International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Dynamic Optimum Performance of Buckling Restrained Braces in Multi-storey Building using FEA

Sneha CS[1], Christin Pious[2]
[1]PG Student, Department of Civil Engineering, Ilahia College of Engineering & Technology, Mulavoor, Kerala, India-686673
[2]Assistant Professor, Department of Civil Engineering, Ilahia College of Engineering & Technology, Mulavoor, Kerala, India-686673
Email address: [1]snehacsnambiar@gmail.com, [2]christinpious2010@gmail.com

***Abstract*— *Civil Engineering structures are subjected to enormous cyclic forces during a seismic event. Steel bracings are the common type which mainly used to resist the lateral loading acting during a seismic activity. The conventional bracing system fails due to the degradation of brace strength under compression that occurs due to the buckling of the brace. Hence, Buckling Restrained Brace (BRB) were invented in the 80's, which have the ability to yield in tension and compression without buckling, thus obtaining a stable hysteresis loop. This study deals with the Non-linear cyclic analysis of all-steel BRBs with different models and a comparative study with concrete filled BRB and all-steel BRB using ANSYS Workbench 16.1. Non-linear time history responses of the multi-storey buildings with all steel BRB and conventional brace were also assessed in this study using ETABS. The case study results shows the effectiveness of Buckling Restrained Braces with different geometries and also indicates the performance of BRB in different geometries and also indicates the performance of BRB in different storey buildings.*

***Keywords*— *BRB core, cyclic loading, drift, energy dissipation, hysteresis curve.*

I. Introduction

Earthquake is a phenomenon generally considered in the context of volcanic activity. An earthquake is the shaking of the earth, caused by the sudden movement of the Earth's tectonic plates. When a building is subjected to seismic waves, large amount of energy is distributed within in the building and the level of damage sustained by the building depends on the dissipation of this energy. A braced frame is a structural system which are very common form of construction, designed to resist lateral forces such as wind and earthquake forces. The main drawback of conventional bracing system is the degradation of brace strength under compression due to buckling of the brace which leads to the invention of Buckling Restrained Braces (BRB).

A BRB is a structural brace in a building, designed to allow the building to withstand cyclical lateral loadings, typically earthquake induced loadings. The concept of BRB was developed in Japan by Nippon Steel at the end of the 1980s and was known by its trademark name of Unbonded Brace. It was first installed in the United States in 1999, in the Plant & Environmental Sciences Building in U. C. Davis. The main component of BRBs consists of a steel core, which is encased by concrete AND a special coating like grease or any unbonded material is applied to the brace to prevent it from bonding to the concrete. The main load resisting element in BRB is the steel core, and the overall buckling of the core steel is resisted by the restraining mechanism provided by the outer casing. The conventional configuration of BRB is the concrete filled BRB which suffers from the heavy weight and curing problem of the mortar core. To overcome these difficulties, conventional BRB can be replaced with all- steel BRB. The only difference is that the unbounding agent used for coating around the core, is eliminated in this type.

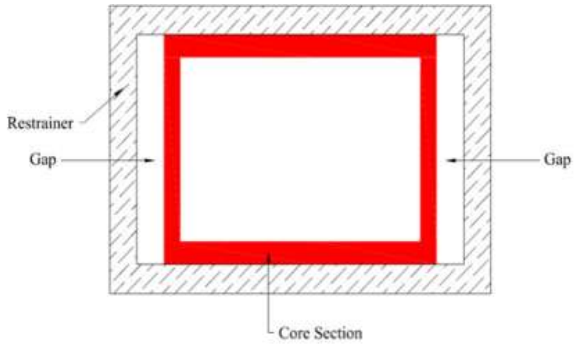


Fig. 1. Typical cross-section of all steel BRB.

II. Scope and Objectives of the Study

Seismic stability of Bracings is an important consideration. Conventional braced frame system behaves less effectively when it is subjected to a seismic force. The characteristic feature of stable energy dissipation without buckling is effective in resisting lateral loads. So the study of Buckling Restrained Braces is necessary for the safety of building stability. The characteristic feature of stable energy dissipation without buckling is effective in resisting lateral loads. The main objectives of this study are follows.

- Study of Finite element (FE) models of steel BRBs with varied geometries subjected to cyclic analysis.
- Identification of satisfactory brace geometries
- Study of performance of BRB in multi-storey buildings compared to conventional bracings.

III. Finite Element Modelling of All Steel brb

A. Geometry

Three-dimensional models were developed to demonstrate the behaviour properly. The models included the core plate

Sneha CS and Christin Pious, "Dynamic optimum performance of buckling restrained braces in multi-storey building using FEA," *International Research Journal of Advanced Engineering and Science*, Volume 3, Issue 2, pp. 137-142, 2018.

and a tube as the restrainer. The dimensions and material properties considered in this thesis are fixed with reference to Indian Standards. The various types of Buckling Restrained Braces that are selected for this thesis can be divided mainly in to three category as follows.

- *Air gap parametric study*: In this study, air gap between core and restrainer is changed as 5mm, 10mm and 15mm respectively. The air gaps were only included in the side directions of the core plate so that buckling occurs in more critical out-of-plane direction.
- *Core section parametric study:* In this study, I section, channel section, plus shape (criss core) and a rectangular section is used.
- *Core material parametric study:* The material of the core section is changed to stainless steel, aluminium and titanium by making the material of the restrainer as steel as constant.
- A comparative study is carried out between conventional BRB and all-steel BRB.

The restrainer is made up of 10mm thick plates welded to a rectangular hollow section and is made constant throughout all sections (140mm×100mm×10mm). The length of the specimens, L, was assumed to be 2000 mm and from the experimental studies made by *Korzekwa et al* the BRB was titled to 50^o with respect to horizontal to ensure bracing set up. The core plate is made up of plate sections with respect of IS 1730-1989.The area of core section is taken as 2600mm^2 so as to make an effective comparison while studying their behaviour. A friction coefficient of 0.1 was used to resemble a sliding greasy surface, and hard contact in the normal behaviour. The same frictional coefficient was considered by *Chou et al*, as the friction coefficient is the factor that governs the potentiality of global buckling in the BRB due to the tension forces transmitted to the restrainer. The value of displacement that corresponds to the yielding of the core (Δy) is taken as 4mm based on the material characteristics as studied by *Hosseinzadeh* and *Mohebi*. The axial deformation (Δbm) of the brace that adopted as 20mm respectively. The boundary condition for all model as fixed at one end and free at other end. Axial displacements were imposed to the other end for all models, following the cyclic quasi-static protocol suggested by American Institute of Steel Construction (AISC) seismic provisions for BRBs as one cycle at ±0.5Δbm, ±Δbm, ±1.5Δbm, ±2Δbm, and ±2.5Δbm respectively.

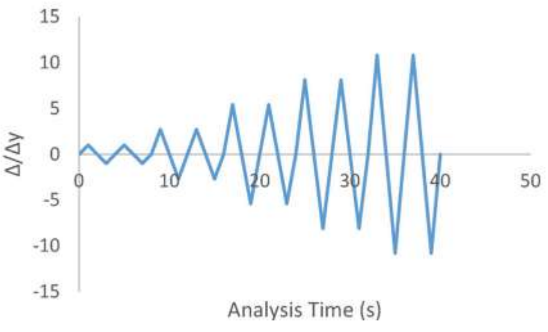


Fig. 2. Loading Protocol of the BRB models according to AISC Seismic Provisions.

The core plate's yield load, Py, and the buckling load of the restrainer Pe [or the Euler's buckling load] are calculated from the formulae mentioned below. If EI is the flexural rigidity of the cross section of the core and L is the length of the core,

P_y = yield stress × cross section area of the core (1)

$$Pe = \frac{\pi^2 EI}{L^2} \quad (2)$$

B. Material Properties

The core plate and the restrainer were made up of mild-steel material with a yield stress of F_y = 240 MPa, Poisson's ratio of 0.3 and Young's modulus of 200 GPa. Non-linear isotropic kinematic combined hardening rule was used with the initial kinematic hardening modulus C and the rate factor γ as 8 GPa and 75, respectively as given by Tremblay and *Korzekwa et al*. To prevent the global buckling mode of braces, the P_e/P_y ratio for all the specimens was selected to be large than 1.57 where, P_e is Euler buckling load and P_y yield strength of the core respectively. Equation (2) shows the Euler buckling formula from which the buckling load of the restrainer, P_e can be calculated.

C. Modelling and Analysis

The BRB sections are modelled using ANSYS Workbench 16.1. A surface-to-surface contact was used to explain the interaction between the core plate and restrainer. A friction coefficient of 0.1 was used to resemble a sliding greasy surface, and hard contact in the normal behaviour. The same frictional coefficient was considered by *Chou et al,* as the friction coefficient is the factor that governs the potentiality of global buckling in the BRB due to the tension forces transmitted to the restrainer. Fig. 3 shows the cross sections of BRBs used for the study. Static cyclic analyses were performed using ANSYS software package. The material properties were assigned, support and loading conditions were provided.

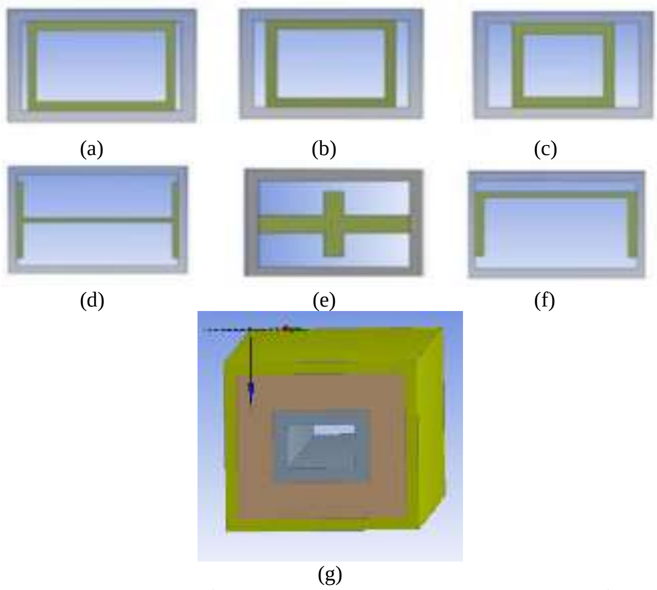


Fig. 3. Cross sections of all-steel BRBs – varying air gaps & shapes of core where (a) 5mm Air gap (b) 10mm Air gap (c) 20mm Air gap (d) I shape core (e) Plus shape core (f) Channel shape core (g) Concrete filled BRB.

Every model was meshed using a *20* noded Hexahedron element [Solid 186] to achieve better accuracy in nonlinear analysis. A damping coefficient of 2.0E-4 was applied to the model to avoid convergence problems and a medium fine mesh as in Figure 4, was however used for the restrainer, as most of the part was expected to remain elastic. The proposed BRBs where thus subjected to Non-Linear cyclic analysis as in Fig. 4 and the total deformation in X axis is calculated. Also a comparison is carried out between conventional BRB and all steel BRB. The load – deflection curves where computed for each and every model to obtain the hysteresis loop. Maximum principal stress and force reaction values were noted.

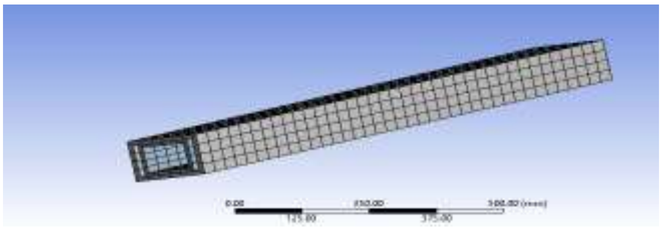


Fig. 4. Meshing on the restrainer and core.

D. Results and Discussions

After the analysis of the structures, the results are noted. The maximum principal stress values and force reaction values of the models are shown in table I and II respectively. The fig. 6 shows the hysteretic and bilinear curves of the proposed BRBs.

- The hysteresis loop of each and every model is obtained by plotting the lateral load versus lateral deformation as in fig. 6. These bilinear curves are obtained by plotting P/Py along Y axis and Δ/ Δy along X axis.
- In the case of 5mm Air Gap BRB, the load carrying capacity of core is less than the other two BRBs (Refer Table II, Air gap study). There is a reduction in Force Reaction about 3.69% than 10mm BRB. The value of Maximum Principal Stress of the core is higher than the other two. Hence simply we can say that the 5mm Air Gap BRB section is weakened.
- In the case of 10mm Air Gap BRB, the total force reaction value is 667.42kN (Refer Table II, Air gap study) which is higher than the other two BRB. The core has minimum stress than the 5mm Air Gap (Refer Table I, Air gap study).There is about 29.96% reduction in the Stress value comparing to 5mm BRB.
- In the case of 20mm Air Gap, there is a reduction in the force reaction about 3.27% than 10mm BRB. Also there is a reduction of 31.09% in Maximum Principal Stress than 5mm BRB.
- For the comparison, 10mm airgap BRB is selected. In the case of concrete filled BRB, the value of Force reaction is more than BRB without concrete fill.
- There is an increase of maximum principal stress at core about 35.47% in Concrete filled BRB than the 10mm air gap BRB.
- Buckling Restrained Braces without concrete filling is more effective than the Buckling Restrained Braces with concrete filling. The stress value of concrete filled BRB is more and hence the failure will be very fast. Also the weight of the BRB with concrete filled is more which increases the total mass of the building.
- In the case of core section parametric study, Criss core section have least stress distribution (Refer Table I, core section study). I core section have higher stress value and lower force reaction among the other two
- .From the shape behaviour of core section, channel section doesn't complete its full load cycles due to its cross-section, it can take only up to 70% (17 steps).
- In the core material parametric study, the maximum principal stress at core is more for Titanium Core BRB. Aluminium has the least value of Maximum principal stress among the other two. Titanium has the higher rate of Force reaction and Aluminium has the lower value of Force reaction.

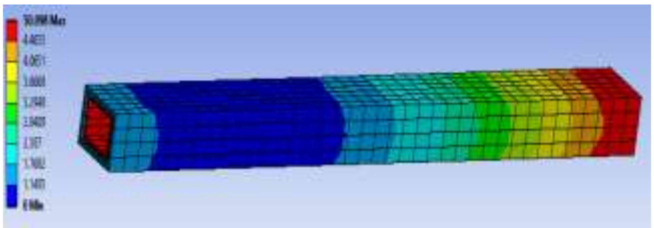


Fig. 5. Total deformation.

TABLE I. Maximum principal stress.

Type of Parametric Study	BRB	Principal Stress (MPa)	
		Restrainer	Core
Air gap Study	5mm	422.14	635.33
	10mm	425.34	445
	20mm	422.30	437.78
Comparative Study	Conventional	511.07	689.62
Core Section Study	I section	500.91	462.9
	+ section	497.66	325.62
	C section	474.65	731.03
Core material Study	Aluminium	259.65	348.81
	Titanium	437.47	1537.3
	Stainless Steel	424.79	988.33

TABLE II. Force reaction.

Type of Parametric Study	BRB	Force Reaction (kN)	
		X axis	Total
Air gap Study	5mm	494.16	642.76
	10mm	511.86	667.42
	20mm	496.10	645.53
Comparative Study	Conventional	546.74	712.74
Core Section Study	I section	476.45	620.35
	+ section	508.15	665.80
	C section	626.92	651.79
Core material Study	Aluminium	733.12	953.52
	Titanium	2086.10	2811.5
	Stainless Steel	1157.90	1503.10

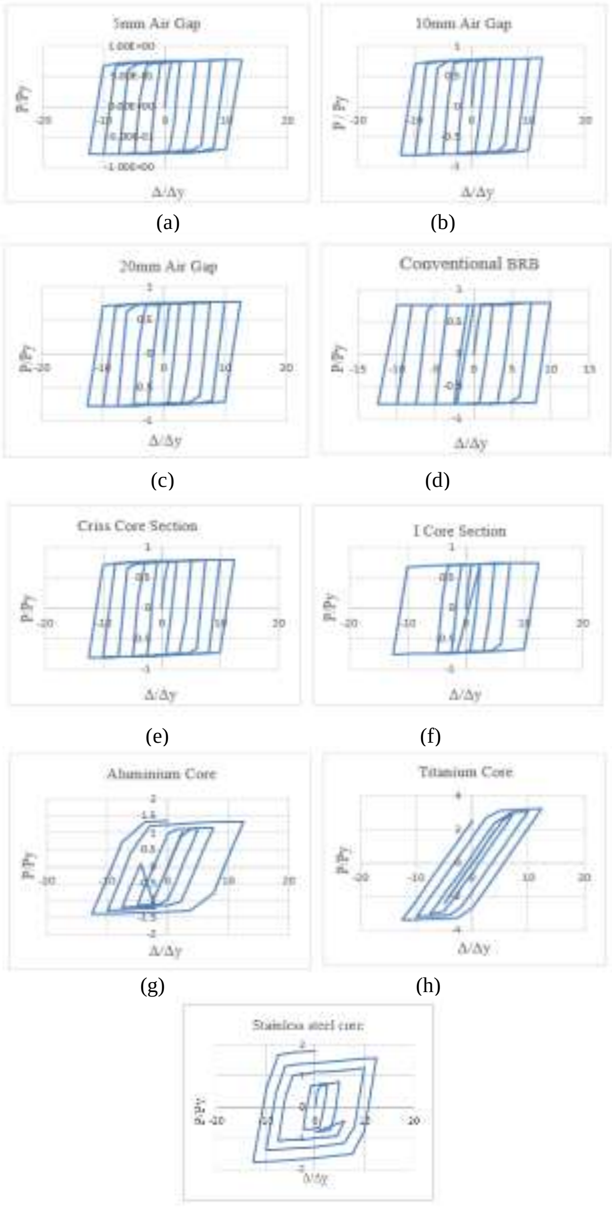


Fig. 6. Hysteretic and bilinear curves of the proposed BRBs.

IV. Performance of BRB in Multi-Storey Buildings

A. Geometry

The nonlinear static analysis is carried out for assessing the performance of all-steel BRBs to evaluate their effect in resisting seismic lateral forces. The study has done on mainly three different storey such as 5, 10 and 15 storey buildings. The buildings are provided with conventional bracings and Buckling Restrained Braces having 10mm Air Gap. The buildings have three bays in X and Y directions with the plan dimension (15 m × 15 m) respectively. The building is kept symmetric in both mutually perpendicular directions in plan to avoid torsional effects. The orientation and size of columns and beams are kept same throughout the height of the structure. Fixed support is provided at the base. The building is considered to be located in seismic zone V. The geometric and material properties are given in the Table III. The earthquake parameter is selected from PEER (Pacific Earthquake Engineering Research Center) Records. The details of earthquake is given in Table IV and the functional graph is shown in fig. 7.

TABLE III. Geometric properties of the model.

Grade of Concrete	M_{30}
Grade of Steel	Fe_{415}
Floor Height	3000mm
Slab Thickness	125mm
Column Dimension	300mm x 450mm
Beam Dimension	300mm x 400mm
Live Load	3.5kN/m^2
Floor Finish	1kN/m^2
Seismic Zone	V
Zone Factor	0.36
Importance Factor	1
Response Reduction Factor	5

TABLE II. Earthquake parameters.

Record Sequence Number	6
EQID	0006
Earthquake Name	Imperial Valley-02
Station Name	El Centro Array #9
Earthquake Magnitude	6.95

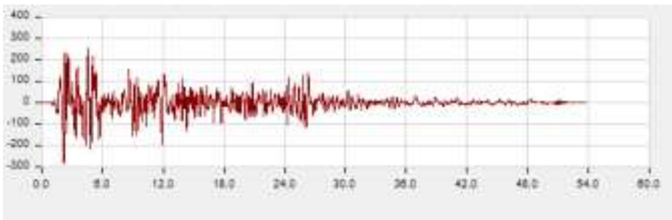


Fig. 7. Function graph of imperial valley-02.

B. Modelling

The 3D models are created using ETABS 2016 Software. Fixed support is provided for all models. Six models are created in which three models are provided with Conventional Bracings and other three with Buckling Restrained Braces. Plan and Elevation is shown in Fig. 8 and 9 respectively. The Earthquake details are selected from PEER Berkeley. The Loads and Support condition are assigned and Nonlinear Time History Analysis is carried out.

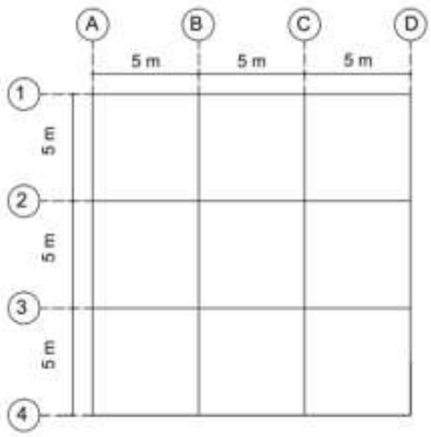
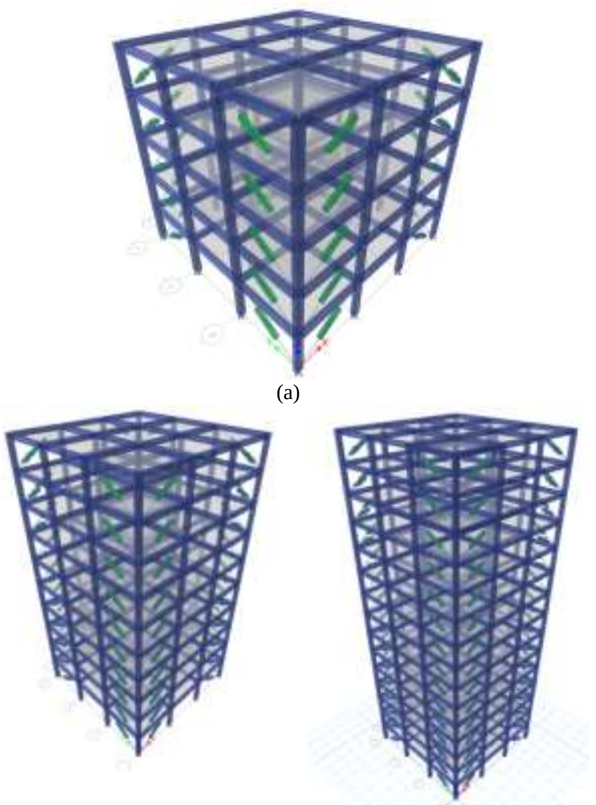


Fig. 8. Plan of the building.



(a)

(b) (c)

Fig. 9. 3D Model of Building (a) 5 Storey (b) 10 storey (c) 15 storey.

C. Results and Discussions

The Nonlinear Time History Analysis (NTHA) is carried out. Maximum storey displacement, Maximum storey shear and Storey drift values were find out and are given in Table V for 5 storey, Table VI for 10 storey and Table VII for 15 storey respectively. Also graphical representation of storey drift and maximum storey displacement is shown in fig. 10 and 11 respectively.

TABLE V. NTHA results for 5 storey building.

Type	Conventional	BRB
Maximum Storey Displacement (mm)	74.84	62.65
Maximum Storey Shear (kN)	4695.38	5105.10
Storey Drift	0.00781	0.00579

TABLE VI. NTHA results for 10 storey building.

Type	Conventional	BRB
Maximum Storey Displacement (mm)	124.11	117.64
Maximum Storey Shear (kN)	3620.31	4527.76
Storey Drift	0.00598	0.00499

TABLE VII. NTHA results for 15 storey building.

Type	Conventiona l	BRB
Maximum Storey Displacement (mm)	215.9	207.46
Maximum Storey Shear (kN)	4818.44	5817.23
Storey Drift	0.007748	0.0067

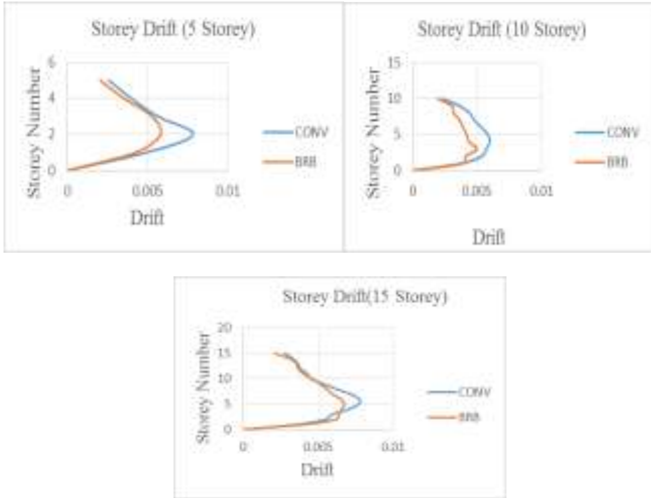


Fig. 10. Graphical representation of storey drift.

Fig.11. Graphical representation of Storey displacement Comparison.

- When the Conventional brace is replaced with BRB, the Storey displacement is decreased as 16.29% in 5 Storey building, 5.21% in 10 Storey building and 3.90% in 15 Storey building respectively.
- The Storey shear is increased after placing the BRB as 8.03% in 5 Storey building, 20.04% in 10 Storey building and 17.17% in 15 Storey building respectively.
- Also the Storey drift value is decreased with the percentage of 25.86% in 5 Storey building, 16.56% in 10 Storey building and 13.53% in 15 Storey building when BRB is used.

V. CONCLUSIONS

- Based on the past studies, the BRB can be effectively used as seismic resisting system. Among other conventional braced frame system Buckling Restrained Brace behaves more effectively when it is subjected to a seismic force.
- From the Shape parametric study, the best configuration is taken as the one which can have more Force reaction and also have less stress value. Hence it is obtained that 10mm Air Gap BRB is more efficient.
- Buckling Restrained Braces without concrete filling is more effective than the Buckling Restrained Braces with concrete filling.

- The stress value of concrete filled BRB is more and hence the failure will be very fast.
- From the Core section parametric study, Rectangular section and Criss core section have approximately equal stress and force reaction and both can be used effectively for further studies.
- From the Core material parametric study, all three materials such as Aluminium, Titanium and Stainless steel gives better results than the structural steel. By considering the economy, structural steel can be used for further studies.
- When the Conventional brace is replaced with BRB in multi-storey buildings, which leads to better performance when the buildings were subjected to Seismic waves.
- BRB can be effectively used in engineering structures in seismic prone areas which have the ability to reduce the damages due to earthquake.

ACKNOWLEDGMENT

I wish to thank the Management, Principal and Head of Civil Engineering Department of Illahia College of Engineering and Technology, affiliated by Kerala Technological University for their support. This paper is based on the work carried out by me (Sneha CS), as part of my PG course, under the guidance of Mrs. Christin Pious (Assistant Professor, Ilahia College of Engineering and Technology, Muvattupuzha, Kerala). I express my gratitude towards her for her valuable guidance.

REFERENCES

[1] G. Della Corte, B. Faggiano, and F. M. Mazzolani, "Innovative steel bracing systems for seismic upgrading of reinforced concrete structures: planning of a testing program," *Atti del XIX Congresso CTA*, Genova, 28-30 settembre, vol. 1, pp. 317-330, 2003.

[2] G. Della Corte, M. D'Aniello, and F. M. Mazzolani, "Seismic upgrading of RC buildings using buckling restrained braces: full-scale experimental tests," *Atti del XX Congresso CTA (Collegio dei Tecnici dell'Acciaio)*, Ischia, 26-28 settembre, 2005.

[3] American Institute of Steel Construction, Inc. (AISC), Seismic provisions for structural steel buildings. *Standard ANSI/AISC 341-05*. Chicago (IL, USA), 2005.

[4] Keh-Chyuan Tsai, Po-Chien Hsiao, Kung-Juin Wang, Yuan-Tao Weng, Min-Lang Lin, Ker-Chun Lin, Chui-Hsin Chen, Jiun-Wei Lai, and Sheng-Lin Lin, "Pseudo-dynamic tests of a full-scale CFT/BRB frame—Part I: Specimen design, experiment and analysis," *The Journal of the International Association for Earthquake Engineering*, vol. 37, issue 7, pp. 1081-1098, 2008.

[5] Gaetano Della Corte "All-steel buckling restrained braces for seismic upgrading of existing reinforced concrete buildings," *The Italian Ministry for Research and Education (MIUR)*, 2009.

[6] W. N. Deulkar, C. D. Modhera, and H. S. Patil, "Buckling restrained braces for vibration control of building structure," *IJRRAS*, vol. 4, issue 4, pp. 363-372, 2010.

[7] Chung-Che Chou, Jia-Hau Liu, and Dinh-Hai Pham, "Steel buckling-restrained braced frames with single and dual corner gusset connections: seismic tests and analyses," *The Journal of the International Association for earthquake Engineering*, vol. 41, issue 7, 2011.

[8] Junxian Zhao, Bin Wu, Wei Li, and Jinping Ou, "Local buckling behavior of steel angle core members in buckling-restrained braces: Cyclic tests, theoretical analysis, and design recommendations," *Engineering Structures*, vol. 66, pp. 129–145, 2014.

[9] Jose A Sy, Naveed Anwar, "Application of BRB in 50 storey building," *International Journal on High Rise Buildings*, vol. 3, no 1, pp. 81-87, 2014.

[10] Zhe Qu, Shoichi Kishiki, Yusuke Maida, Hiroyasu Sakata, and Akira Wada, "Seismic responses of reinforced concrete frames with buckling restrained braces in zigzag configuration," *Engineering Structures*, vol. 105, pp. 12–21, 2015.

[11] Sh. Hosseinzadeh and B. Moheb, "Seismic evaluation of all-steel buckling restrained braces using FEA," *Journal of Constructional Steel Research*, vol. 119, pp. 76–84, 2016.

[12] Ramazan Ozcelik, Yagmur Dikiciasik, and Elif Firuze Erdil, "The development of the buckling restrained braces with new end restrains," *Journal of Constructional Steel Research*, vol. 138, pp. 208–220, 2017.