11044	420	6.859	0.016331	2546	0.2305
7	9434	420	6.616	0.015752	2672	0.2832
8	7824	420	5.703	0.013579	2513	0.3212
9	6214	420	4.594	0.010938	2236	0.3598
10	4604	420	3.814	0.009081	2035	0.4420
11	2994	420	2.772	0.006600	1469	0.4906
12	1384	420	1.677	0.003993	786.2	0.5681

Table 5. Maximum responses badkhshan.

i	W_i [kN]	H_i [cm]	δ_{max} [cm]	γ_{max} [rad]	Q_i [kN]	V_i
1	*19094*	*530*	*6.04*	*0.0114*	*4278*	*0.2240*
2	*17484*	*420*	*8.83*	*0.0210*	*4038*	*0.2309*
3	15874	420	9.39	0.0223	3480	0.2192
4	14264	420	9.43	0.0224	3390	0.2376
5	12654	420	11.9	0.0284	3139	0.2480
6	11044	420	12.2	0.0291	3087	0.2795
7	9434	420	10.8	0.0257	3245	0.3439
8	7824	420	8.49	0.0202	3015	0.3853
9	6214	420	6.61	0.0157	2825	0.4546
10	4604	420	5.61	0.0133	2587	0.5619
11	2994	420	4.09	0.0097	2214	0.7394
12	1384	420	2.63	0.0062	1485	1.0729

Figure 15 compares story drift angles of Kabul and Badakhshan provinces. It clearly indicates that the structures in Badakhshan province yields more than its capacity. In order to reduce the story drift, shear force and natural period of the structure in Badakhshan province, a passive control device is introduced. Buckling Restrained Braces with hysteretic behavior are installed as a passive device to control lateral displacement and reduce the natural period and shear force at each story.

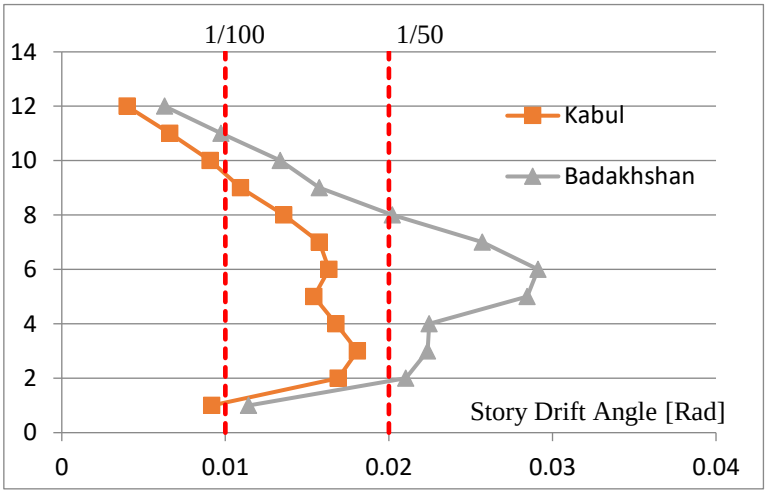


Figure 15. Story drift angle comparison of Kabul and Badakhshan provinces. (Source: Author)

6. Frame Structures with Buckling Restrained Braces

6.1 Buckling Restrained Brace Design

BRB element is modeled by a truss element with Hysteresis or bilinear Behavior. Figure 16, 17, and 18 shows the deformation of the frame and buckling restrained brace, the configuration of forward diagonal buckling brace, and the forces acting on the frame and buckling restrained braces.

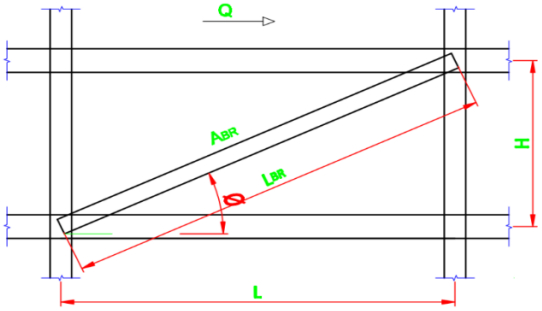


Figure 16. BRB configuration. (Source: Author)

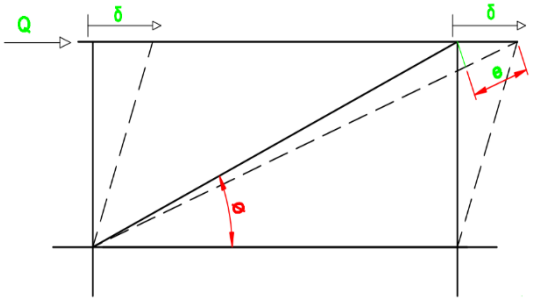


Figure 17. Deformation of BRB. (Source: Author)

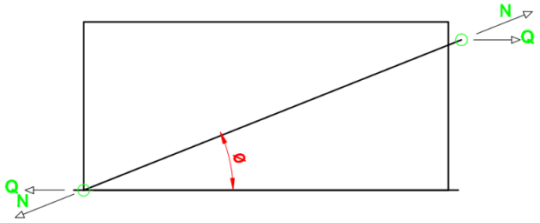


Figure 18. Forces acting on BRB. (Source: Author)

From brace configuration in figure 16, and brace deformation in figure 17 the following is known:

L_{BR}: length of BRB element

$A_{BR:}$ Area of BRB element

L: length of span in which BRB element is used

H: Story height

To find out the length of the BRB element and $Cos\theta$, the following formula is used:

$$L_{BR} = \sqrt{L^2 + H^2}$$

$$Cos\theta = \frac{L}{l_{BR}}$$

Shear fore Q acting on brace is calculated as follows:

$$Q = N \cdot Cos\theta \quad (1)$$

N: Axial force of BRB element

Yield shear force Q_Y equals:

$$Q_Y = N_Y \cdot Cos\theta = A_{BR} \cdot \sigma_Y \cdot Cos\theta \quad (2)$$

N_Y: Yield stress of steel grade used in BRB element (grade of steel used)

Brace stiffness K_{BR} is calculated as follows:

$$\sigma = \mathrm{E} \cdot \varepsilon \quad (3)$$

$\sigma : Stess, \varepsilon : Strain$

$$\varepsilon = \frac{e}{L_{BR}} \quad (4)$$

$$N = A_{BR} \cdot \sigma \quad (5)$$

From equation (3) to (5)

$$N = A_{BR} \cdot \sigma = \mathrm{E} \cdot A_{BR} \cdot \varepsilon = \frac{\mathrm{E} \cdot A_{BR}}{l_{BR}} \cdot e \quad (6)$$

In which

$$\delta \cdot Cos\theta = e \quad (7)$$

e: elongation

From equation (7), (6) and (1)

$$Q = N \quad Cos\theta = \frac{E * A_{BR}}{l_{BR}} \quad Cos^2\theta * \delta$$

$$Q = K \cdot \delta \quad (8)$$

$$K = \frac{E * A_{BR}}{l_{BR}} \quad Cos^2\theta \quad (9)$$

The required area for buckling restrained brace is obtained by the following formula:

$$A_{BR} = \frac{Q_Y}{\sigma_Y \cdot Cos\theta} \quad (10)$$

Where E is young's modulus and E1=0.01E is post young's modulus.

Yield shear force, required area and stiffness Buckling Restrained Brace

The required cross-sectional area A_{BR} of the yielding portion of the brace and the horizontal shear stiffness K_{BR} of the brace structure is calculated as:

$$A_{BR} = \frac{Q_Y}{\sigma_Y * cos\theta}, K_{BR} = \frac{E * A_{BR}}{l_{BR}} * cos^2\theta$$

Q_Y is a yield shear force obtained from the difference between capacity of structure and base shear force distribution for Badakhshan province calculated by time history analysis. Table 6 lists the required shear force for the design of Buckling Restrained Braces.

Table 6 .Yield shear force for design of BRB

Level i	*Vi[KN]*	*Original shear force capacity Kabul [KN]*	*BRB Shear force [KN]*	*Increased assumption [KN]*	*BRB Status*
1	4278	3000	1278	1000	Considered
2	4038	2990	1038	1000	Considered
3	3480	2950	530	1000	Considered
4	3390	2880	510	1000	Considered
5	3139	2770	369	1000	Considered
6	3087	2610	477	1000	Considered
7	3245	2410	835	1000	Considered
8	3015	2157	858	1000	Considered
9	2825	1840	985	1000	Considered
10	2587	1470	1117	0	Not/ Considered
11	2214	1020	1194	0	Not/ Considered
12	1485	507	978	0	Not/ Considered

Table 7 lists story span, story height, modulus of elasticity, the yield stress of brace steel, and secondary modulus elasticity.

Table 7. Given properties of brace design

H[cm]	*L[cm]*	*E[KN/cm^2]*	*F_Y[KN/cm^2]*	*E_1[KN/cm^2]*
530	914	20500	25.5	205

In this study, Q_Y is assumed to be 1000 kN, and brace length, brace angle, the required area of the braces, horizontal shear stiffness K_{BR} of the brace, and other properties for each story is calculated as:

The length of BRB element:

$$L_{BR} = \sqrt{L^2 + H^2} = \sqrt{914^2 + 530^2} = 1057\,cm$$

Brace angle

$$Cos\theta = \frac{L}{l_{BR}} = \frac{914}{1057} = 0.865$$

$$\theta = 30^0$$

The required area for Bucking restrained brace is equals:

Q_Y: The shear force acting on BRB element is taken from Table 6

$$A_{BR} = \frac{Q_Y}{\sigma_Y \cdot Cos\theta} = \frac{1000}{25.5 \cdot 0.865} = 45.3cm^2$$

As per plan two braces are need for each story so the area for one brace is 23cm^2
The required horizontal shear stiffness equals:

$$K = \frac{\mathrm{E} \cdot A_{BR}}{l_{BR}} \cdot Cos\theta^2 = \frac{20500 \cdot 45.3}{1057} \cdot 0.865^2 = 657.4\, KN/cm^2$$

Brace axial force

$$N = A_{BR} \cdot \sigma = 45.3 \cdot 25.5 = 1155KN$$

Brace shear force

$$Q = N \cdot Cos\theta = 1155 \cdot 0.865 = 1000KN$$

Frame displacement:

$$Q = K \cdot \delta$$

$$\delta = \frac{Q}{K} = \frac{1000}{657.4} = 1.52cm$$

Buckling Restrained Brace elongation

$$e = \delta \cdot Cos\theta = 1.52 \cdot 0.865 = 1.31cm$$

Or

$$\sigma = \mathrm{E} \cdot \varepsilon$$

$$\varepsilon = \frac{\sigma}{\mathrm{E}} = \frac{25.5}{20500} = 0.0012439$$

$$\varepsilon = \frac{e}{l_{BR}}$$

$$e = \varepsilon \cdot l_{BR} = 0.0012439 \cdot 1057 = 1.31cm$$

6.2 Buckling Restrained Braces Configuration

From the capacity of the structure and required shear force for BRB element in table 6 and story drift of each story in Badakhshan province, it is concluded that the building yields from first up to the ninth story and the maximum story drift is more than the allowable limit in Badakhshan province. In order to control and limit the story drift of each story, ductility is provided to the structure with the installation of buckling restrained Brace elements in these stories. Two configurations of forward

diagonal and backward diagonal buckling restrained braces are installed in each frame. To investigate the full response of the building both of the following patterns of bracing are considered:

Pattern A**:** The BRB elements are installed from the first up to the ninth story.

Pattern B**:** the BRB elements are installed from first up to the twelfth story

In these two patterns, Buckling Restrained Braces with various core cross section areas are installed and the responses of the building have been investigated and BRB elements with the optimum arrangement of the core cross-section area are selected. Figures 19 and 20 illustrate patterns A and B.

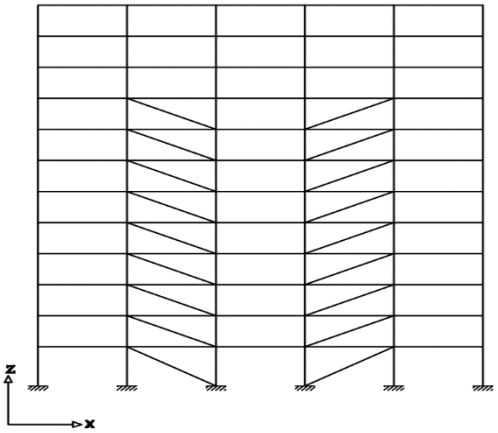


Figure 19. Installation of BRB in Pattern A. (Source: Author)

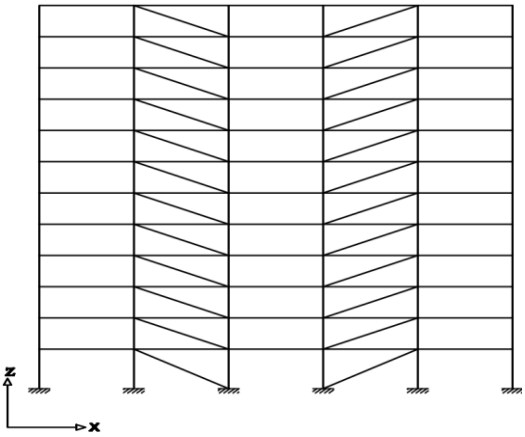


Figure 20. Installation of BRBR in Pattern B. (Source: Author)

7. Results Nonlinear Time History Responses Analysis of Frame Structure with BRB

Nonlinear dynamic response analysis has been carried out for Badakhshan province in both patterns. Figure 21 shows the relationship between story and story drift angle for various core cross-section areas of BRBs in pattern A. Figure 22 show the relationship between story and story drift angle for various core cross-section areas of BRBs in pattern B.

The results of responses of pattern A and pattern B show that in pattern A the story drift angle is suppressed till 9th floor but as there is no brace in the upper three floors thus, the story drift angle has a sudden increase. On the other hand, in pattern B the story drift angle is suppressed in all floors as BRBs are used in the entire frame.

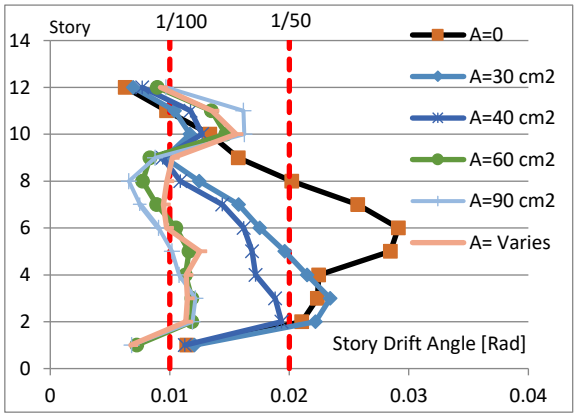


Figure 21. Story vs story drift angle. Pattern A. (Source: Author)

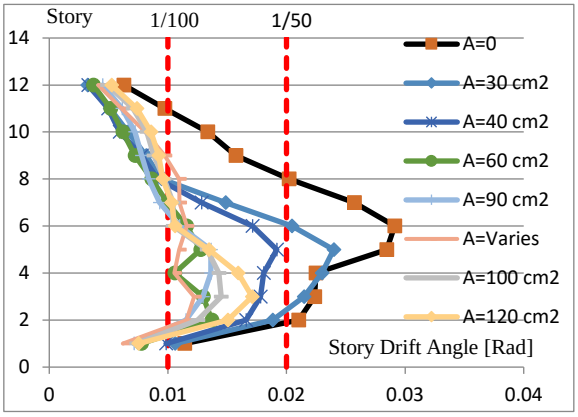


Figure 22. Story vs story drift angle. Pattern B. (Source: Author)

Figure 23 shows the distribution of maximum shear force over the height of building for various cross section areas of BRB.

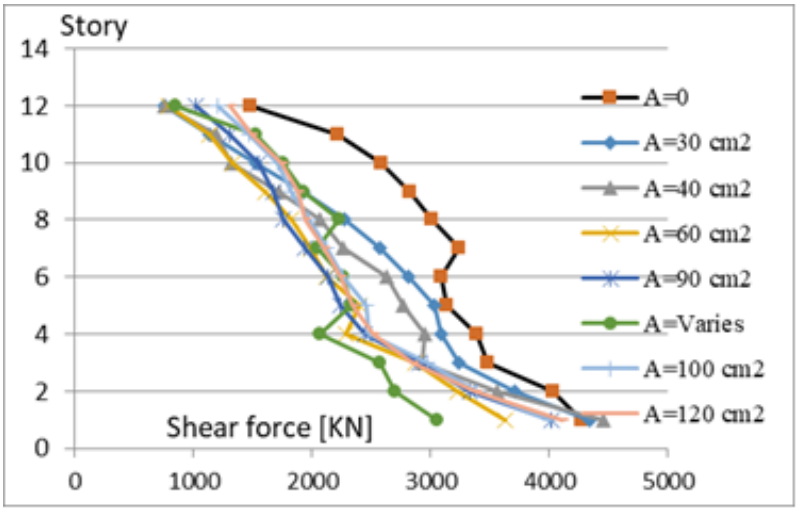


Figure 23. Maximum distribution of shear force. (Source: Author)

From various cross section areas of brace in both patterns it is concluded that pattern B with varying cross section area gives the optimum arrangement. Therefore, pattern B with varying cross sections is selected.

Time History Analysis of Frame with BRB has been carried out for Badakhshan province with various cross section area of steel core of BRB from which the most effective arrangement is selected. Table 8 indicates the optimum required area for steel core of the Buckling Restrained Braces for each story of the frame structure.

Table 8. Optimum Required Area for BRB Steel Core

Floor	*1 to 4*	*5 to 7*	*8 and 9*	*10*	*11 to 12*
BRB Area [cm^2]	70	60	50	40	30

Figure 24 shows the Hysteretic relationship of the frame and Buckling Restrained Braces for the first story which illustrates that Buckling Restrained Brace has the same performance in tension and compression. Furthermore, it shows that half of the shear force has been resisted by BRB.

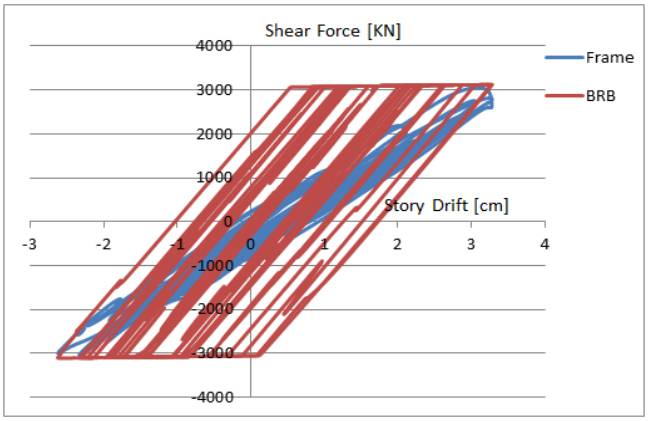


Figure 24. Shear force vs story drift. (Source: Author)

Eigenvalue analysis of the frame structure is carried out with installation BRB elements with varying cross sections. Table 9 lists a natural period Ts, damping factor hs, a participation factor βs and an effective mass ratio ρs of each mode s in X direction.

Table 10 lists the result of Nonlinear dynamic response analysis in which story weight Wi, story height Hi, maximum story drift δmax, maximum story drift angle γmax, maximum shear force Qi, and maximum shear coefficient Vi for each story i with varying cross section of BRBs installed. Figure. 25 illustrates the distribution of maximum story drift angle over the height of building for bare frame and for frame with installation of BRBs having varied optimum arrangement of cross sections areas.

With installation of BRB the fundamental period each mode significantly decreases and on the other hand natural frequency increases. Moreover, the maximum story drift is smaller than the allowable limit. After employing BRBs in the frame structure, the average response of the structure in terms of maximum story drift angel is within the code limitation.

Table 9. Eigen values

s	T_S [sec]	h_s	β_s	ρ_s
1	1.467	0.0173	3.958	0.7886
2	0.503	0.0289	1.545	0.1202
3	0.291	0.0466	0.885	0.0394
4	0.204	0.0652	-0.604	0.0184
5	0.188	0.0707	0.001	0.0000

Table 10 Maximum responses

i	W_i [kN]	H_i [cm]	δ_{max} [cm]	γ_{max} [rad]	Q_i [kN]	V_i
1	19094	530	3.279	0.0061	3061	0.1603
2	17484	420	4.859	0.0115	2703	0.1545
3	15874	420	5.129	0.0122	2569	0.1618
4	14264	420	4.426	0.0105	2063	0.144
5	12654	420	4.601	0.0109	2329	0.1840
6	11044	420	4.876	0.0116	2269	0.2054
7	9434	420	4.611	0.0109	2040	0.2162
8	7824	420	4.595	0.0109	2231	0.2851
9	6214	420	4.086	0.0097	1925	0.3097
10	4604	420	3.394	0.0080	1756	0.3814
11	2994	420	2.559	0.0060	1530	0.5110
12	1384	420	1.731	0.0041	854.7	0.6175

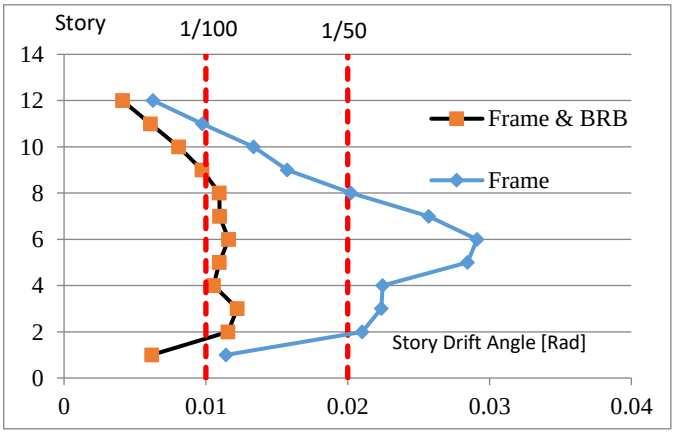


Figure 25. Story vs. story drift angle. (Source: Author)

8. Conclusions

The dynamic response of steel frame and steel frame braced with buckling restrained brace has been studied in 2 provinces of Afghanistan by time history analysis with artificial ground excitation. The results of nonlinear dynamic time history analysis show that different stories have quite different dynamic characteristics. The response of steel frame structure in terms of story drift angle was investigated and compared with the maximum allowable limit. The response of the structure for the province of Kabul was under the maximum allowed range while the response of the structure for severe ground motions of Badakhshan province was more than the allowable limit; therefore, to control the response of the structure in Badakhshan province, Buckling Restrained Braces (BRBs) were introduced as passive devices. In order to minimize the earthquake induced damage in frame

structural members, the passive control device is required to yield before the main frame does. The buckling restrained brace consists of a steel core, when subjected to strong earthquake loads, it undergoes significant inelastic deformation and provides great ductility, consistent repeatable cyclic behavior and have the capacity to sustain multiple seismic events without significant strength degradation.

The following are some conclusions drawn from the study:

1. With installation of Buckling Restrained Braces the natural period of the structure decrease from to 2.6 seconds to 1.4 seconds and the maximum shear force is decreased from 4278 KN to 3000 KN.
2. The maximum story drift angles of structure with BRB are decreased from 0.03 to 0.01 and are within the allowable code limitation.
3. With installation of BRB, equivalent mass ratio and participation factors are decreased from 3.99 and 0.802 to 3.95 and 0.788 respectively.
4. In order to attain the optimum arrangement, sizing the proper area for steel core is of great importance. Too small areas will not decrease the story drifts angles while too large areas will prevent brace yielding and also increase the design base shear.

9. Recommendations

Steel structures with passive devices are not very common in Afghanistan as most low and middle rise structures do not use any passive devices to control lateral displacements. The introduction of Buckling Restrained Braces as passive devices is an effective way to control the lateral displacement of steel structures in high seismic hazard areas, save lives and property. Since the introduction of BRBs is a new phenomenon in Afghanistan; therefore, this section purposes the usage of Buckling Restrained Brace as passive devices in steel buildings and provide suggestions for further research in this area as follows:

1. Further research shall be conducted with actual ground motions and the response of the steel structures shall be investigated.
2. The response and behavior of the building should be investigated for more than one ground motions.

10. References

[1] R. L. Wheeler, C. G. Bufe, M. L Johnson, and R. L. Dart. “Seism Tectonic Map of Afghanistan with Annotated Bibliography,” US Geological Survey, Reston, Virginia, Report 2005-1264

[2] O. S. Boyd, C. S. Mueller, and K. S Rukstales “Preliminary Earthquake Hazard Map of Afghanistan,” US Geological Survey, Reston, Virginia, Report 2007-1137

[3] W. N. Deulkar, C. D. Modhera & H. S. Patil ”Buckling Restrained Braces For Vibration Control of Building Structure”, Buckling Braces for Building Structures, Volume. 4 issue. 4, pp. 363-372, September 2010.

[4] R. Polekar, H.R. Magarpatil, “Design and Development of Buckling Restrained Braces Using Matlab”, international journal of scientific & technology research volume 8, issue 08, pp 1432-1435august 2019

[5] E. Arunraj, V. S. Jebadurai, S. D. Abraham, C. Daniel, G. Hemalatha “Analytical Investigation of Buckling Restrained Braced Frame Subjected To Non-Linear Static Analysis”, International Journal of Engineering and Advanced Technology, Volume-8 Issue-5, pp 334-338, June 2019

[6] R. Sabelli, S. Mahin, C. Chang, “Seismic demands on steel braced frame buildings with buckling restrained braces”, Elsevier Engineering Structures, pp 655-666, 2003

[7] S. Hussain, P. V. Benschoten, M. A. Satari, “Buckling Restrained Braced Frame (BRBF)
Structures”, Analysis Design and Approvals Issues

[8] Minimum Loads for Buildings and Other Structures, American Society of Civil Engineers, 2006.

[9] Afghan Structural Code, Afghan National Standard Authority, April 2012.

[10] W. T. SEGUI, LRFD Steel Design, University of Memphis U.S., Global Engineering, 2013.

Acknowledgement

I would like to thank my Dad and family members for their unconditional support, love, and guidance throughout my life and my professional career.

Appendix

Abbreviations

BRB:	Buckling Retrained Braces
BRBF:	Buckling Retrained Brace Frame
CBF:	Conventional Braced Frame
L_{BR}:	length of BRB element
$A_{BR:}$	Area of BRB element
L:	length of span in which BRB element is used
H:	Story height
T:	The fundamental period of the structure
T_L:	Long –period transition period

The geometric properties of the selected profile sections and earthquake related coefficient are listed in below tables.

Table 1. Geometric properties of profile sections

No	Profile	$I_x\ [cm^4]$	$S_x\ [cm^3]$	$r_x\ [cm]$	$I_y\ [cm^4]$	$S_y\ [cm^3]$	$r_y\ [cm]$	A[cm^2]
1	H400x678	301100.0	12442.2	18.67	106800.0	5002.53	11.12	864
2	H400x340	122600.0	6039.4	16.8	46850.0	2325.0	10.4	433
3	IPE 600	92080	3069.3	24.3	3387	307.9	4.7	156
4	IPE 500	48200	1928	20.4	2142	214.2	4.3	116
5	IPE 300	8356	557.1	12.5	604	80.5	3.6	53.8

Table 2. Plastic moment and modulus elasticity

No	Profile	Plastic modulus $M_{PX}\ [cm^3]$	Plastic modulus $M_{PY}\ [cm^3]$	Module of Elasticity E [KN/cm2]
1	H400x678	15400	7685	20500.00
2	H400x340	6997	3543	20500.00
3	IPE 600	3512	486	20500.00
4	IPE 500	2194	336	20500.00
5	IPE 300	628	125	20500.00

Table 3. /Table 305.3-1 Afghan Structural Code importance factors

Risk category from Table 3.5.1-1 ABC	Snow importance factor Is	Ice importance factor-Thickness Ii	Ice importance factor-wind Iw	Seismic importance factor Ie
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50

Table 4. Values of site coefficient Fa

Site class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at Short Period				
	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	Shall be determined in accordance with section 311 ABC.				

Table 5. Values of site coefficient FV

Site class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at Short Period				
	S1 = 0.1	S1 = 0.2	S1 = 0.3	S1 = 0.4	S1 = 0.5
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.8	1.4	1.3
D	2.4	2.0	1.2	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	Shall be determined in accordance with section 311 ABC.				

Author Profile:



Mohammad Naser Amin received B.Sc. degree in Civil and Industrial Construction from Kabul Polytechnic University in 2010 and M.Sc. degree in Civil Engineering and Architecture from Toyohashi University of Technology Aichi, Japan in 2017. Presently he is working as assistant professor in the Department of Building Construction Management, Kabul Polytechnic University, Kabul Afghanistan. His areas of research include Seismic Evaluation of Steel & Concrete structures, study of devices used in building structures to reduce earthquake caused displacement and Quality Management in Construction projects.