Assessment of Influencing Design Parameters of Buckling Restrained Brace on its Performance on MATLAB

Umang Shah[1], Prof. H. R. MagarPatil[2, *]

[1] *Post Graduate Student, Dept. of Civil Engineering,*
Dr. Vishwanath Karad MIT-World Peace University, Pune, Maharashtra, India.

[2] *Professor, Dept. of Civil Engineering,*
Dr. Vishwanath Karad MIT-World Peace University, Pune, Maharashtra, India

KEYWORDS

Buckling Restrained Braces
Influencing Parameters
MATLAB
Seismic Responses
Storey Drift

ABSTRACT

Day by day as the amount and intensity of earthquakes are increasing, the need for earthquake resistant building is also increasing. But always designing strong column and weak beam is not solution because it will definitely increase cost of construction. This paper presents a summary of current practice and recent developments in the application of passive energy dissipation systems for seismic protection of structures. Major topics that are presented include design of Buckling Restrained Braces (BRB), factors influencing Design Parameters of BRB on its performance and the use of MATLAB for evaluating the same. In recent years, Buckling Restrained Braced Frames (BRBFs) are widely used as seismic force-resisting systems due to their significant ductility and energy dissipation capacity. Buckling-restrained braces are braced frame structural system components that do yield in both tension and compression, thus acting as energy dissipators. They do not only stiffen their parent structures but reduce drift too. In this study, parameters affecting performance of Buckling Restrained Brace such as Stiffness, Material of Core, Core Member Length, and Bracing angle were analyzed. MATLAB being a high-performance language for technical computing, it integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Therefore, it is used for evaluation of potential drift and design of Buckling Restrained Brace in early stages of design and later the results obtained on MATLAB were verified on another structural analysis software ETABS. A numerical example is also provided to understand the concepts better.

1. INTRODUCTION

1.1. GENERAL

Earthquake is the sudden release of energy from earth's lithosphere that causes shaking of the surface of the earth. The intensity of earthquake may be different varying from so weak that are not even felt to strong earthquake that may cause huge destruction. When it hits the surface of the earth they may cause tremendous damage to the structures. Therefore earthquake resistant buildings are designed to protect the building during earthquake.

As we already know that no structure can be entirely immune to damage caused by earthquake, our goal is to build a fairly resistant building to reduce the damage as much as possible during seismic activity, which basically means that the loss of life is reduced. The conventional practice to earthquake resistant design of building is to provide building with high strength, stiffness and inelastic deformation capacity to withstand the earthquake generated forces. But with the advancement in technology, for designing earthquake resistant building now it's not necessary to strengthen the building but we can reduce the forces generated on structural members due to earthquake.

The most advance techniques of earthquake resistant design and construction are:

- Base Isolation
- Energy Dissipation Devices
- Damping Devices and Bracing systems

Amongst these, Buckling Restrained Braces are more effective than any other method of earthquake resistant building as:

- With the use of bracing in structure, the member sizes of structural element of building also reduces which eventually affects the construction cost.
- It provides most effective utilization of interior space of structure.
- It resists all the different types of vibration.
- It is also maintenance free.

Due to its high quality and performance it is widely used these days

1.2. BUCKLING RESTRAINED BRACES

Buckling Restrained Brace is seismic device designed to allow the building to resist cyclical lateral loadings, typically earthquake-induced loading it consists of axially yielded full plastic core with axially decoupled restrained mechanism. This axially decoupled restrained mechanism suppresses overall buckling. It is so prepared that there is no degradation during compression. Buckling restrained braces can be modeled using truss element and uniaxial material hysteresis rules. Considering that core is plastic throughout its length.

Looking forward to components of buckling restrained braces as shown in fig.1, it consists of slender steel core to resist compression and tensile forces, concrete casing for preventing buckling under compression and supporting core and the main component i.e. bond preventing layer to prevent undesired interaction between core and casing.

- Steel Core

Steel Core is the main component of BRB. The steel core is responsible to resist complete axial force developed in bracing. It is composed of ductile material and designed to yield under both tension and compression. The middle length of steel core is designed to yield inelasticity. The non-yielding length on both sides has increased cross-section area to ensure it remains elastic and hence plasticity is concentrated in middle part of steel core.

- Bond Preventing Layer

The interaction between core and external restraining member is major factor that affects the performance of buckling restrained brace. The frictional force between core and external restraining member should also be considered during analysis. Two types of contact forces are generated between core and external member i.e. Normal contact force and Tangential friction force. Bond Preventing Layer prevents undesired interaction between core and casing.

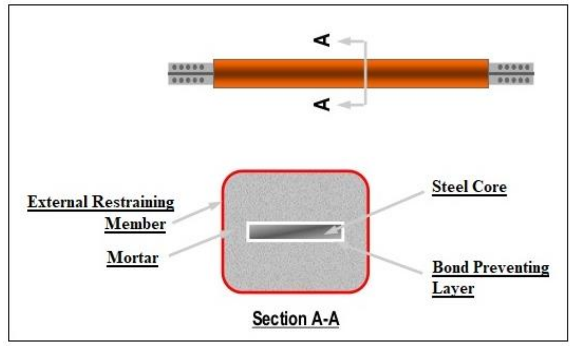

Fig. 1: Components of Buckling Restrained Braces

- External Restraining Member

The external restraining member is mainly responsible to prevent overall buckling of brace. It mainly provides lateral resistance and support to steel core.

Connections are also a major factor of concern. They are mainly responsible for transferring forces from structure to brace. The connection of buckling restrained brace to RCC or steel framing of structure is very important and major factor affecting the performance of buckling restrained brace. Generally the brace is attached through a gusset plate to the structure. The connection may be of different types, but the major 3 types are,

- Welded
- Bolted
- Pinned

1.3. FACTORS INFLUENCING DESIGN PARAMETERS OF BRB

Focusing on parameters affecting performance of Buckling Restrained Brace, Stiffness, Material of Core, Core Member Length, and Bracing angle are studied. Material being an integral part which directly influences various parameters such as the mechanical, physical, chemical properties was studied deeply. Main property that influence the selection of material is stiffness as it governs the deflection of structural member. Looking forward to extensive properties the behavior of BRB is also depended on core member length and core width to thickness ratio as it affects the slenderness property of member which if not studied with care may lead to buckling failure of member. Also placing of Brace at proper angle is necessary for efficient design consideration as stiffness imposed on structure varies with the angle with which it is placed between the column beam junctions.

1.4. MATLAB

As known, software testing can improve quality of results. To test effectively, the tests are run with appropriate test cases, expected outputs are determined along with correct arithmetic operations. Automated testing framework is generated using MATLAB.

At first, data such as Height of Storey, Seismic Zone, Importance Factor, Response Reduction Factor, Design Acceleration Coefficient, Modulus of elasticity, Moment of Inertia are acquired.

The data is then computed using the set of expressions. For that we designate each input data by set of letters or set of symbols which will help us to pick and recognize the data with ease. For example, Floor Height of Storey is denoted by F, Seismic Zone by Z, and Modulus of Elasticity by E.

The MATLAB then computes the data according to codal formula provided and then the final output of required data is generated and displayed.

2. METHODOLOGY

2.1. GENERAL

Factors such as seismic weight of each floor, zone factor, acceleration coefficient, modulus of elasticity, stiffness etc. are needed to be considered in the design of BRB.

According to IS 1893, a building located somewhere in India is considered. From the location of the building, values such as seismic zone factor (Z), importance factor (I), design acceleration coefficient (Sa/g), response reduction factor (R) are then considered. From the values acquired, clause 6.4.2 of IS 1893 (Part 1): 2016 is used and design horizontal seismic coefficient (A_h) is obtained.

$$A_h = \frac{(Z/2)\,(S_a/g)}{(R/I)} \qquad \text{- [1]}$$

From the design horizontal seismic coefficient (A_h), design base shear (V_B) along any principle direction of the building is found. This is obtained by multiplying seismic weight of building (W) to the design horizontal seismic coefficient (A_h) as per clause 7.6.1 of IS 1893 (Part 1): 2016.

$$V_B = A_h W \qquad \text{- [2]}$$

After finding out the total design base shear, the lateral forces acting on each storey is evaluated. The Lateral Load Distribution is the major factor affecting the design of Buckling Restrained Brace.

Lateral Load Distribution with height by the Static Method is done by following expression to which the base shear is multiplied to get the lateral load on each storey. Lateral forces on each storey is given by

$$= V_B \times (W_i h_i^2 \;/\; \sum W_i h_i^2) \qquad \text{- [3]}$$

For most practical purposes, an accurate estimate of the stability effects may be obtained by what is commonly referred to as P-delta analysis. Elaborating the name, P means the force acting on the body and delta means the horizontal displacement. This is basically a destabilizing effect. Seismic and wind loads also induce horizontal deflection in the members. If a uniformly distributed lateral load of 'f' per unit height H is applied to a flexural cantilever, the lateral displacement Δ at the top for a constant EI is (Naeim, 2001):

$$\Delta = (0.125\, f\, H^4) / EI \qquad \text{- [4]}$$

Storey drift is the difference of displacements between two consecutive stories divided by the height of that storey and which should not be exceeded by 0.004 times the storey height, under the action of design base shear V_B with partial safety factor for all loads taken as 1.0 as per IS 1893:2016 under clause 7.11.1.

Later design of buckling restrained braces is continued with basic stress formula i.e. stress is equal to force per unit cross sectional area, and on basis of area calculated the stiffness of bracing is calculated by following formula(Chopra, 2015):

$$K_{brace} = (AE/L)\cos^2\Theta \qquad \text{- [5]}$$

With the bracing stiffness calculated, column stiffness according to column end condition considered is added, to get total stiffness of structure. Stiffness of structure is governing parameter for the deflection of storey. The deflection of storey after placing of braces is then verified by following formula where, F is force acting, k is its stiffness, and x is deformation:

$$x = F / k_{total} \qquad \text{- [6]}$$

Hence, it is known if the Buckling Restrained Brace provided is suitable or not. If the deformation of structure is cut down to large extent or even if optimization of sections is possible under this bracing then it means that the bracing provided are best suited to structure.

3. MODELING OF BRB

3.1 GENERAL

A four-storey reinforced concrete office building shown in the fig.2. The building is located in Shillong (seismic zone V). The soil conditions are medium stiff and the entire building is supported on a raft foundation. The R. C. frames are infilled with brick-masonry. The lumped weight due to dead load is 12 kN/m^2 on floors and 10 kN/m^2 on the roof. The floors are to cater for a live load of 4 kN/m^2 on floors and 1.5 kN/m^2 on the roof.

Determine design seismic load on the structure as per new code(Sudhir, K, 2005).

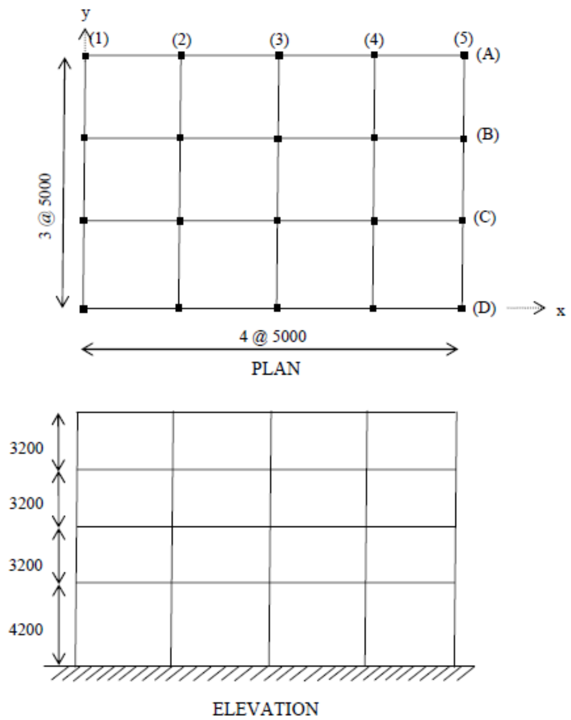

Fig. 2: Plan and Elevation of building

3.2. DESIGN PARAMETERS

For seismic zone V, the zone factor Z is 0.36 (Table 2 IS: 1893). Being an office building, the importance factor, I, is 1.0 (Table 6 of IS: 1893). Building is required to be provided with moment resisting frames detailed as per IS: 13920-1993. Hence, the response reduction factor, R is 5. (Table 7 of IS: 1893 Part 1)

3.3. SEISMIC WEIGHTS

The floor area is 15×20=300 sq. m. Since the live load class is 4kN/sq.m, only 50% of the live load is lumped at the floors. At roof, no live load is to be lumped. Hence, the total seismic weight on the floors and the roof is:

Floors:
W1=W2 =W3 = 300×(12+0.5×4) = 4,200 kN

Roof:
W4 = 300×10 = 3,000 kN

Total Seismic weight of the structure,
W = ΣWi = 3×4,200 + 3,000 = 15,600 kN

3.4. FUNDAMENTAL PERIOD

Lateral load resistance is provided by moment resisting frames infilled with brick masonry panels. Hence, approximate fundamental natural period as per clause 7.6.2. IS: 1893 Part 1.

EL in X-Direction:

$T = 0.09h / \sqrt{d} = 0.09(13.8) / \sqrt{20} = 0.28$ sec

EL in Y-Direction:

$T = 0.09h / \sqrt{d} = 0.09(13.8) / \sqrt{15} = 0.32$ sec

3.5. LATERAL LOAD DISTRIBUTION

The building is located on Type II. From Fig. 2 of IS: 1893, for T=0.28 sec, Sa/g = 2.5.

A_h = (0.36) (1)/ (2) (5)) (2.5)
=0.09

Design base shear: (Clause 7.5.3 of IS: 1893:2016 Part1)

V_B $= A_h W = 0.09 \times 15{,}600$
= 1,404 kN

The design base shear is to be distributed with height as per clause 7.7.1. Table 1 and Fig. 3 gives the calculations and the design seismic force for the entire building respectively. And Table 2 shows Storey Deflection and Storey Drift and as per formulae in manual section.

Table 1: Lateral Load Distribution with Height by the Static Method:

Storey Level	Wi (kN)	Hi (m)	Wi x Hi^2/1000	Wi x Hi^2/ ∑ $WixHi^2$	Lateral forces on i^{th} level (kN)
4	3000	13.8	571.32	0.424	595.29
3	4200	10.6	471.91	0.350	491.40
2	4200	7.4	229.99	0.171	240.08
1	4200	4.2	74.08	0.055	77.22
			1347.3	**1.0**	**1404**

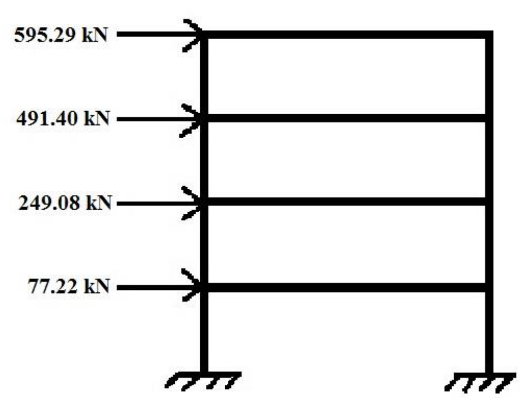

Fig. 3: Line Diagram of Lateral Load Distribution

Table 2: Deflection and storey drift calculated as per formulae given in manual method section

Storey level	Deflection of Structure without BRB (m)	Storey Drift of Structure without BRB	Deflection of Structure with BRB (m)	Storey Drift of Structure with BRB	Limiting Storey Drift as per IS Code
4	0.000143	0.0066355	0.018356	0.00023144	0.0552
3	0.0042779	0.0030828	0.015162	0.00073327	0.0424
2	0.036955	0.00055877	0.0073894	0.0006769	0.0296
1	0.12852	3.4048e-05	0.0023804	0.00056675	0.0168

Area of core for Buckling Restrained Brace is designed as per maximum lateral force calculated on structure. A = Axial Force/Stress = 415 × cos 45 / 415 × 10^{-3} = 1014.4043 mm^2

Stiffness of Core Bracing

K_{brace} = ((1014.4043) (210×10^6) (cos2 45) / 4.36 × 10^6)
= 24282.284 kN/m

Stiffness of column

K_{col} = (2×12×210×10^6× 5300 ×10^{-8})/(3.2^3)
=8151.8555 kN/m

Therefore the total stiffness of modified structure is summation of stiffness of bracing and column

I.e. $K_{total} = K_{brace} + K_{column}$

=32434.1394 kN/m

The final deflection of structure is shown in table where in we can see the decrease in deflection and storey drift which means results of proposed design and procedure are correct.

3.6. FORMULATION ON MATLAB

MATLAB being a matrix-based language allowing the most natural expression of computational mathematics, a code is formulated to acquire data which is then calculated to obtain necessary output.

At first, data such as Height of Story, Seismic Zone, Importance Factor, Response Reduction Factor, Design Acceleration Coefficient, Modulus of elasticity, Moment of Inertia are acquired.

The data is then computed using the set of expression mentioned above in the methodology section. For that, we designate each input data by set of letters or set of symbols which will help us to pick and recognize the data with ease.

The MATLAB then computes the data according to codal formula provided and then the final output of required data is generated and displayed.

The output file generated on MATLAB includes the result with its limiting / restricting value to verify if it is correct or not. The same load conditions were applied to the structure analyzed on ETABS and the results were verified on that too. The results of ETABS also matched by which we can conclude that code is correct.

4. FACTORS AFFECTING BRB

4.1. STIFFNESS

Amount of deflection occurred under applied load is measured in terms of stiffness. Stiffness is the extent to which an object resists deformation in response to an applied force. The stiffness is defined as:

$$k = F/\delta \qquad - [7]$$

Where, F is the force on the body and δ is the displacement produced by the force.

The elastic modulus is not the same as the stiffness of a material component made from that material. Elastic modulus is a property of the constituent material; stiffness is a property of a structure or component of a structure, and hence it is dependent upon various physical dimensions that describe that component. That is, the modulus is an intensive property of the material; stiffness, on the other hand, is an extensive property of the solid body that is dependent on the material and its shape and boundary conditions.

$$k = AE/L \qquad - [8]$$

Which in case of BRB is:

$$k_{brace} = AE/L\cos^2\Theta \qquad - [9]$$

Where,
A is the cross-sectional area,
E is the elastic modulus (or Young's modulus),
L is the length of the element

Therefore, it is seen that stiffness is directly proportional to modulus of elasticity and inversely proportional to deflection. So, as the modulus of elasticity is increased, the stiffness of member increases but which results in decrease in deflection of structural member.

$$k = F/\delta = AE/L\cos^2\Theta \qquad \text{- [10]}$$

Modulus of Elasticity of some materials are given in Table 3

Table 3: Modulus of Elasticity of some materials

Material	Modulus of Elasticity (N/m2 or GPa)
Rubber	0.01 - 0.1
Aluminum	69
Concrete	17
Diamond	1220
Glass	50
Iron	210
Stainless Steel	180
Structural Steel	200

For core material, average Modulus of Elasticity is taken and also economic considerations are taken care of. If rubber is considered, it will deflect the structure too much. On the other hand if diamond is taken into account with high modulus of elasticity, it will be as such very costly along with which it will make structure too stiff (actually brittle), and will prove failure under relatively small deformation demands.

4.2. MATERIAL OF CORE

While selecting a material, the material properties must satisfy the operating conditions and function of the component or the structure being designed. The properties, which the choice of material, can be summarized under the following categories:

- Mechanical Properties: e.g. stiffness, strength, ductility, hardness, toughness, etc.
- Physical Properties: e.g. density, electrical conductivity, thermal conductivity, etc.
- Chemical Properties: e.g. corrosion resistance in various environments.

The functional requirements of a product are directly determined by the mechanical, physical and chemical properties. However, for the product to be technically manufactured, the material must have the right manufacturing properties. For example, a forged component requires a material with sufficient flow ability without cracking during forging, a cast component requires a material that flows readily in the molten state and fills the mould and on solidification does not produce undesirable pores and cracks.

Therefore we need to compare these parameters before choosing the material that best suits us for our application, in our case the core of bracing. After comparing many different material the main materials that are controversial are stainless steel and aluminum.

Aluminum and Stainless Steel looks similar, but they are actually quite different. Major differences that should be kept in mind when deciding which type of metal to use are:

- Strength to weight ratio. Aluminum is typically not as strong as steel, but it is also almost one third of the weight. This is the main reason why aircraft are made from Aluminum but structural components are made of stainless steel.

- Welding: Stainless is relatively easy to weld, while Aluminum can be difficult.

- Strength: Stainless steel is stronger than Aluminum (provided weight is not a consideration).

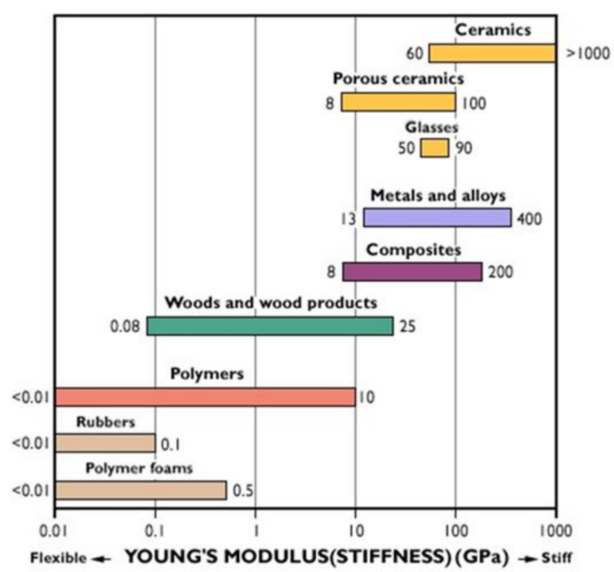

Fig 4: Young's Modulus of Different Materials

- Young's modulus: Comparing it for both materials, the modulus of elasticity of stainless steel is almost 3 times that of aluminum i.e. the stainless steel provides better resistance to material to elastic deformation under load. Values of Young's Modulus for different materials are given in Fig. 4

- Corrosion: Stainless steel is made up of iron, chromium, nickel, manganese and copper. The chromium is added as an agent to provide corrosion resistance. Also, because it is non-porous the resistance to corrosion is increased. When aluminum is oxidized, its surface will turn white and will sometimes pit. In some extreme acidic or base environments, Aluminum may corrode rapidly with catastrophic results.

- Electrical Conductivity: Stainless steel is a really poor conductor compared to most metals. Aluminum is a very good conductor of electricity.

- Thermal properties. Stainless can be used at much higher temperatures than Aluminum which can become very soft above about 400 degrees.

4.3. CORE MEMBER LENGTH

Length of core member is directly influenced by slenderness ratio of member. Slenderness ratio refers to the ratio of the effective length of a column to the least radius of gyration of its cross section. Slenderness ratio reflects how likely the chances of the column to fail by buckling are. The maximum effective slenderness ratio should be as per IS 800: 2007, Table 3. Slenderness ratio

$$\lambda = L_e / r = KL / r \qquad \text{- [11]}$$

Where,
L = actual length of the column member
L_e = KL, effective length
r = radius of gyration

As the length of core increases, the maximum effective slenderness ratio the axial load bearing capacity of member starts decreasing. The change in member length affects majorly to the buckling pattern of the core member.

Looking forward to stiffness, when the length increases beyond the allowable slenderness ratio, it starts decreasing the stiffness of member which will initiate buckling and lead to higher deformation of Storey.

Any imperfection in length of bracing will lead to initial imperfection on Buckling Restrained Braces. Therefore performance tends to be impacted widely.

4.4. CORE WIDTH TO THICKNESS RATIO

The cross-section area of core is determined by axial load to be resisted by the member. Width to thickness is determined after section area is determined. The ratio of width to thickness is to be maintained properly to resist the maximum load with minimum steel consumption.

While keeping the cross-section area constant, the smaller width to thickness ratio results in larger stress on external restraining member whereas greater width to thickness ratio results in lesser stress on external restraining member. That is because, although the restraining ratio of BRB is consistent, the core member with a smaller width-to thickness ratio leads to smaller section modules of external member when the external members' stiffness is the same.

Therefore, when the core contact force effect is almost the same, the stiffness requirement for the BRB with a small core width-to thickness ratio becomes stricter(Jiang, Guo, Zhang, & Zhang, 2015).

As per IS 800: 2007 the performance of element widely depends on width to thickness ratio. According to the ratio of width to thickness, the class of section is classified whether the element is Plastic (Class 1), Compact (Class 2), Semi-compact (Class 3), or Slender (Class 4). The behavior of element widely depends on the type of category in which it falls.

But, while keeping area constant and comparing width to thickness ratio: the element with lower width to thickness will tend to resist more axial force than the one with higher ratio as the thickness will provide more resistance against buckling of element.

4.5. BRACING INCLINATION ANGLE

In a braced multi-storey building, the planes of vertical bracing are usually provided by diagonal bracing between two lines of columns, as shown in the Fig. 5. Either single diagonals are provided, as shown, in which case they must be designed for either tension or compression, or crossed diagonals are provided, in which case slender bracing members carrying only tension may be provided.

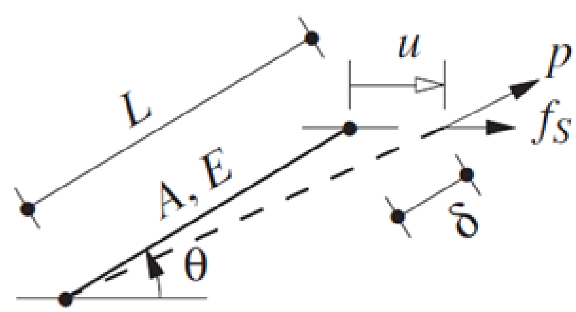

Fig. 5: Bracing Angle Detailing

Forces in the individual members of the bracing system are determined for the appropriate combinations of force actions. The vertical bracing are designed to resist the forces due to the following:

- Wind loads

- Equivalent horizontal forces, representing the effect of initial imperfections

- Second order effects due to sway

Table 4 below gives an indication of how stiffness varies with bracing layout for a constant size of bracing cross section.

Table 4: Variation of Stiffness with Inclination

Case Study	Bracing Length	Angle of Bracing	Ratio of Stiffness(Compared to Bracing at 45°)
1	2h	26°	0.80
2	1.5h	34°	0.91
3	h	45°	1.00
4	0.75h	53°	0.96
5	0.5h	63°	0.82

Where possible, bracing members inclined at approximately 45° are recommended because it not only offers an efficient system compare with other systems but also strong and compact connections between bracing member and beam-column juncture will be achieved

5. RESULTS

On comparing the G+4 building based on equivalent static force method, it is observed that the values are identical for both the outputs of MATLAB coding and ETABS analysis.

Also, the results of lateral forces, storey displacement and storey drift matches with the solution of the problem statement solved using manual method.

The output of MATLAB given in Fig.6 (a) and Fig.6 (b) which is been verified with the results of ETABS is given in Fig 7.

As it is seen that the output on MATLAB gives same results as on ETABS, it is observed that the Manual Method of design of bracing is verified by MATLAB coding. Hence, the MATLAB coding based on these formulae can be used for assessing Influencing Design Parameters of Buckling Restrained Brace on its Performance.

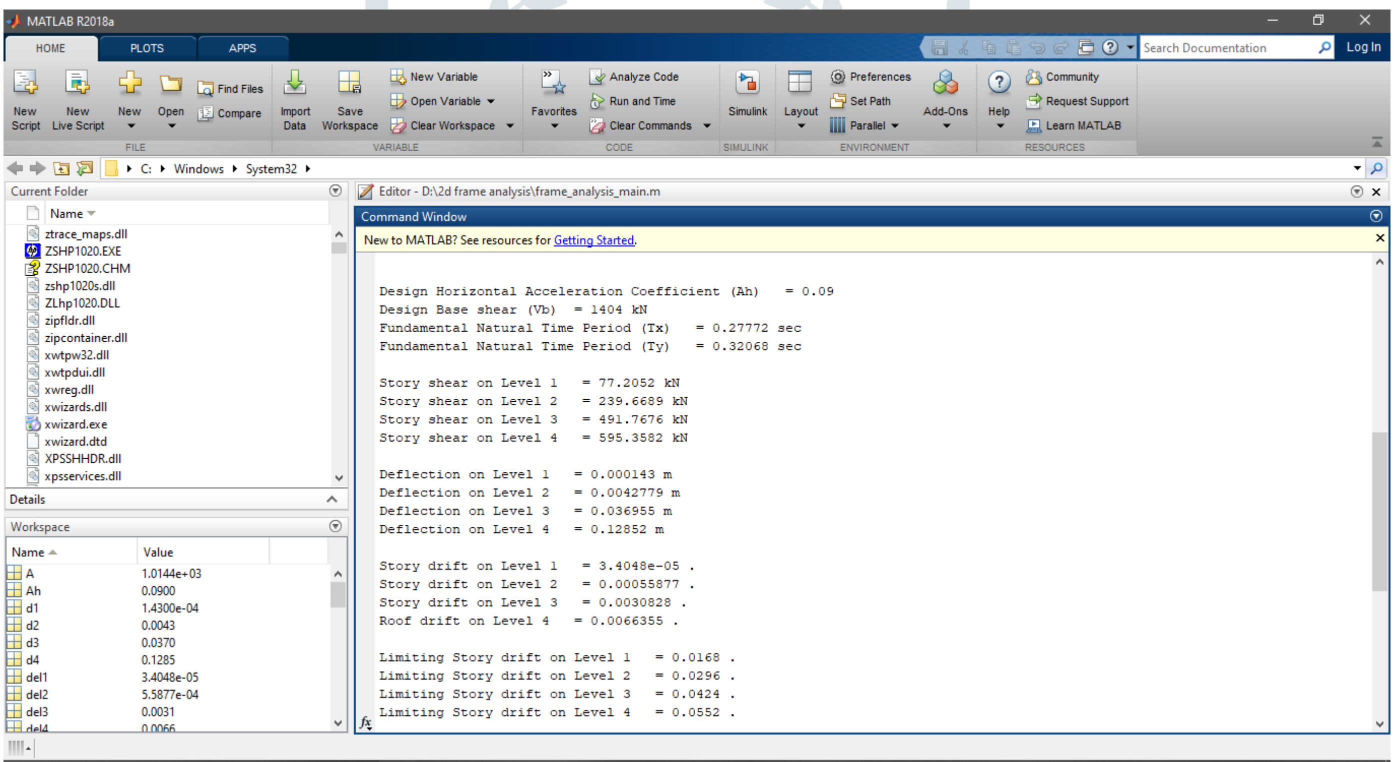

Fig. 6(a): Output on MATLAB

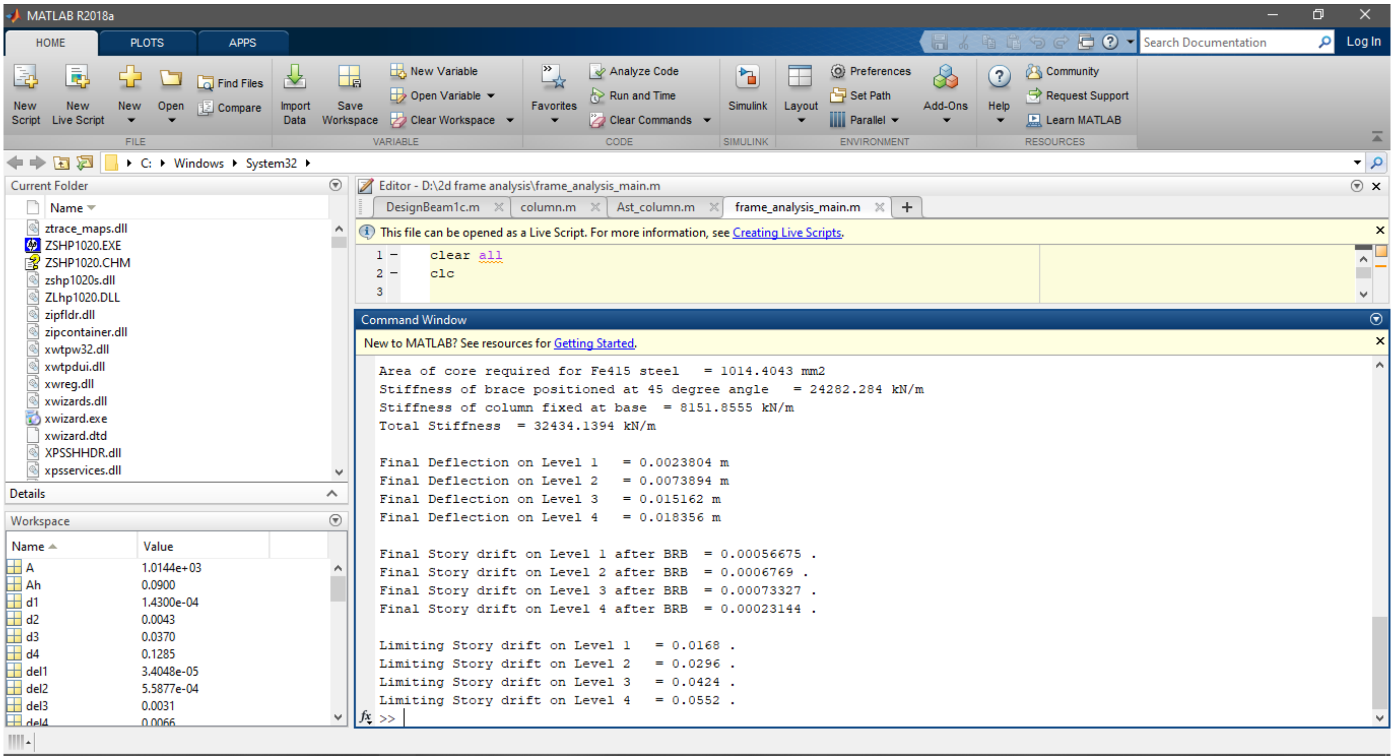

Fig. 6(b): Output on MATLAB

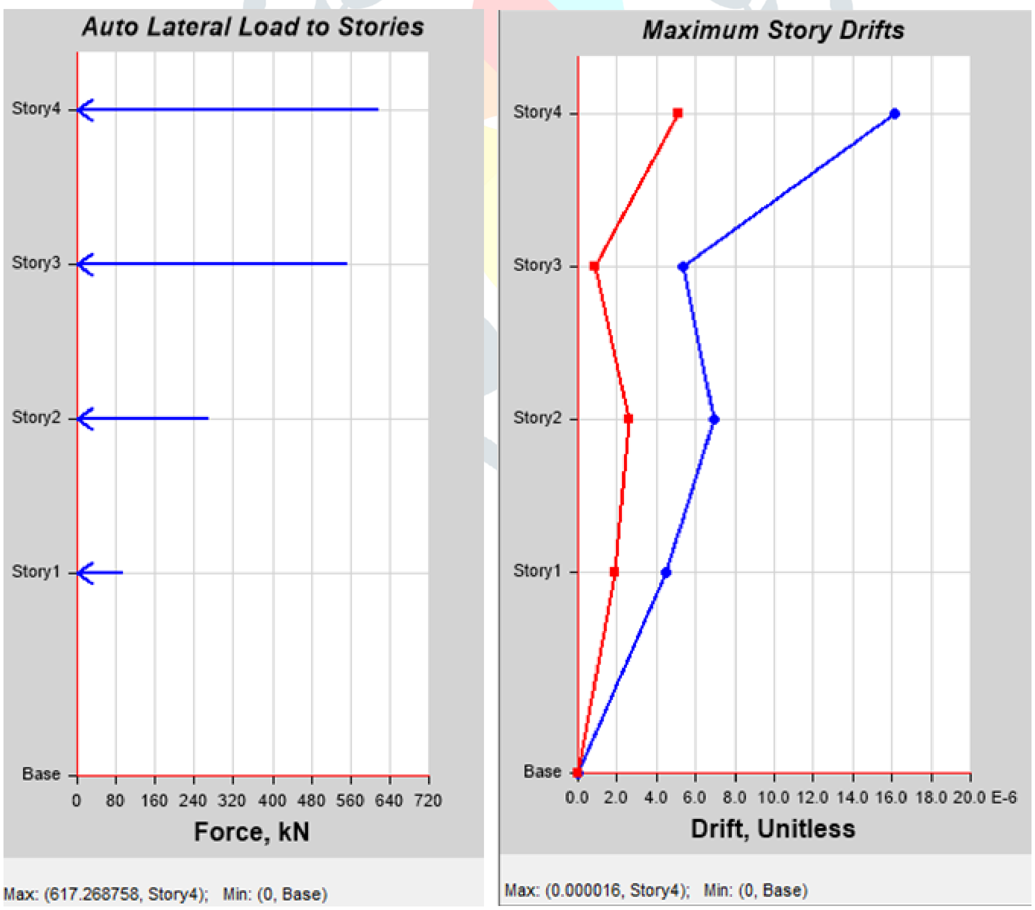

Fig. 7: Output on ETABS – Lateral Forces and Storey Drift

6. CONCLUSIONS

This paper has provided a discussion on the key features of the most commonly utilized passive energy dissipation devices and an explanation of the current code-based approach to analysis and design of structures incorporating such devices.

These analysis results provide the following key insights into seismic behavior, collapse performance and potential design enhancements for BRB.

The influences of BRB parameters on its performance are investigated. Following conclusions are obtained in this study:

1. Stiffness is directly proportional to modulus of elasticity and inversely proportional to deflection. So as we increase the modulus of elasticity, stiffness of the member increases but which results in decrease in deflection of structural member.

2. Steel is widely used as structural component due to high strength to weight ratio, modulus of elasticity, strength and corrosion resistance property.

3. As the length of core increases than the maximum effective slenderness ratio the axial load bearing capacity of member starts decreasing. The change in member length affects majorly to the buckling pattern of the core member.

4. While keeping area constant and comparing width to thickness ratio: the element with lower width to thickness will tend to resist more axial force than the one with higher ratio as the thickness will provide more resistance against buckling of element.

5. Where possible, bracing members inclined at approximately 45° are recommended because it not only offers an efficient system compare with other systems but also strong and compact connections between bracing member and beam-column juncture will be achieved.

Simple MATLAB codes are developed to do the complicate computation based on the correlations under different boundary conditions. Also this code provides an efficient way for experimental data analysis by avoiding duplicate work.

Also, the proposed procedure is an efficient and straightforward design procedure to design BRB. The output results that were computed on MATLAB were verified by numerical example and also by structural designing software ETABS. And we got verified results. Hence, was proved to be used for the analysis of high-rise buildings.

7. REFERENCES

[1] ASCE/SEI 705. 2006. Minimum Design Loads for Building and Other Structures. Reston, VI: American Society of Civil Engineers.

[2] IS: 800. 2007. General Construction in SteelCode of Practice. NewDelhi: B.I.S.

[3] IS: 875 (Part I, II , III). 1987. Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures. New-Delhi: B.I.S.

[4] IS: 1893 (Part I). 2002. Criteria for Earthquake Resistant Design of Str+uctures. NewDelhi: B.I.S..

[5] Naeim, Farzad, ed., *The Seismic Design Handbook* (Boston, MA: Springer US, 2001) <https://doi.org/10.1007/978-1-4615-1693-4>

[6] Ahmed, Munir, Shahzadi Tayyaba, and Muhammad Waseem Ashraf, 'Effect of Buckling Restrained Braces Locations on Seismic Responses of High-Rise RC Core Wall Buildings', *Shock and Vibration*, 2016 (2016) <https://doi.org/10.1155/2016/6808137>

[7] Andrews, Blake M., Larry A. Fahnestock, and Junho Song, 'Ductility Capacity Models for Buckling-Restrained Braces', *Journal of Constructional Steel Research*, 65.8–9 (2009), 1712–20 <https://doi.org/10.1016/j.jcsr.2009.02.007>

[8] FEMA P695, 'Quantification of Building Seismic Performance Factors FEMA P695', *Fema P695*, June, 2009, 421

[9] Filiatrault, A., and S. Cherry, 'Parameters Influencing the Design of Friction Damped Structures', *Canadian Journal of Civil Engineering*, 16.5 (2010), 753–66 <https://doi.org/10.1139/l89-110>

[10] Guo, Yan Lin, Peng Peng Fu, Peng Zhou, and Jing Zhong Tong, 'Elastic Buckling and Load Resistance of a Single Cross-Arm Pre-Tensioned Cable Stayed Buckling-Restrained Brace', *Engineering Structures*, 126 (2016), 516–30 <https://doi.org/10.1016/j.engstruct.2016.08.013>

[11] Heysami, Alireza, 'Types of Dampers and Their Seismic Performance During an Earthquake', *Current World Environment*, 10.Special-Issue1 (2015), 1002–15 <https://doi.org/10.12944/cwe.10.special-issue1.119>

[12] Isolation, Seismic, and Energy Dissipation, 'Seismic Isolation and Energy Dissipation (Systematic Rehabilitation)', *Rehabilitation*, 1–28

[13] Iwata, Mamoru, 'Applications-Design of Buckling Restrained Braces in Japan', *13 Th World Conference on Earthquake Engineering*, 3208, 2004

[14] Jiang, Ziqin, Yanlin Guo, Bohao Zhang, and Xuqiao Zhang, 'Influence of Design Parameters of Buckling-Restrained Brace on Its Performance', *Journal of Constructional Steel Research*, 105 (2015), 139–50 <https://doi.org/10.1016/j.jcsr.2014.10.024>

[15] Mayes, Ronald L., ‘Interstory Drift Design and Damage Control Issues’, *The Structural Design of Tall Buildings*, 4.1 (1995), 15–25 <https://doi.org/10.1002/tal.4320040104>

[16] Rahnavard, Rohola, Mohammad Naghavi, Maryam Aboudi, and Mohamed Suleiman, ‘Investigating Modeling Approaches of Buckling-Restrained Braces under Cyclic Loads’, *Case Studies in Construction Materials*, 8.December 2017 (2018), 476–88 <https://doi.org/10.1016/j.cscm.2018.04.002>

[17] Sabelli, Rafael, and Ian Aiken, ‘U . S . Building-Code Provisions for Buckling-Restrained Braced Frames : Basis and Development’, *13 Th World Conference on Earthquake Engineering*, 1828, 2004

[18] Silwal, Baikuntha, Osman E. Ozbulut, and Robert J. Michael, ‘Seismic Collapse Evaluation of Steel Moment Resisting Frames with Superelastic Viscous Damper’, *Journal of Constructional Steel Research*, 126 (2016), 26–36 <https://doi.org/10.1016/j.jcsr.2016.07.002>

[19] Surendran, Nayana, and Asha Varma P, ‘Buckling Restrained Braces (BRB) – A Review’, *International Journal of Engineering and Technology(IRJET)*, 4.3 (2017), 2320–24 <https://irjet.net/archives/V4/i3/IRJET-V4I3603.pdf>

[20] Symans, M D, A M Asce, F A Charney, F Asce, ; A S Whittaker, M Asce, and others, ‘Energy Dissipation Systems for Seismic Applications: Current Practice and Recent Developments’, *Journal of Structural Engineering*, 134.1 (2008), 3–21 <https://doi.org/10.1061/ASCE0733-94452008134:13>

[21] Takeuchi, Toru, ‘Buckling-Restrained Brace: History, Design and Applications’, *Key Engineering Materials*, 763 (2018), 50–60 <https://doi.org/10.4028/www.scientific.net/kem.763.50>

[22] Tremblay, R., L. Poncet, P. Bolduc, R. Neville, and R. DeVall, ‘Testing and Design of Buckling Restrained Braces for Canadian Application’, *13th World Conference on Earthquake Engineering*, 2893, 2004

[23] Usami, Tsutomu, Chunlin Wang, and Jyunki Funayama, ‘Low-Cycle Fatigue Tests of a Type of Buckling Restrained Braces’, *Procedia Engineering*, 14 (2011), 956–64 <https://doi.org/10.1016/j.proeng.2011.07.120>

[24] Zaruma, Santiago, and Larry A. Fahnestock, ‘Assessment of Design Parameters Influencing Seismic Collapse Performance of Buckling-Restrained Braced Frames’, *Soil Dynamics and Earthquake Engineering*, 113.February (2018), 35–46 <https://doi.org/10.1016/j.soildyn.2018.05.021>