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Modification of Buckling Restrained Braces and Evaluating the Deflection Amplification Factor

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Abstract: ***Buckling is a main problem in every structure. It is a sudden change in shape or deformation of a structural component under load. Under moderate to severe earthquakes, buckling of compressive braces may cause damage to the joints and connections. So Buckling-Restrained Braces (BRBs) have been widely implemented in framed structures to reduce damage during severe earthquakes. Unlike conventional braces that buckle under compression, the core of BRBs yields both in tension and compression under the restraining effect of the casing. A typical buckling-restrained brace (BRB) is composed of a ductile steel core, which is designed to yield in both tension and compression. To avoid global buckling in compression, the steel core is usually wrapped with a steel casing, which is subsequently filled with mortar or concrete. So in this work the deflection amplification factor of these braces are found out. As DAF predicts the maximum capacity of the structure, so a deep study in this field is necessary. DAF is the ratio of in-elastic deformations to elastic deformation. So after finding the DAF of these BRBs and by knowing the elastic deformation of the structure we can easily find the in-elastic deformation. For this works the analysis are carried out using etabs and abaqus software.***

Keyword: Buckling restrained braces, Deflection amplification factor, Buckling, In-elastic deformation, Etabs, Abaqus,

I. INTRODUCTION

Structural engineer has great concern in designing earthquake resisting system to dissipate energy effectively from the structure. Steel bracing are mainly used to resist the lateral loads acting during a seismic activity. Braced frame is a structural system designed to resist wind and earthquake force. Members in braced frames are not allowed to sway laterally. Conventional type of lateral load resisting systems is concentrically-braced frames and eccentrically braced frames. They have weaknesses such as difference in the tensile and compressive capacity of the braces, non uniform and unstable cyclic behavior due to the buckling of the elements. Under moderate to severe earthquakes, buckling of compressive braces, may cause damage to the joints and connections. Thus Buckling-Restrained Braces (BRBs) have been widely implemented in framed structures to reduce damage during severe earthquakes. A BRB is a structural brace in a building, designed to allow the building to withstand cyclical lateral loadings, typically earthquake-induced loading. It consists of a slender steel core, a concrete casing designed to continuously support the core and prevent buckling under axial compression and also an interface region that prevents undesired interactions between the two. Braced frames that use BRBs are known as buckling-restrained braced frames, or BRBFs. So BRBF is a structural steel frame that provide lateral resistance to buckling. Compressive buckling is prevented by means of an exterior confining tube. A BRB is composed of a ductile steel core, which is designed to yield in both tension and compression. To avoid global buckling in compression, the steel core is usually wrapped with a steel casing, which is subsequently filled with mortar or concrete.

In this project work the BRBs are modified in abaqus and its deflection amplification factor is evaluated and a relationship is established. The longitudinal core geometries of BRBs are modified in Abaqus by varying the cross section of steel core. Then in order to get the inelastic behaviour of BRB's cyclic analysis is done. The cyclic loading is applied on one end of BRBs steel ore as an amplitude and the hysteresis curves are plotted. Using the hysteresis curve data, plastic hinges are generated for BRB hardening. Then the hinges are assigned to the corresponding BRB's and pushover analysis is done. From the pushover results, the maximum in-elastic displacement is obtained. The maximum elastic displacement is obtained by conventional equivalent static analysis. Thus DAF can be determined as it is the ratio of in-elastic deformation by elastic deformation. DAF predicts the maximum capacity of the structure, so a deep study is necessary in this field.

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A. Scope and Objectives

The scope of the study is performance of the BRBs can be predicted. BRBFs response under seismic loads can be determined. Overall cost can be reduced.Can predict the maximum capacity of the structure. And can establish the relation of DAF to building capacity in terms of inelastic deformation.

The main objectives are :

1) To find the location of higher values of buckling load in the structure .
2) To determine the plastic characteristics of modified BRBs through hysteresis curve
3) To determine the DAF of modified BRBs by pushover analysis.
4) To find out the relation of DAF to building capacity in terms of inelastic deformation.
5) To find out the ductility demand of braced frames.

II. MODELLING AND ANALYSIS

A. Modelling of building

The structure is modelled in etabs. The material property used are concrete of M30 and rebar of Fe415. Beam of size 250x250mm, column of 500x500mm and slab of 120mm thickness is provided. The plan of the structure is shown below. The height of the building is 30m floor to floor height is 3m and number of stories provided is 10.

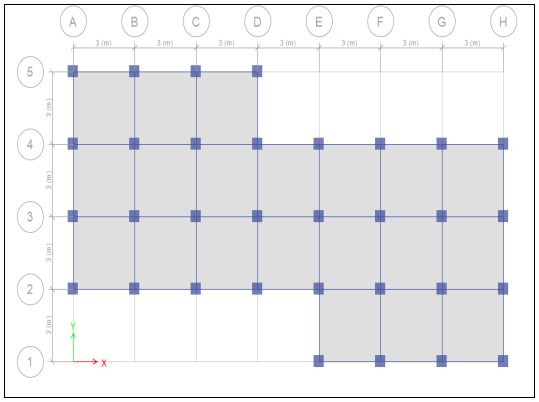


Fig.1 Building Plan

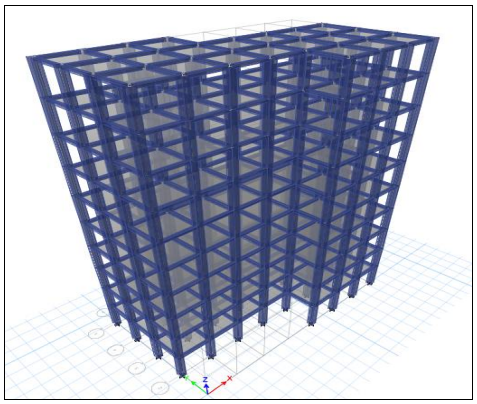


Fig.2 3D Model of building

The various loads used in the analysis are dead, live, wind load and seismic load. The details are given in table below.

Table.1 Loading details

Dead load *(As per IS 875: 1987 Part 1)*	
Parapet	2kN /m
Wall load	12kN /m
Floor finish	1 kN/m^2
Live load *(As per IS 875 : 1987 Part 2)*	
Residential building	2 kN/m^2
Roof	1.5kN/m^2
Wind load *(As per IS 875: Part 3)*	
Wind speed in kerala	39m/s
Topography factor,k2	1.0
Terrain factor,k3	1.0
Building class	B
Seismic load *(As per IS 1893: 2002)*	
Seismic zone factor, Z	0.16
Importance factor, I	1
Response reduction factor, R	5

The structure is designed in etabs using the properties shown above and the section became safe after designing. So the given section properties and material properties are correct.

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B. Buckling Analysis

Buckling analysis is done in etabs, to find the portion where buckling load is maximum. The coloured portion is the area where buckling load is maximum.

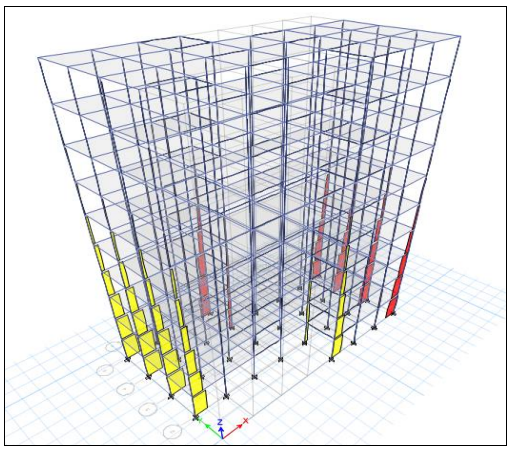


Fig. 3 Buckling analysis result .

Table.2 Buckling load factor from Etabs

Case	Mode	Scale factor
Buckling	1	17.094
Buckling	2	18.099
Buckling	3	20.024
Buckling	4	27.852
Buckling	5	29.117
Buckling	6	32.164

In conventional method, to avoid buckling we should multiply these buckling load factors as factor of safety to the loads acting on the building and design as per the resultant loads. Instead of this, the provision of using buckling restrained braced frame on the building should be analysed.

C. Modelling of Buckling Restrained Braced Frames

The BRBFs are modelled in etabs. The modelling is done based on Star Seismic manual. As per this manual yield stress of BRBF core is 262Mpa, tensile strength of BRBF core material is 399.89Mpa. These are designed in etabs by auto select list option. Etabs will itself give the most economical and suitable BRBF for the structure based on its material and section property. Here the etabs has given BRBF of size Star seismic 26.5. The details for Star seismic 26.5 is given in table below. After performing the buckling analysis we have got the portion where buckling load is maximum, so we have to assign the BRBF in that area by using quick draw option.

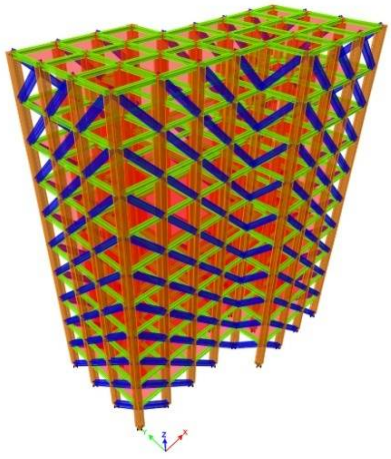


Fig.4 Building assigned with BRBF

Table.3 Details of Star seismic 26.5

Weight	25.54kN
Depth	406.4mm
Width	304.8mm
Area of steel core	17cm^2
Axial stiffness	676133.98 kN /m

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D. Capacity Analysis

Capacity analysis of BRB is done to find the level of performance of BRB. It is also called push over analysis. From this analysis we get a graph between axial force versus axial deformation. Through push over analysis maximum capacity of BRB is found out. The results from etabs is shown below. From the curve we get immediate occupancy, life safe and collapse prevention.

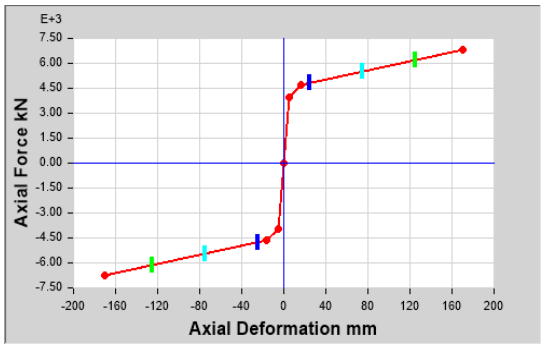


Fig.5 Capacity curve

Table.4 Inference from Pushover curve

Level of BRB Performance	Maximum deformation (mm)
Immediate occupancy	25
Life safety	75
Collapse prevention	125

Etabs consist of options for importing Star seismic data base suited for the modelled BRB section. Etabs have no provision for modifying BRB longitudinal section. So optimized size of star seismic BRB is selected from the star seismic database according to the buckling resistance the model needed. From the selected star seismic BRB properties and analysis result, the values needed to model and analyse the same in Abaqus is collected. Using Abaqus, BRB steel core geometry is modified and performed cyclic analysis.

E. Modelling of BRBs

BRB is modeled in abaqus software by using the dimensions of star seismic 26.5 and the result obtained from capacity analysis. BRB has 3 parts- steel core, steel tube and concrete encasement. Using the dimension of star seismic 26.5 given in table 4, the BRB is carefully drawn. First separately the outermost part called steel tube is drawn, then the concrete encasement and finally the inner part called steel core is drawn. After that all the three parts are assembled together to get the required BRB.

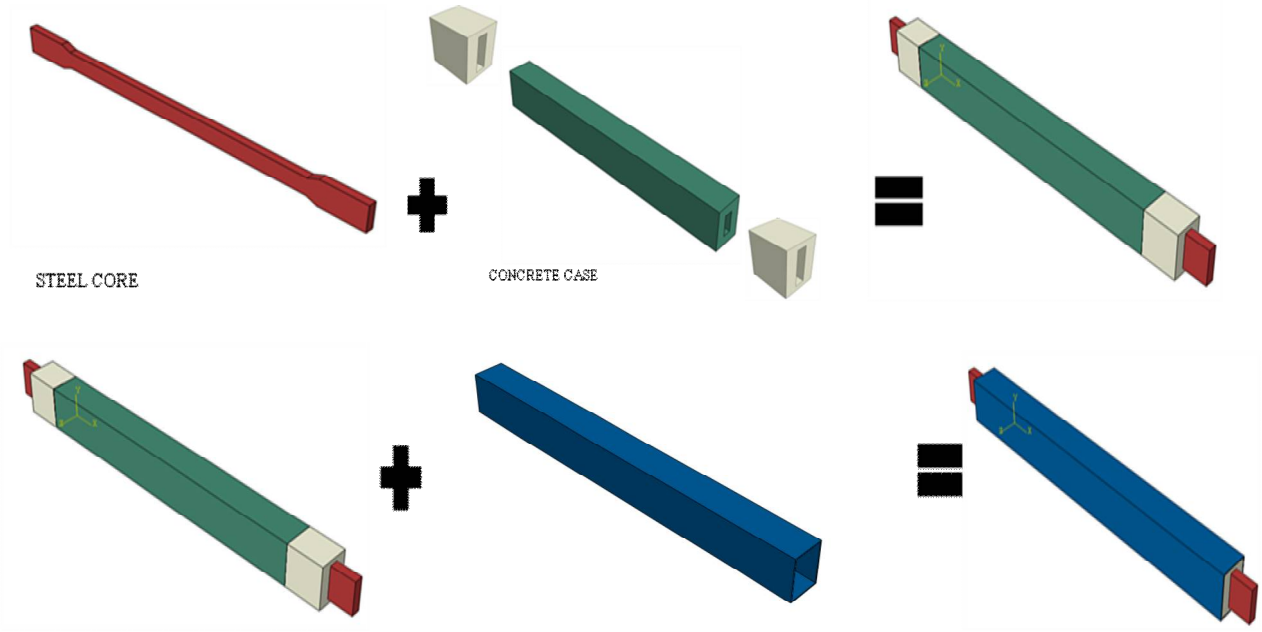


Fig.6 Standard BRB

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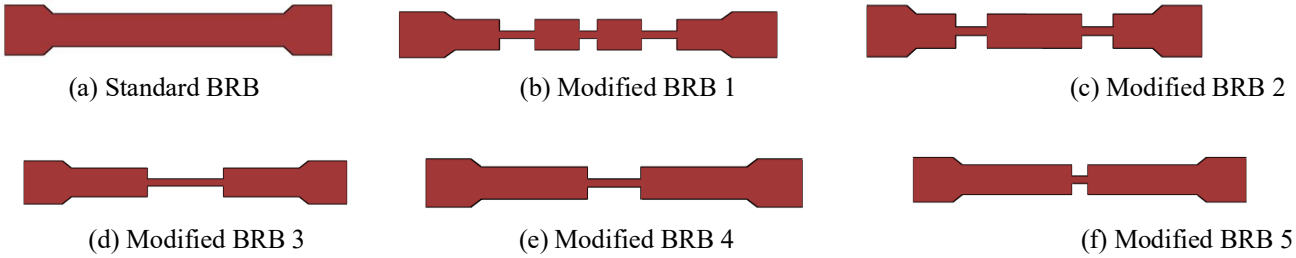
Table.5 Material Properties

Concrete case	
Density	2400 kN/m^3
Young's modulus	25000Mpa
Poisson's ratio	0.2

Steel core and tube	
Density	7850 kN/m^3
Young's modulus	200000Mpa
Poisson's ratio	0.3
Yield stress	262Mpa
Tensile stress	399.89Mpa

F. Modification of BRBs

The BRBs are modified in abaqus software. The longitudinal core geometries of BRBs are modified in abaqus by varying its cross section that is the length and thickness of steel core. The different modified BRBs are shown below.



(a) Standard BRB (b) Modified BRB 1 (c) Modified BRB 2

(d) Modified BRB 3 (e) Modified BRB 4 (f) Modified BRB 5

Fig.7 Modified steel cores

G. Cyclic Analysis

Static loads exhibit very little movement and have little or no change due to the balance and the equal action of the opposing forces in the structure. On the other hand, cyclic loaded structures have movement due to impact, waves, wind gusts and strong earthquakes. In order to get the inelastic behaviour of BRB's cyclic analysis is done. Cyclic loading is applied on one end of the BRB's steel core as amplitude, and the other end is kept fixed. The time period given is 80 seconds. The loading protocol is taken from faculty handbook of polytechnic university Romania. Through cyclic analysis we get hysteresis curves.

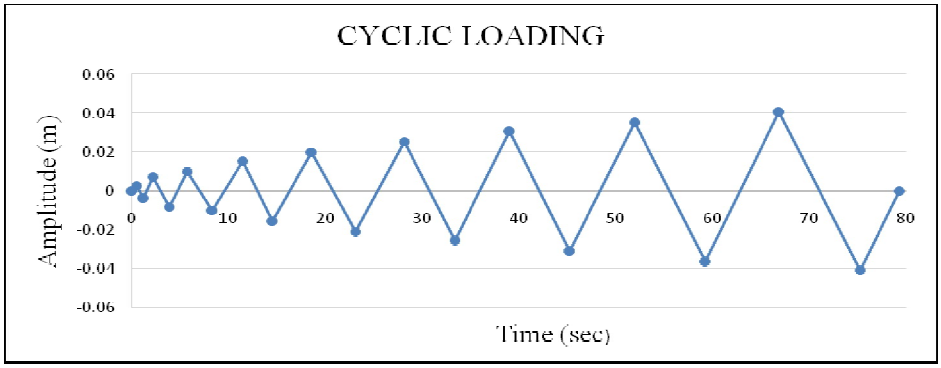


Fig.8 The Loading protocol

Tie constraint is used to make contact between concrete encasement and steel tube. Friction coefficient of 0.1 is used to make contact between steel core and encasement. Then one end of steel core is fixed and other end of steel core has given displacement only in –z direction. The steel core is the yielding member, so when an earthquake occurs, only the steel core will vibrate. It will move or displace only in –z direction and all other sides are restrained thus giving the brace more safety during earthquake and the building or brace won't vibrate and will remain safe. Then after that rectangular finite element analysis meshes were created for accurate results.

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Then cyclic loading should be applied on end of steel core as amplitude as already said, and as a result we can get the hysteresis curves of BRBS in abaqus.The cyclic load- deflection curve of modified BRB's are used to define inelastic plastic hinges as per ATC40 and FEMA273.

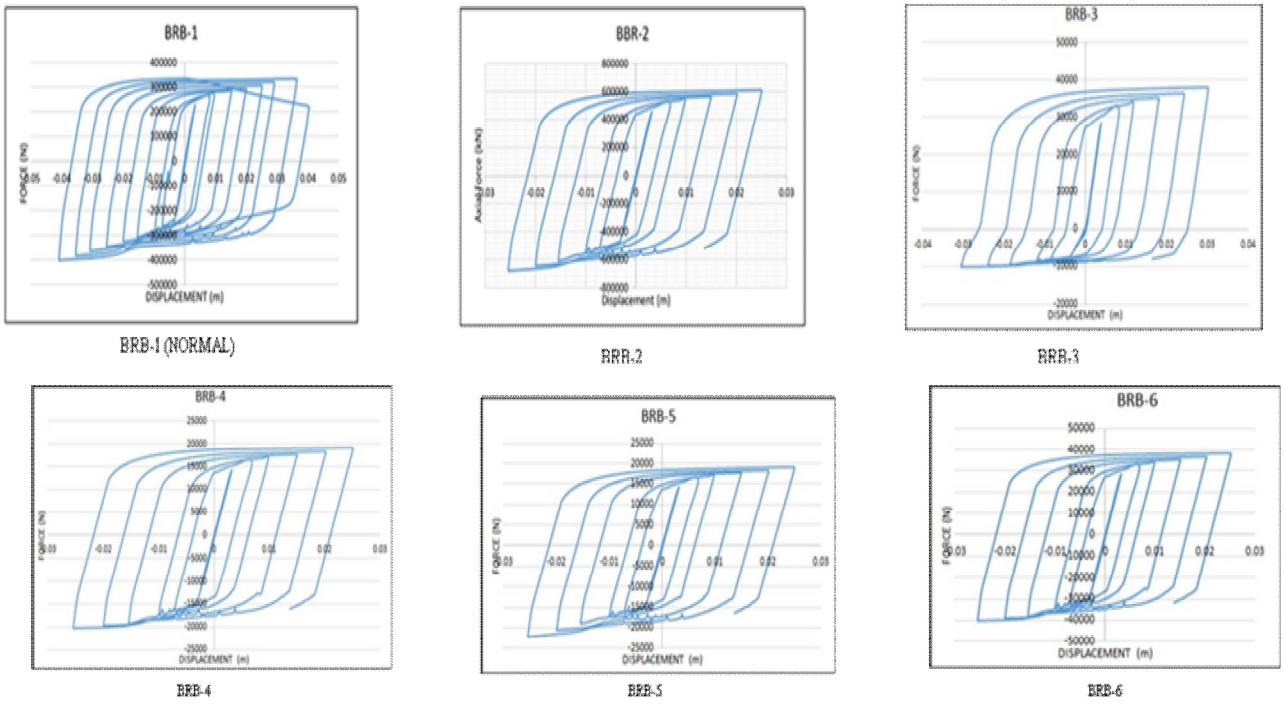


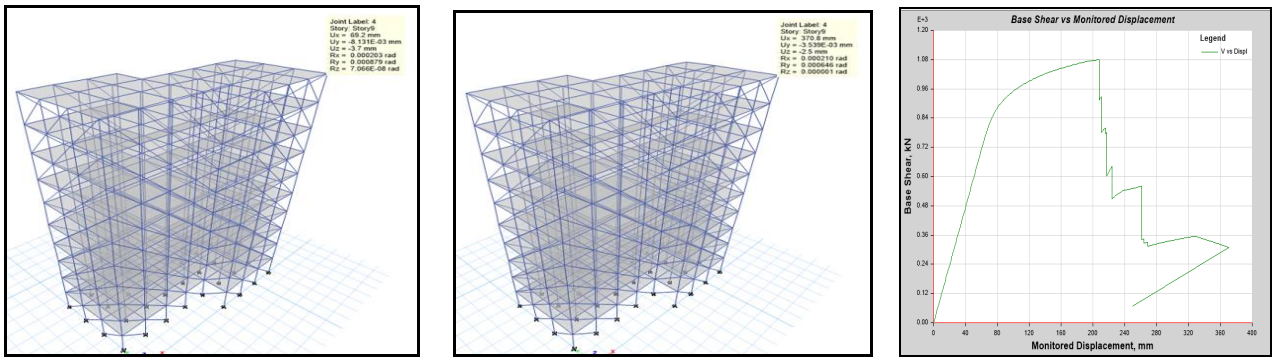
Fig.9 Hysteresis curves of different BRBs

From these hysteresis curves brace with most stiffness is BRB-2 and BRB-3. As it shows less displacement under higher values of axial load

H. Pushover Analysis

Using the hysteresis curve data, plastic hinges are generated for BRB hardening. Then the hinges are assigned to the corresponding BRB's and pushover analysis is done. From the pushover results, the maximum inelastic displacement is obtained. The maximum elastic displacement is obtained by conventional equivalent static analysis. Deflection Amplification Factor = Inelastic Displacement/Elastic Displacement. Thus the results of static equivalent analysis and pushover analysis of different BRBs are shown below-

1) BRB-1

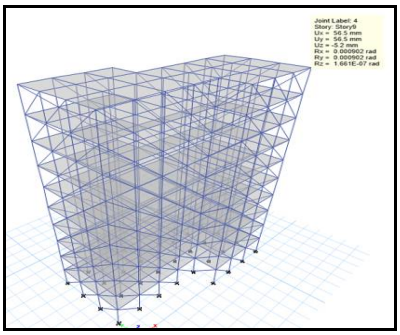


Elastic displacement =69.2mm | In- elastic displacement=370.8mm | Base shear vs displacement curve

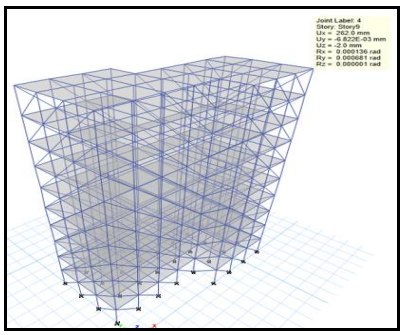
The elastic displacement from equivalent static analysis is 69.2 mm and inelastic displacement 370.8mm so the deflection amplification factor is 370.8/69.2 = 5.4.

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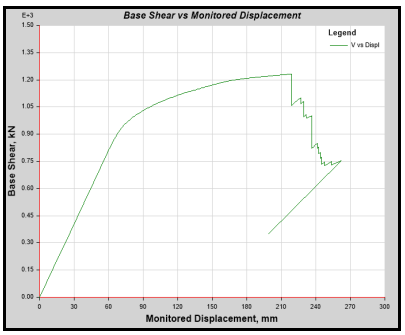
2) *BRB-2*



Elastic displacement =56.5mm

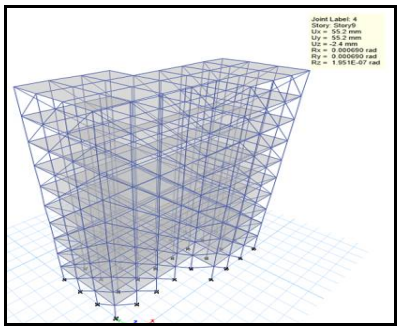


In- elastic displacement=262 mm

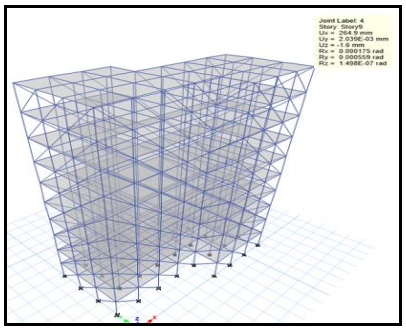


Base shear vs displacement curve

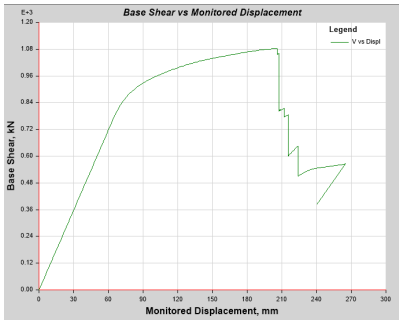
3) *BRB-3*



Elastic displacement =55.2mm

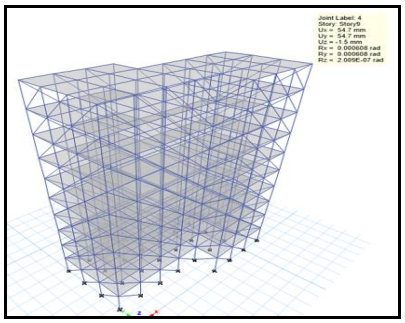


In- elastic displacement=264.9mm

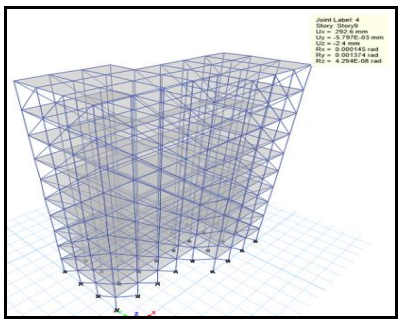


Base shear vs displacement curve

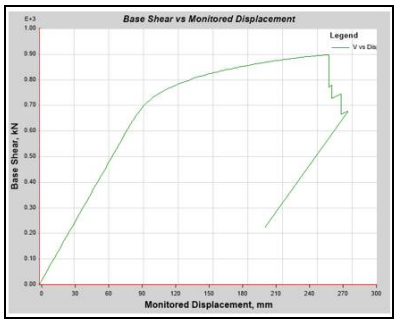
4) *BRB-4*



Elastic displacement=54.7mm

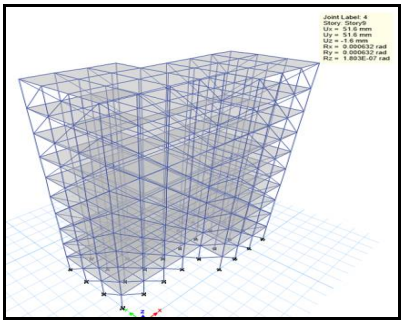


In-elastic displacement=292.6mm

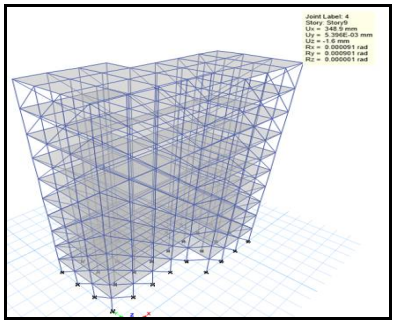


Base shear vs displacement curve

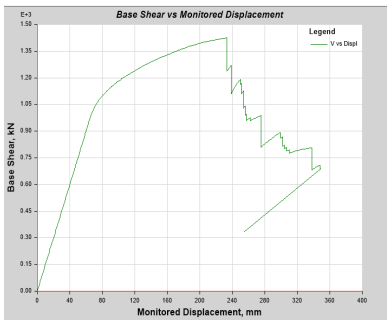
5) *BRB-5*



Elastic displacement=51.6mm



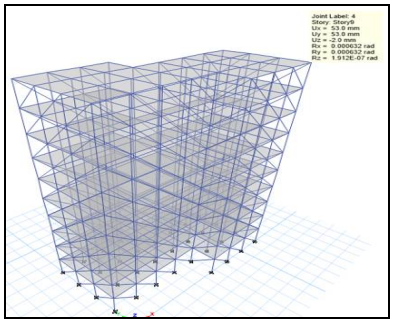
In-elastic displacement=348.9mm



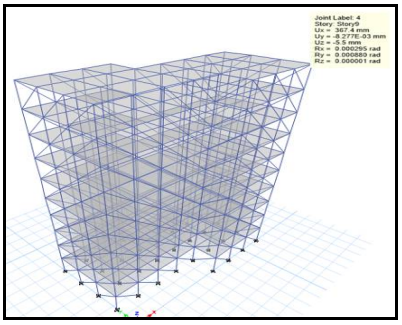
Base shear vs displacement curve

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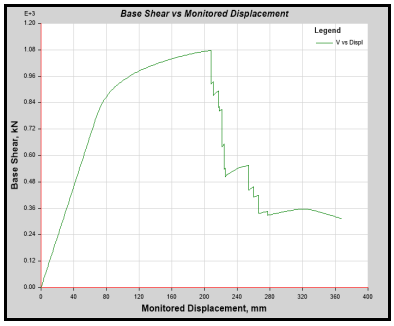
6) BRB-6



Elastic displacement=53mm



In-elastic displacement=367.4mm



Base shear vs displacement curve

III. INFERENCES

Base shear is regarded as the summation of all sorts of earthquake forces that could cause inelastic and elastic deformations. DAF shows the variation of elastic property of the corresponding structure. Since DAF are introduced to predict the expected maximum deformation, it appeared supreme for BRB-5 and BRB-6. Sensible ratio of displacements are exhibited by BRB-2 and BRB-3, indicating their prevailing functionality over other BRBs. Moderate prospect of deformation is seen in BRB-1, thereby deducted their quite good stability after the most economic ones .Ductility demand is defined as the ratio of maximum displacement to the yield displacement. The stability status of the BRBs are determined from the relativeness of this parameter with DAF (AISC 2001). Lesser the percentage of variation between DAF and Ductility Demand, more will be the stability.

Table.6 Shows the Stability status of the proposed BRBs

Model Designation	Ductility Demand	Deflection Amplification Factor	Percentage Variation (%)	Stability status
BRB-1	4.80	5.4	11.11	Good
BRB-2	3.71	4.6	19.34	Good
BRB-3	3.78	4.8	21.25	Good
BRB-4	3	5.3	43.39	Poor
BRB-5	4.53	6.8	33.38	Average
BRB-6	4.80	6.9	30.43	Average

From the table BRB-1, BRB-2 and BRB-3 had shown the good stability status but as per ACI 318, the ratio of ultimate strength to yield strength should be less than 1.25.Taking this codal preference into consideration, the corresponding ratio for BRB-1 obtained is 1.29, since this ratio slightly violated the concerned codal specification, BRB-2 and BRB-3 are regarded as more stable over BRB-1.

IV. CONCLUSIONS

From the work it can be concluded that if we have the elastic deformation of the structure and DAF of BRBs, then we can easily find the in-elastic deformation or maximum capacity of the structure without performing the long time consuming pushover analysis. As DAF is the ratio of in-elastic deformation to elastic deformation. Also from this work we can see that the most effective BRB for buckling resistance is BRB-2 and BRB-3. The peak value of buckling is experienced on the floor level of the structure. Also from the hysteresis curves brace with most stiffness is BRB-2 and BRB-3, as it shows less displacement under higher values of axial load. The hardening property of BRBs further increased the stability characteristics due to modification. The highest range of DAF is attained for BRB-5 and BRB-6, while BRB-2 and BRB-3 acquired economy. The ductility demand is significantly expressed in BRB-2 and BRB-3, indicating good yielding and lesser chance of failure. Poor stability status in terms of ductility demand is shown by BRB-4. Thus the most effective BRB for buckling resistance is BRB-2 and BRB-3.

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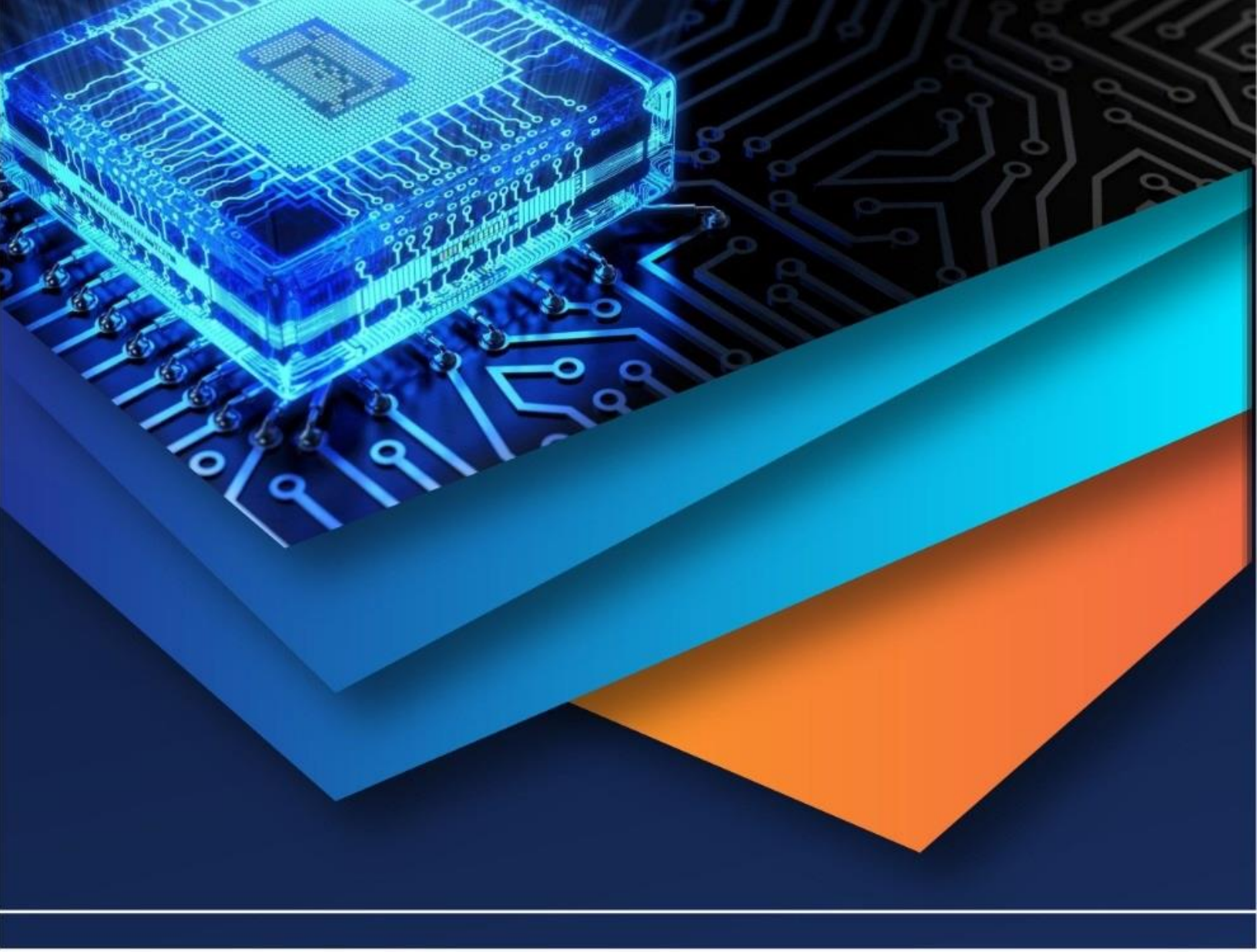
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