Research Article

Parametric Study on Buckling Restrained Braced Asymmetric Building with and without Soil Structure Interaction

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ARTICLE INFO	ABSTRACT
	Earthquakes are one of the Earth's most destructive forces. The seismic waves throughout the ground can destroy buildings; take lives, and costs tremendous amounts of money for loss and repair. When these seismic waves pass through the soil layer, its properties get affected drastically. In conventional structural design method, effects due to interaction between super-structure and underlying soil are not considered. Generally, analysis is carried out by considering the base as fixed. Neglecting Soil Structure Interaction effect for a structure founded on hard soil is reasonable. But, for a structure founded on either soft or medium soil neglecting SSI has a great impact on structural response and design. These impacts are amplified when irregularities are present in building. Different lateral load resisting systems are used to mitigate this seismic response. One such option is using Buckling Restrained Braces (BRB). In the present study, ten-storey vertically asymmetric R.C. building is incorporated with BRB having two storey X configuration. The response of buildings will be analysed under different soil conditions like medium and soft. The influence of soil-structure interaction is compared with the results obtained when the structure is assumed to be fixed at the base. To find out seismic performance, different parameters such as base shear, storey displacement, storey drift and overturning moment is studied using ETABS software. Different analysis methods like Equivalent Static Force Method (ESFM), Response Spectrum Method (RSM) and Non Linear Time History Method (NLTHM) are carried out to find the response of the structure.

Key Words—Soil-Structure Interaction, Lateral load resisting systems, Buckling Restrained Braces (BRB), vertically asymmetric |

1. INTRODUCTION

Recent advancements in seismic design have focused on enhancing the structural resilience of buildings to minimize damage and repair costs after earthquakes.
One significant development is the Buckling Restrained Braced Frame (BRBF), which has been engineered to offer superior seismic resistance compared to traditional braced frames. The BRBF, equipped with Buckling Restrained Braces (BRBs), not only improves the ability to withstand severe seismic events but also provides a practical solution for reducing structural damage. This approach allows for the efficient dissipation of energy and facilitates the restoration of buildings to their original condition with manageable effort.

1.1 Buckling Restrained Brace
Buckling Restrained Braces (BRBs) are rising as an option in contrast to regular brace in high seismic regions because of their capacity to yield in pressure and strain. Customary steel supporting components show deviated conduct under cyclic stacking for example high flexibility in strain and buckling under pressure. This steadiness issue viewpoints the general cyclic reaction of the component, reflected by the cyclic corruption. By expelling the buckling wonder, BRBs offer adjusted, amazingly malleable and dissipative cyclic conduct. A run of the mill BRB comprises of a yielding steel centre that gives hub opposition limited by a mortar/concrete-filled steel packaging that gives buckling and flexural obstruction. The centre of BRB is separated into three zones i.e. yielding zone, transition zones and connection zones. Since buckling of braces

in conventional Concentric Braced frames (CBFs) causes corruption in the brace quality under pressure and enormous unequal vertical burden in shafts, an elective way to deal with structuring CBF frameworks to forestall brace buckling was created. The framework was called buckling-restrained braced frames (BRBFs). Buckling restrained braces have vitality dissipative conduct that is significantly better from that of Special Concentrically Braced Frames (SCBFs). Contrasted with other seismic frameworks, the structures are normally planned with an expanded central period and lower seismic burdens. This thus will prompt a decrease in segment and pillar sizes and less difficult associations. Moreover, BRB can be utilized in seismic retrofitting of structures. At long last, in case of a seismic tremor, since the harm is focused over a moderately little territory for example the brace's yielding center, post-seismic tremor examination and substitution of BRB is moderately simple.
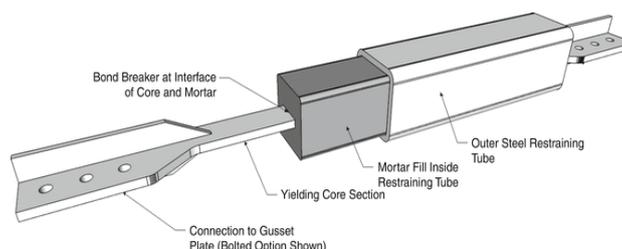

Fig. 1 shows a schematic view of BRB. (https://doi.org/10.1007/978-3-642-36197-5_313-1)

Advantages of BRB are
1. It yields in both tension and compression. high energy dissipation capacity.
2. BRB increases fundamental period of building, this leads to reduction in member (beams & column) sizes.
3. BRBs can be utilized in seismic retrofitting.
4. Using BRB is cost efficient than using Special Concentrically Braced Frames.

1.2 Soil Structure Interaction
Soil-structure interaction (SSI) plays a critical role in determining a structure's seismic response, yet traditional design methods often overlook its impact. SSI describes the mutual influence between a building and the soil it rests on: the structure's movement affects the soil, and conversely, the soil's response influences the building's behavior. While many design codes suggest that SSI improves seismic performance by increasing flexibility and damping, this assumption is only valid for certain conditions, such as lightweight structures on stiff soils. For heavy structures on soft soils, like tall buildings or nuclear power plants, disregarding SSI can lead to dangerous inaccuracies. The increased natural period of a structure due to SSI can result in resonance with prolonged seismic waves, potentially amplifying ground vibrations. Additionally, SSI includes kinematic interaction, where the foundation fails to match the free-field ground movement, and inertial interaction, where the structure's mass causes additional soil deformation. Both phenomena can significantly impact the seismic performance of a building, making accurate SSI consideration essential for ensuring safety and structural integrity.

2. OBJECTIVE OF STUDY

To Study Storey displacement, Base shear, Storey drift and Overturning moment
To study response of building when soil flexibility is considered.
To Obtain optimum location of BRB. Analysis Method used are
2.1   Equivalent Static Method
2.2   Response spectrum method
2.3   Non linear time history analysis

3. LITERATURE REVIEW

Literature Survey is carried out to study on the performance of reinforced concrete building having BRB as lateral force resisting system. Effect of considering SSI has also been reviewed through literature survey. Various research papers from reputed national/international journal and conferences consisting and experimental studies have been reviewed.
Siva Naveen E, Nimmy Mariam Abraham and Anitha Kumari S D performed analysis on a 9 storey regular frame modified by incorporating 54 irregular configurations. Out of various types of single irregularities analyzed, stiffness irregularity was found to have maximum influence on the response. Among the cases having combinations of irregularities, the configuration with mass, stiffness and vertical geometric irregularities showed maximum response. Analysis was done using ETABS Software. The combination of stiffness and vertical geometric irregularities showed maximum displacement response whereas the combination of

re-entrant corner and vertical geometric irregularities showed less displacement response.

Archana J. Satheesh, B. R. Jayalekshmi and Katta Venkataramana studied on performance of RC buildings of varying heights of 5,10 and 15 storeys subjected to EL-Centro (1940) seismic ground motion for Non Linear Time History Analysis.The study aimed to identify the variation in seismic responses of three dimensional building frames due to varying locations as well as eccentricity of mass considering mass ratios up to 5 along the height of the building. Analysis was done using finite element software LS DYNA. The torsional behavior was evaluated in terms of variation in base shear, fundamental natural period, roof deflection and floor rotation. The results showed that the in-plan eccentricity of the mass irregularities had least influence on the seismic response when irregularities were present in the lower half of the frames. It was observed that with the increase in height of the location of irregular masses from the base of the buildings, the natural period increased. With increase in mass ratios, base shear increased. It was observed that maximum roof rotation increased with increase in the height of the buildings and the 15 storey buildings had the highest roof rotation.

Sanyogita and Babita Saini Compared 3 storey, 6 storey and 12 storey regular and setback irregular frames on the basis of seismic responses. The main objective of the study was to create 3D models using ETABS and study various seismic parameters such as base shear, storey displacement, storey drift for different types of irregularities created in medium rise and high rise building. It was concluded that with increase in setback, the base shear decreased.

Shehata E. Abdel Raheem, Momen M. M. Ahmed and G. A. Abdel-shafy investigated structural seismic response demands for the class of L-shaped buildings through evaluating the plan configuration irregularity of re-entrant corners and lateral–torsion coupling effects on measured seismic response demands. The measured responses included story drift, inter-story drift, story shear force, overturning moment, torsion moment at the base and over building height. The results proved that building models with high irregularity were more vulnerable due to the stress concentration and lateral torsional coupling behavior than that with regular buildings. Three-dimensional model were constructed by ETABS software (CSI 2016) for Response Spectrum analysis.

T. Naga Sai, P.Kamatchi and A.S.Santhi carried out linear time history analysis for a typical 10 storey asymmetrical building with and without viscoelastic dampers using SAP2000 software. Eccentricities in X-direction were considered by varying the column sizes in the frame. Reduction in response of a typical asymmetric building, due to the addition of viscoelastic dampers was quantified for different eccentricities for four different earthquakes.

4. DETAILS OF BUILDING AND MODELLING OF STRUCTURE

Building model details such as material properties and section properties of various building elements are described in following table given below:

Storey height	4.6 m
No. of Bays in X-Direction	4
No. of Bays in Y-Direction	4
Bay Width in X-Direction	4.6 m
Bay Width in Y-Direction	4.6 m
Column Size	450 mm X 450 mm
Beam Size	230 mm X 450 mm
Slab Thickness	135 mm
Number of storey	G+9
External Wall Thickness	230 mm
Internal Wall Thickness	110 mm
Parapet Wall Height	1 m
Live Load	Roof :- 1.5 kN/m^2
	Other Floor :- 3 kN/m^2
Floor Finish	1 kN/m^2
Load Combination	As per IS 1893-2016
Mass Source	1DL+0.25LL
f$_{ck}$ (Characteristic Strength of Concrete)	30 N/mm^2
f$_y$ (Yield Strength of Steel)	415 N/mm^2
Unit Wt. of Concrete	25 kN/m^2
Unit Wt. of Masonry	20 kN/m^2

Seismic Data:

Earthquake Zone	IV (0.24)
Soil Type	II (medium), III(soft)
Response Reduction Factor	5 (SMRF)
Importance Factor (I)	1
Damping	5 %
Earthquake for NLTHM	Bhuj Earthquake

Notation for various models:
3 support conditions are taken :- F(fixed), M(medium soil) and S(soft soil).
3 frames are considered :- S(simple), E(BRB at edge) and C(BRB at corner).
Mass irregularity ratio of 3 is considered on 9th floor.

No BRB		
SF	SM	SS
9SF	9SM	9SS
Buckling Restrained Braced Frame at corner		
CF	CM	CS
9CF	9CM	9CS
Buckling Restrained Braced Frame at edge		
EF	EM	ES
9EF	9EM	9ES
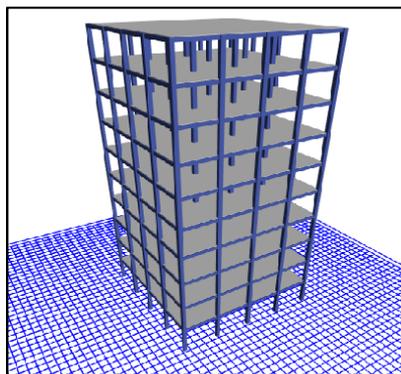
Fig. 2 Simple building
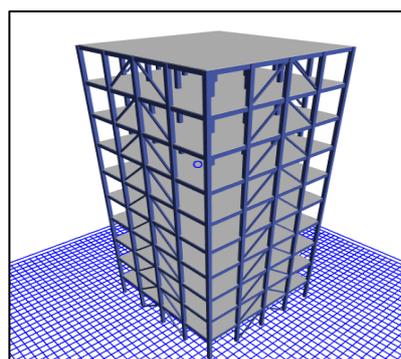
Fig. 3 Location of BRB at corner
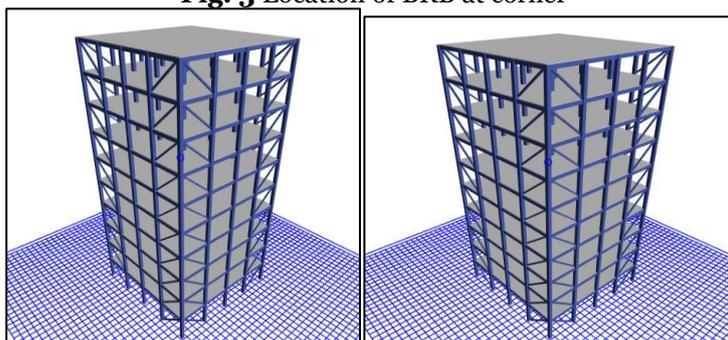
Fig 4. Location of BRB at edge
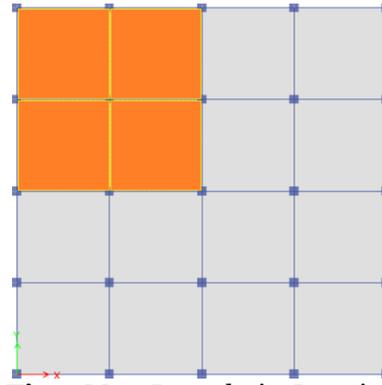
Fig 5. Mass Irregularity Location

Soil Properties:

Soil Type	Shear Wave Velocity (m/s)	Density (kN/m³)
Medium soil	560	19
Soft Soil	180	15

Details of SSI spring modelling:
The effect of SSI at the base of the structure is simulated by assigning springs at the base of each column for 6 degree of freedom. Spring stiffness is calculated using formulas proposed by Gazetas 1991, as given below (Eqs. 1, 2, 3, 4, 5, 6).

$$K_z = \frac{2GL}{(1-\theta)}[0.73 + 1.54X^{0.75}], \qquad \text{(Eq. 5.1)}$$

$$K_Y = \frac{2GL}{(2-\theta)}[2 + 2.5X^{0.85}], \qquad \text{(Eq. 5.2)}$$

$$K_x = K_Y - \frac{2GL}{(0.75-\theta)}\left[1 - \frac{B}{L}\right] \qquad \text{(Eq. 5.3)}$$

$$K_{rx} = \frac{G}{(1-\theta)}I_{bx}^{0.75}\left(\frac{L}{B}\right)^{0.25}\left|2.4 + 0.5\left(\frac{B}{L}\right)\right| \qquad \text{(Eq. 5.4)}$$

$$K_{ry} = \frac{3G}{(1-\theta)}I_{by}^{0.75}\left(\frac{L}{B}\right)^{0.75} \qquad \text{(Eq. 5.5)}$$

$$K_t = 3.5GI_{bz}^{0.75}\left(\frac{B}{L}\right)^{0.4}\left(\frac{I_{bz}}{B^4}\right)^{0.2} \qquad \text{(Eq. 5.6)}$$

Where,

$$X = \frac{A_b}{4L^2}$$

A_b = area of foundation, I_{bx} = moment of inertia about longitudinal axis, I_{by}= moment of inertia about lateral axis, I_{bz} = moment of inertia about vertical axis, B = half of the width of foundation, L = half of the length of foundation, K_z = translational stiffness in vertical direction, K_y = translational stiffness in lateral direction, K_x = translational stiffness in longitudinal direction, K_{rx} = rotational stiffness about longitudinal axis, K_{ry} = rotational stiffness about lateral axis, K_t = rotational stiffness about vertical axis, θ = Angle of repose, E = Elastic modulus of soil, G = Shear modulus of soil

5. RESULTS AND OBSERVATIONS

In this work, mass irregular building is compared with normal building. Three support conditions are taken that are fixed base, base with medium soil and base with soft soil. Buildings were analysed by three methods such as Equivalent Static Method, Response Spectrum Method and Non-Linear Time History Method. Total eighteen number of models are analysed and various parameters studied are base shear, storey displacement, storey drift and overturning moment.

5.1   Results of Equivalent Static Analysis (ESA)
A)   Storey Displacement
It is the displacement of a storey with respect to the base of a structure.

From the analysis, maximum storey displacement was observed for mass eccentric building with soft
Small displacement is observed at base level for buildings with medium soil and soft soil at base.

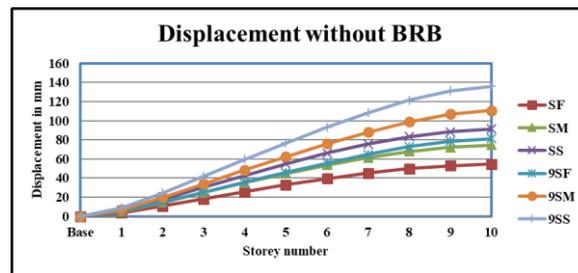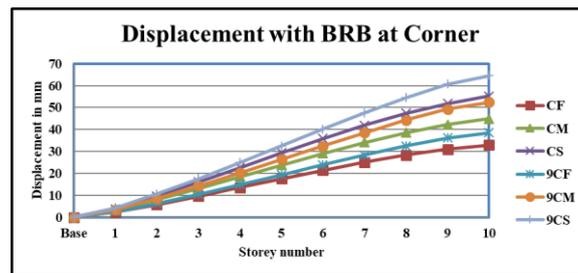**Fig. 6:** Displacement without BRB (ESA)

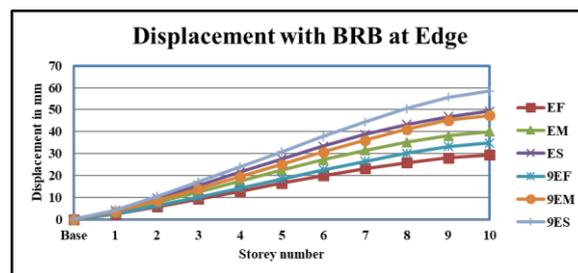**Fig. 7:** Displacement with BRB at corner (ESA)

Fig. 8: Displacement with BRB at Edge (ESA)

B)   Storey drift
Storey drift is defined as displacement of one storey with respect to other storey.
More is the storey drift more damage occurs to walls and column. Use of BRB significantly reduced drift.
Maximum storey drift was observed at middle storeys. Storey drift increased by 36-67% when base condition
changed from fixed to medium to soft soil. It increased by 36-38% when mass eccentricity was introduced.
Inclusion of BRB reduced drift by 51- 61%. And BRB at edge position was about 8% efficient than BRB at
corner position.
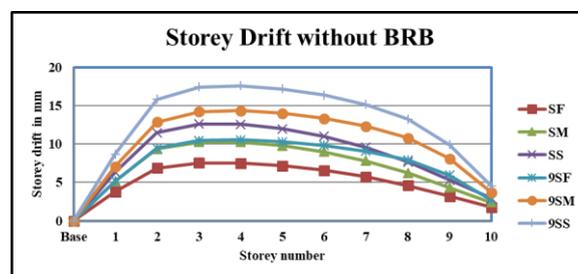
Fig. 9: Storey drift without BRB (ESA)

Storey Drift with BRB at Corner
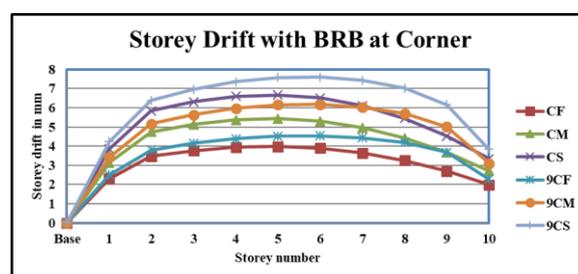
Fig. 10: Storey drift with BRB at corner (ESA)

BRB at edge position. Overturning moment increased as support condition changed from fixed support to medium soil to soft soil.
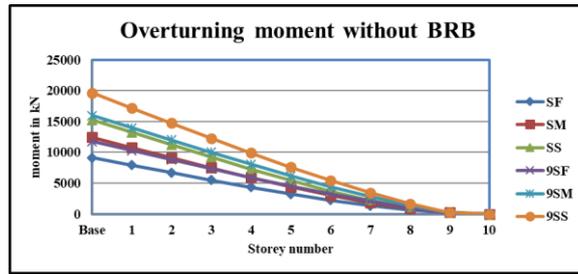
Fig 12: Overturning Moment without BRB (ESA)
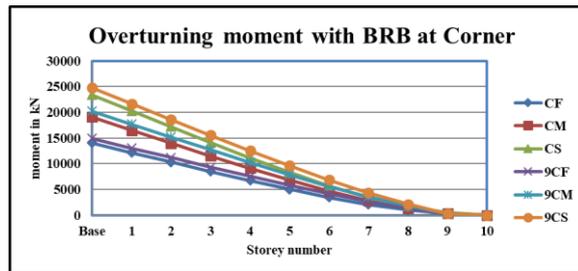
Fig 13: Overturning Moment with BRB at Corner (ESA)
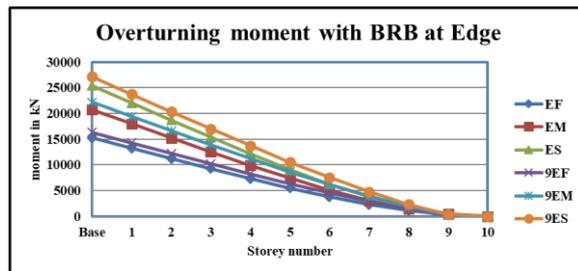
Fig 14: Overturning Moment with BRB at Edge (ESA)

D) Base Reaction
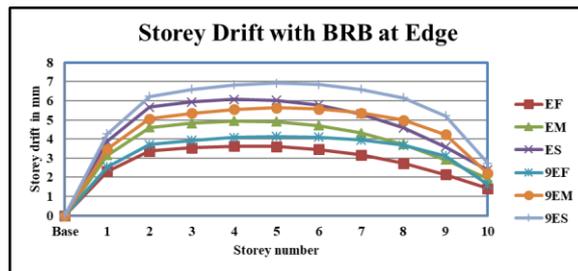
Fig. 11: Storey drift with BRB at Edge (ESA)

C) Overturning Moment

Maximum Overturning moment was observed for mass eccentric building having soft soil at base and
It is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure.
Maximum base reaction was attracted by mass eccentric building with soft soil base and BRB at edge position. However, introduction of mass eccentricity was not having major effect in response.
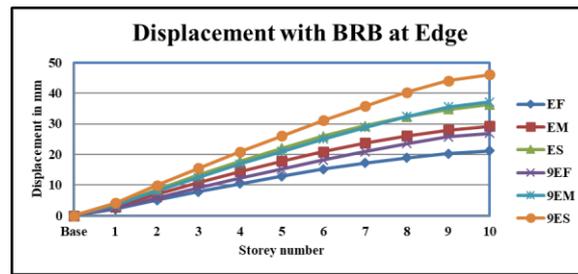
Fig. 15: Base Reaction (ESA)

5.2   Results of Response Spectrum Analysis (RSA)
A)   Storey Displacement
From the analysis, maximum storey displacement was observed for mass eccentric building with soft soil at base and minimum for regular building having BRBs at edge position and having fixed base. Introduction of BRB reduced displacement by 45% to 61%. BRB at edge position was 3% to 5% more efficient as compared to BRB at corner position. Small displacement is observed at base level for buildings with medium soil and soft soil at base.
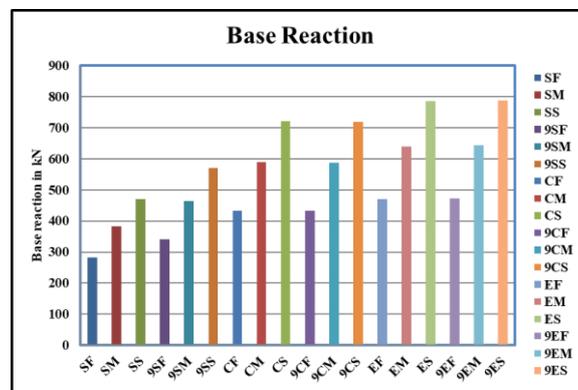
Fig. 16: Displacement without BRB (RSA)
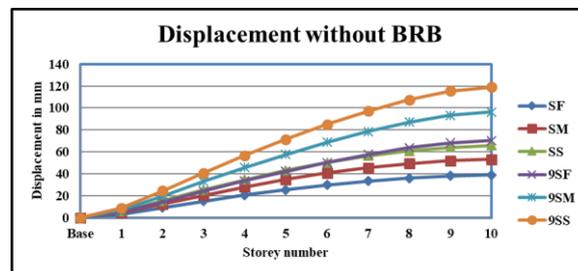
Fig. 17: Displacement with BRB at corner (RSA)
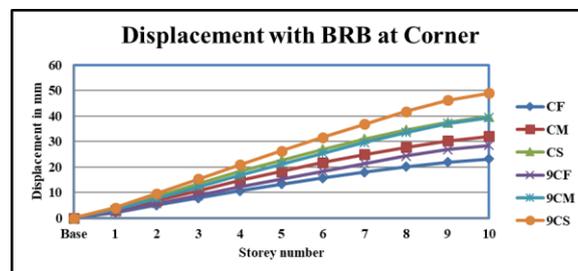
Fig. 18: Displacement with BRB at Edge (RSA)

B) Storey drift
Storey drift increased by 36-69% when base condition changed from fixed to medium and soft soil. It increased by about 64% when mass eccentricity was introduced. Inclusion of BRB reduced drift by 53-65%. And BRB at edge position was about 8% efficient than BRB at corner position.
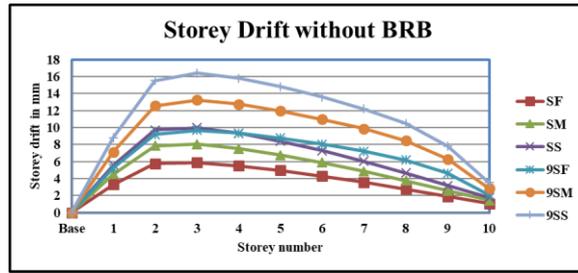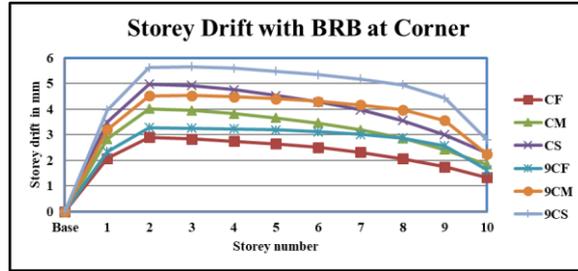
Fig. 19: Storey drift without BRB (RSA)

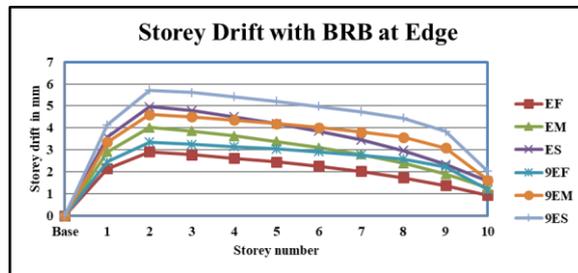**Fig. 20:** Storey drift with BRB at corner (RSA)

Fig. 21: Storey drift with BRB at Edge (RSA)

C) Overturning Moment

Maximum Overturning moment was observed for mass eccentric building having soft soil at base and BRB at edge position. Overturning moment increased as support condition changed from fixed support to medium soil to soft soil.
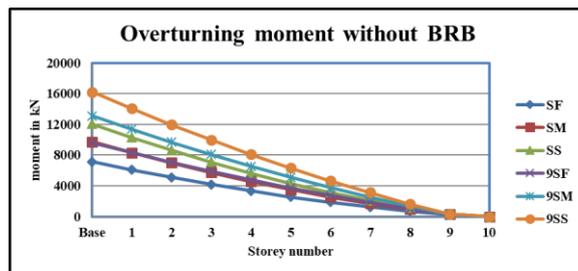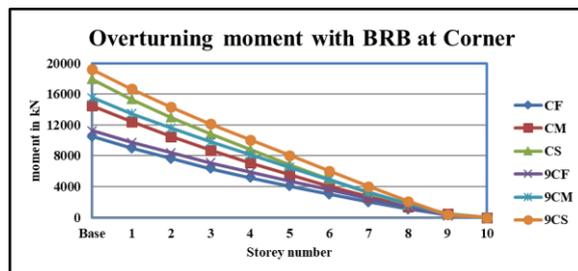

Fig 22: Overturning Moment without BRB (RSA)

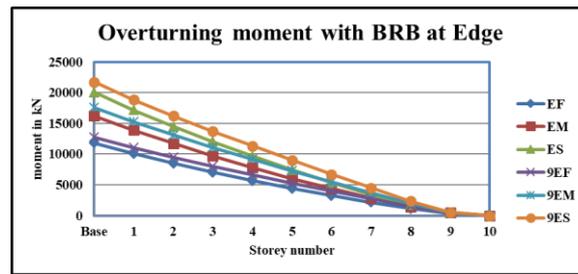**Fig 23:** Overturning Moment with BRB at Corner (RSA)]

Fig 24: Overturning Moment with BRB at Edge (RSA)]

5.3 Results of Time History Analysis (THA)
A) Storey Displacement

From the analysis, maximum storey displacement was observed for mass eccentric building with soft soil at base and minimum for regular building having BRBs at edge position and having fixed base. Introduction of BRB reduced displacement by 41- 55%. BRB at edge position was about 1% more efficient as compared to BRB at corner position. Small displacement is observed at base level for buildings with medium soil and soft soil at base.
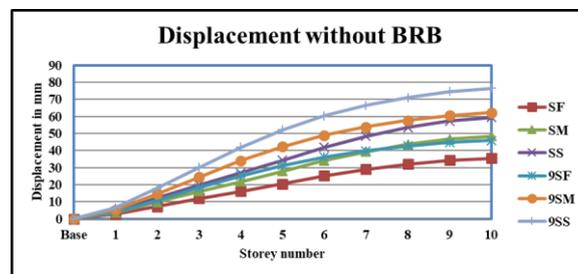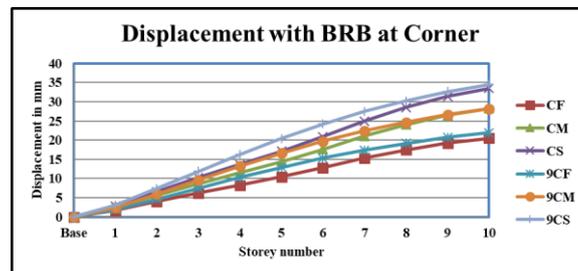

Fig. 25: Displacement without BRB (THA)

Fig. 26: Displacement with BRB at corner (THA)

Fig. 27: Displacement with BRB at Edge (THA)

B) Storey drift

Storey drift increased by 36-69% when base condition changed from fixed to medium and soft soil. It increased by about 64% when mass eccentricity was introduced. Inclusion of BRB reduced drift by 53-65%. And BRB at edge position was about 8% efficient than BRB at corner position.
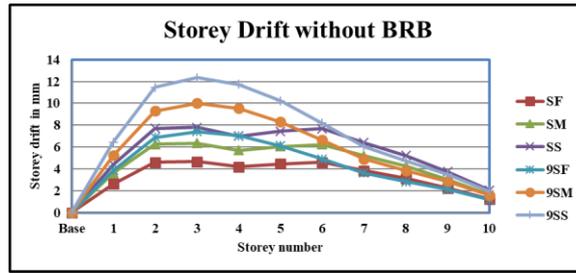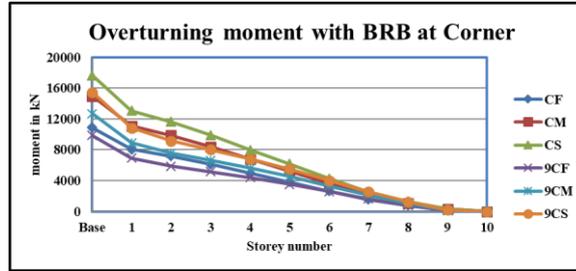
Fig. 28: Storey drift without BRB (THA)

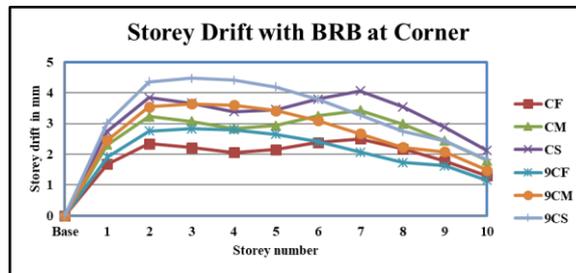**Fig. 29:** Storey drift with BRB at corner (THA)

Fig 32: Overturning Moment with BRB at Corner (THA)
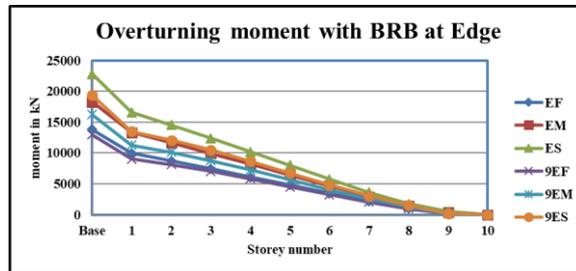
Fig 33: Overturning Moment with BRB at Edge (THA)
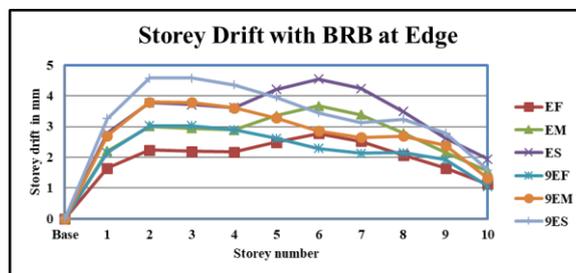
6. CONCLUSION

Fig. 30: Storey drift with BRB at Edge (THA)

C)   Overturning Moment
Maximum Overturning moment was observed for mass eccentric building having soft soil at base and BRB at edge position. Overturning moment increased as support condition changed from fixed support to medium soil to soft soil.

Fig 31: Overturning Moment without BRB (THA)

Effect of Soil Structure Interaction is introduced in building by using spring dashpot at the base of building. Spring stiffness is calculated using Gazetas equation. Also vertical asymmetry is considered in form of mass eccentricity on the upper floor so it can affect the building maximum. To reduce the effect of earthquake and mass eccentricity, Buckling Restrained Braces are incorporated and analysis is carried out. Following conclusions are drawn from the analysis.

- It is seen from graphs that maximum response is observed for building with combination of soft soil at base and mass eccentricity.
- Building with fixed base having no mass eccentricity and incorporating BRB at edge position gives minimum response.
- Displacement decreased by 40-75% when BRB was used.
- Small displacement is observed at base level in case of building where spring dashpot are considered. Hence considering base as fixed can be unhealthy practice while analysing building

when soft or medium soil is present in ground. But can be ignored when hard soil is present.

- Storey drift is reduced by 51-61% when BRB is incorporated. This may result to occurrence of less damage to walls.
- Maximum lateral force is attracted by mass eccentric building with soft soil at base and BRB at edge position.
- Overturning moment is maximum for mass eccentric building with soft soil at base and BRB at edge position as it attracts maximum lateral load.
- From the results obtained, BRB at edge position controls earthquake response more efficiently than BRB at corner position.

7.   REFERENCES

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