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Seismic Response of Multi-Storey Building with Buckling Restrained Brace System

Lepaksharadhya C B[1] and S M Maheshwarappa[2]

Post Graduate Scholar[1] and Associate Professor[2]

Department of Civil Engineering

Siddaganga Institute of Technology

Tumakuru, Karnataka

India

ABSTRACT

Buckling Restrained Braces (BRBs) are made up by a steel core surrounded by a buckling restraining system, coated with an unbonding material. The buckling restrained system prohibits steel core from buckling when in compression. Experimental studies have been carried out to study the behavior of BRBs. Experimental results showed that the BRB exhibit stable hysteresis response with substantial energy dissipation and ductility. Therefore, seismic performance of buildings or other structure can improve effectively by using BRBs. In this work, numerical studies of eleven models were conducted using ETABS software. The numerical tests were carried out in different scenarios, i.e. building the model with a conventional brace system, building models with partial BRBs system and building models with BRBs system. From both equivalent static analysis and response spectrum analysis main findings are the effects of yielding core length on partial replaced BRBs system and BRBs system buildings are significant in controlling or altering base shear, maximum storey displacement and storey drift, and time period. Also, BRBs are effective in reducing the axial force for column and footing.

Key Words: *Buckling Restrained Brace, Yielding Core, Seismic Response, ETABS.*

1. INTRODUCTION

Buckling restrained braced (BRB) frames have been used as lateral load resisting system for both new and retrofit construction from last few years. Buckling restrained brace (BRB) typically made up of by a steel core element which is enclosed in a steel tube filled with concrete or grout such that buckling of the brace under compression is prevented. Thus, total axial load is assumed to be resisted by the core and the outer steel tube only resists buckling of the core element.

BRBs have very good axial hysteresis behavior and compression strength is typically higher than tensile strength. Compression strength showed up to 10-15% higher than tensile strength [12]. BRBs are more effective for reducing storey drifts in buildings than other concentric braced framing or moment framing systems. Maximum average storey drifts in SCBRB system in four storey buildings showed nearly 13% and 28% smaller than that in the braced frame with full core BRBs for both DBE and MCE levels, also decrease in storey drifts in ten storey building is almost 10% for both DBE and MCE levels respectively [14].

BRBs are very effective in controlling storey deformations as well as in reducing column axial forces and frame base shears under high intensity earthquakes [1]. Also values of damping ratio for the frames with BRBs were significantly higher than the cases of bare frames and frames with a conventional brace. Values showed between 6.4% and 10.2% were observed for the cases with BRBs, while values of 0.38% and 0.41% were observed for the bare frames and the frames with a conventional brace respectively [2].

2. PROJECT DESCRIPTION

2.1 Overview

Analysing the behaviour of building with Buckling Restrained Brace System of different yielding core length is the main intent of this study. Analysis has been carried out for eleven models by using ETABS software. Both static and dynamic analyses have been carried out for models with seismic zone factor as 0.36 and soil type as type-I.

2.2 Objectives

- To determine effect of yielding core length of BRBs on seismic response of multi-storey building by varying the yielding core length.
- To determine effect of partial and full replacement of BRBs on seismic response of multi-storey building.

3. MODELLING

3.1 Structure Dimensions

Fig.3.1 shows the building models dimensions used in this study. The height of the building is 70m while the span measured 7m from centre to centre of columns. There are 6 bays along X-axis and 4 bays along Y-axis. They have bracing at periphery in middle two bays of all four sides.

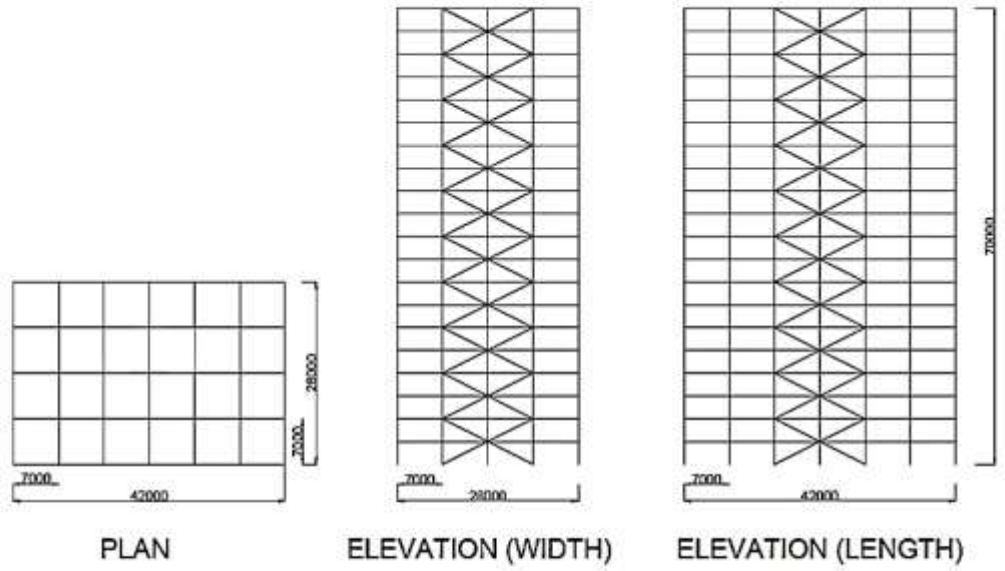

Fig.3.1 Structure Dimensions (Plan, Elevation along Width and Length)

3.2 Material Property

Tables 3.1 to 3.3 illustrate the property of materials used in this study. There are 3 materials; they are M30 grade concrete, HYSD500 grade rebar and Fe250 grade steel.

Table.3.1 Concrete Property

Material Name	M30
Directional Symmetric Type	Isotropic
Weight per Unit Volume	24.9926kg/m^3
Modulus of Elasticity, E	27386.13MPa
Poisson’s Ratio, U	0.2
Coefficient of Thermal Expansion, A	0.0000055C^{-1}

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Shear Modulus, G	11410.89MPa
Compressive Strength, f_{ck}	30MPa

Table.3.2 Rebar Property

Material Name	HYSD500
Directional Symmetry Type	Uniaxial
Weight per Unit Volume	76.9729kN/m^3
Modulus of Elasticity, E	200000MPa
Coefficient of Thermal Expansion, A	0.0000117C^{-1}
Minimum Yield Strength, F_y	500MPa
Minimum Tensile Strength, F_u	545MPa
Expected Yield Strength, F_{ye}	550MPa
Expected Tensile Strength, F_{ue}	599.5MPa

Table.5.3 Steel Property

Material Name	Fe250
Directional Symmetry Type	Isotropic
Weight per Unit Volume	76.9729kN/m^3
Modulus of Elasticity, E	210000MPa
Poisson's Ratio, U	0.3
Coefficient of Thermal Expansion, A	0.0000117C^{-1}
Shear Modulus, G	80769.23MPa
Minimum Yield Stress, F_y	250MPa
Minimum Tensile Strength, F_u	410MPa
Effective Yield Stress, F_{ye}	275MPa
Effective Yield Strength, F_{ue}	451MPa

3.3 Models

Total of 11 models (including conventional brace system building model) are created, material property and section are kept constant for all these models. But, braces are kept as different property and section by maintaining same member stiffness.

3.3.1 Models classification:

These are categorised into three groups for achieving objectives;

1. Model of multi-storey building with conventional brace system
   - 2CP
2. Models of multi-storey buildings with partial BRB system of different yielding core length
   - 1BP(100)+1CP
   - 1BP(80)+1CP

- 1BP(60)+1CP
- 1BP(40)+1CP
- 1BP(20)+1CP

3. Models of multi-storey buildings with BRB system of different yielding core length
    - 2BP(100)
    - 2BP(80)
    - 2BP(60)
    - 2BP(40)
    - 2BP(20)

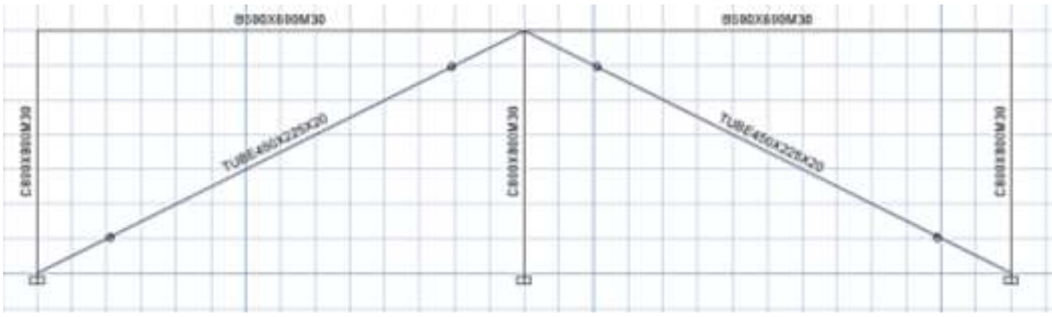

Fig.3.2 Frames with Conventional Brace System

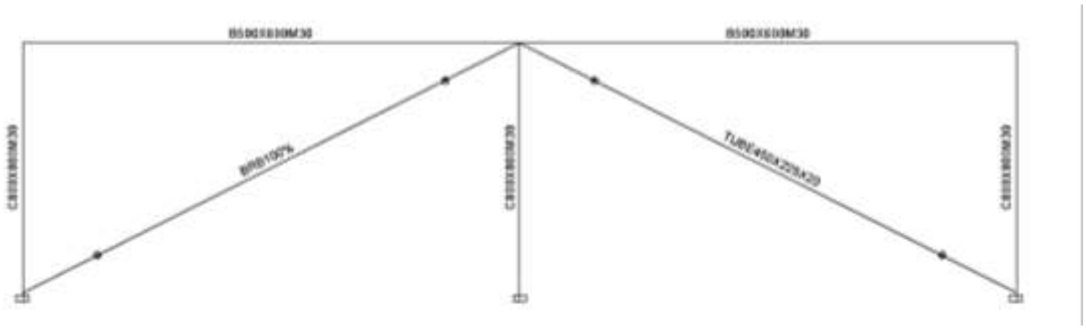

Fig.3.3 Frames with Partial BRB System

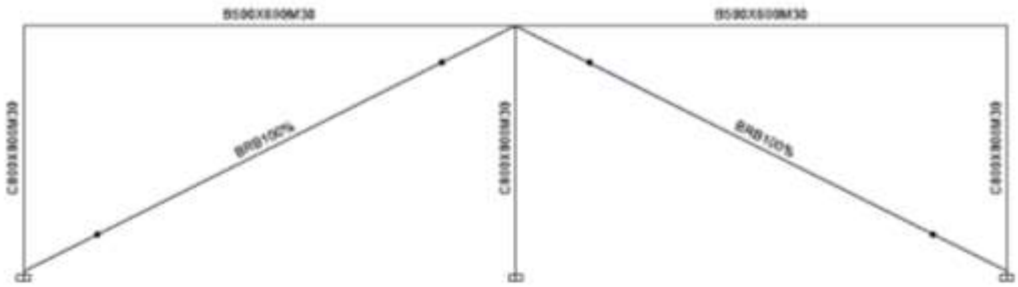

Fig.3.4 Frames with BRB System

*****CP = Conventional Bracing with Pinned End
******BP = Buckling Restrained Bracing with Pinned End.

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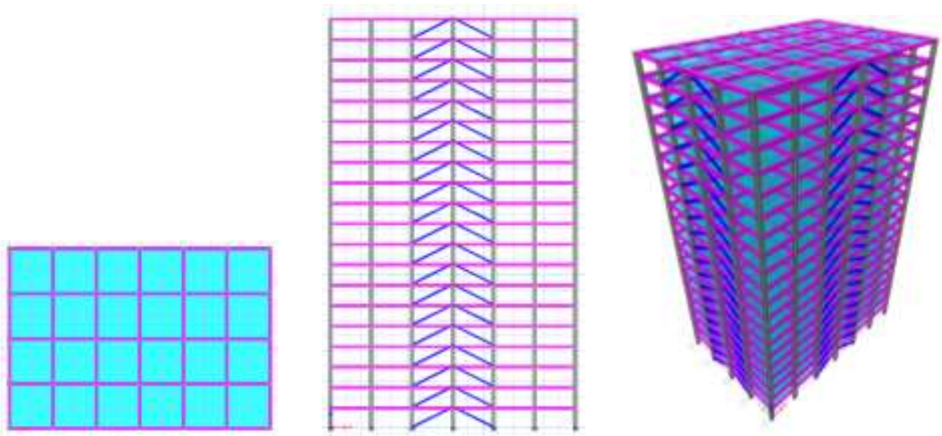

(a) Plan (b) Elevation (c) 3D View

Fig.3.5 ETABS Model of Multi-storey Building with Different Structural Members

4. RESULTS AND DISCUSSION

4.1 Base Shear

Table.4.1 Results of Base Shear

MODEL	YIELDING CORE LENGTH (%)	BASE SHEAR (KN)				MODEL TYPE
		ESX	ESY	RSX	RSY	
2CP	—	7792.03	7575.45	7792.05	7575.44	Models of multi-storey building with conventional brace system
1BP(100)+1CP	100	7578.82	7285.49	7578.82	7285.47	Models of multi-storey buildings with partial BRB system of different yielding core length
1BP(80)+1CP	80	7551.25	7259.06	7551.26	7259.05	
1BP(60)+1CP	60	7514.06	7223.37	7514.05	7223.37	
1BP(40)+1CP	40	7457.57	7169.1	7457.55	7169.08	
1BP(20)+1CP	20	7383.11	7097.41	7383.1	7097.42	
2BP(100)	100	7377.45	7012.37	7377.44	7012.37	Models of multi-storey buildings with BRB system of different yielding core length
2BP(80)	80	7323.93	6961.61	7323.92	6961.61	
2BP(60)	60	7252.23	6893.51	7252.22	6893.51	
2BP(40)	40	7143.89	6790.45	7143.41	6790.46	
2BP(20)	20	7002.93	6656.05	7002.94	6656.06	

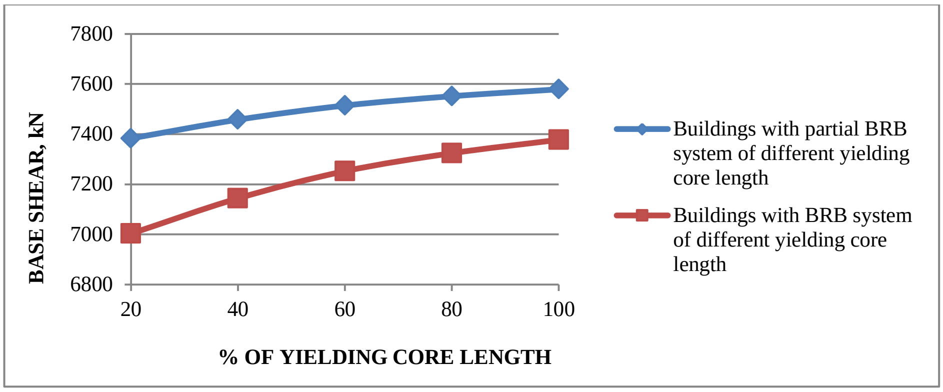

Fig.4.1 Effect of Yielding Core Length on Base Shears for Equivalent Static Force along X- Axis

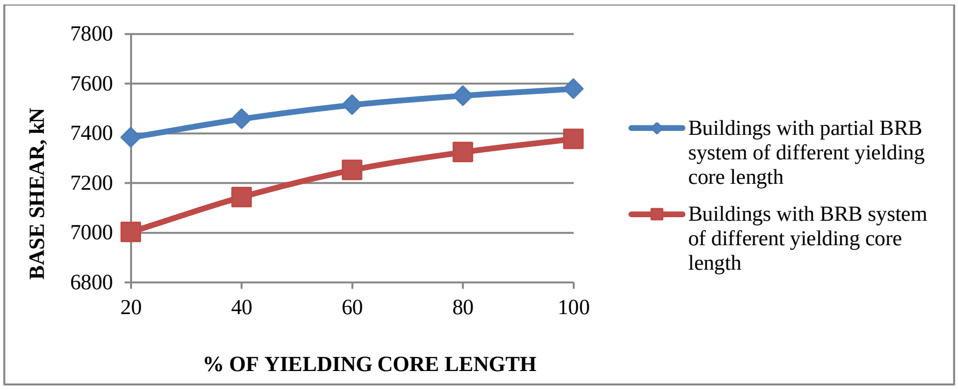

Fig.4.2 Effect of Yielding Core Length on Base Shears for Response Spectrum Force along X- Axis

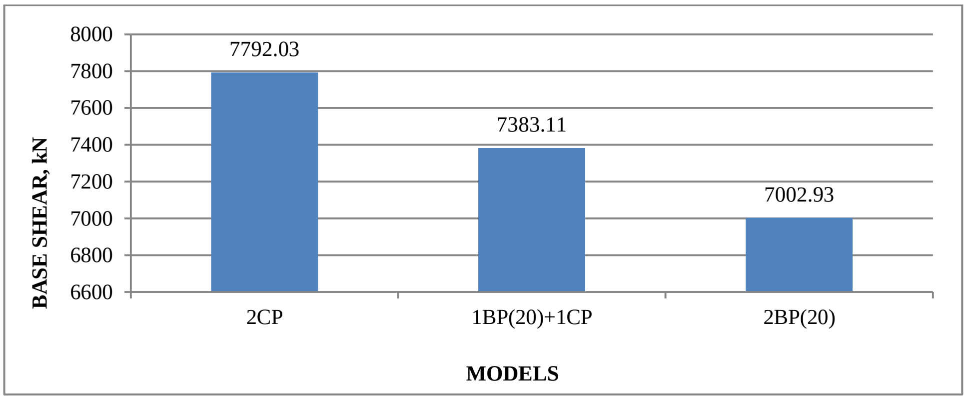

Fig.4.3 Effect of Replacement by BRBs on Base Shears for Equivalent Static Force along X- Axis

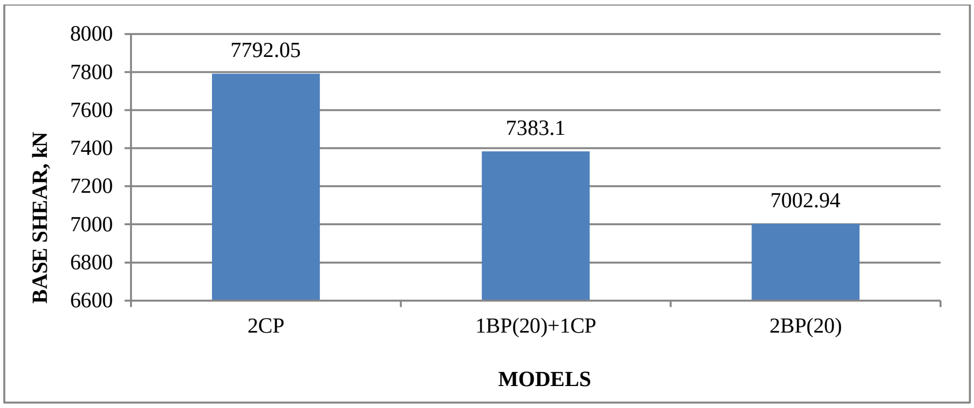

Fig.4.4 Effect of Replacement by BRBs on Base Shears for Response Spectrum Force along X- Axis

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Table.4.1 summarizes base shear results of all the models. The base shears of partial replaced BRBs system and complete replaced BRBs system models of buildings are significantly lesser than the conventional braces system models of buildings. Model 2CP has 7792.03 KN and 7575.45 KN base shear along X and Y direction respectively.

Models of partially replaced BRBs system with varying yielding core length have less base shear than conventional up to 5.25% and 6.31% along X and Y direction respectively. Fig.4.1 and 4.2 show concave down that both represent rate of decreasing increases with decreasing the yielding core length. Effect of yielding core length on partial replaced BRBs system is not much significant in controlling or altering base shear.

Models of completely replaced BRBs system or Models of BRBs system with varying yielding core length have less base shear than conventional up to 10.13% and 12.14% along X and Y direction respectively. The base shear also less than partial replaced BRBs system. Fig.4.1 and 4.2 show concave down that both represent rate of decreasing increases with decreasing the yielding core length. Effect of yielding core length on BRBs system is significant in controlling or altering base shear.

4.2 Storey Displacement

Table.4.2 Results of Max Storey Displacement

MODEL	YIELDING CORE LENGTH (%)	MAX. STOREY DISPLACEMENT (mm)				MODEL TYPE
		ESX	ESY	RSX	RSY	
2CP	—	59.97	62.54	44.52	45.64	Models of multi-storey building with conventional brace system
1BP(100)+1CP	100	59.13	60.99	44.01	44.68	Models of multi-storey buildings with partial BRB system of different yielding core length
1BP(80)+1CP	80	59.23	61.09	44.13	44.81	
1BP(60)+1CP	60	59.33	61.2	44.25	44.97	
1BP(40)+1CP	40	59.56	61.43	44.52	45.25	
1BP(20)+1CP	20	59.86	61.73	44.87	45.59	
2BP(100)	100	58.32	59.47	43.51	43.7	Models of multi-storey buildings with BRB system of different yielding core length
2BP(80)	80	58.51	59.66	43.76	43.97	
2BP(60)	60	58.72	59.88	44.06	44.28	
2BP(40)	40	59.17	60.34	44.6	44.84	
2BP(20)	20	59.74	60.92	45.26	45.53	

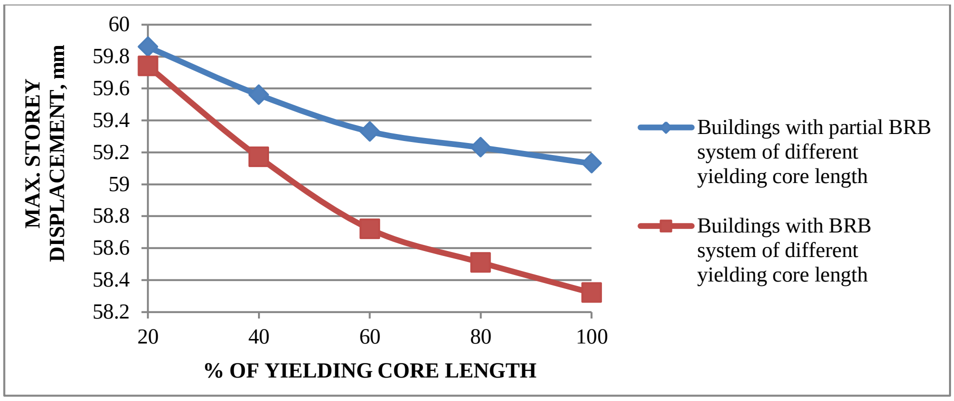

Fig.4.5 Effect of Yielding Core Length on Max Storey Displacements for Equivalent Static Force along X- Axis

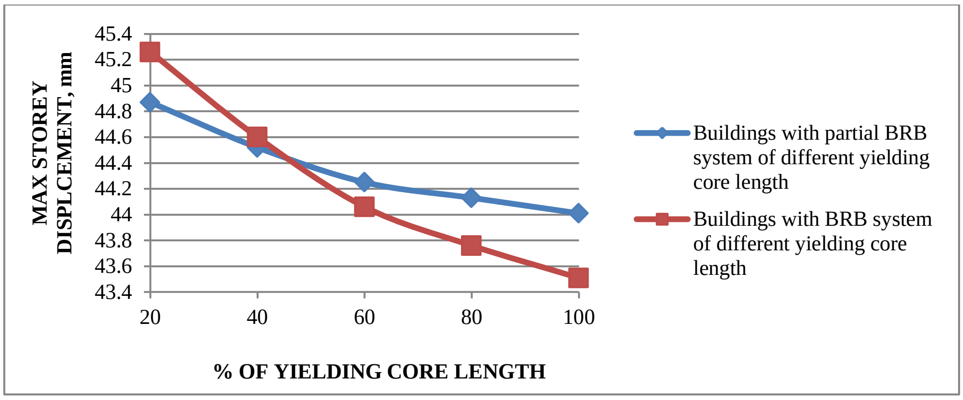

Fig.4.6 Effect of Yielding Core Length on Max Storey Displacements for Response Spectrum Force along X- Axis

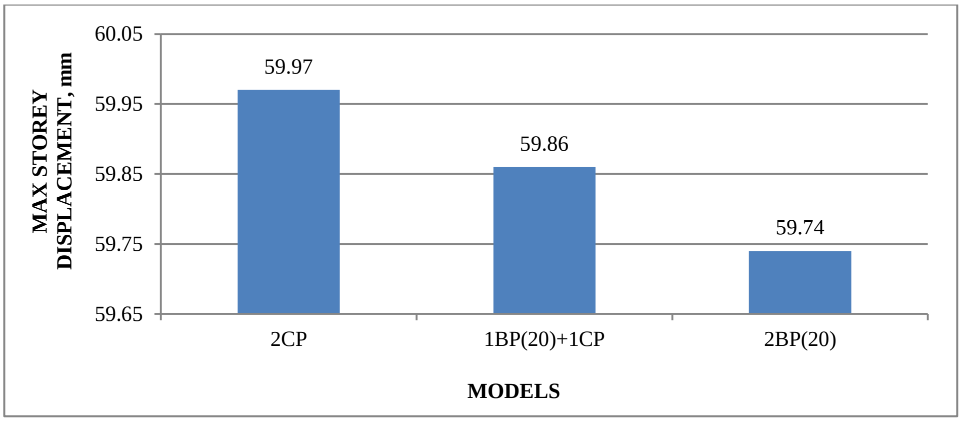

Fig.4.7 Effect of Replacement by BRBs on Max Storey Displacements for Equivalent Static Force along X- Axis

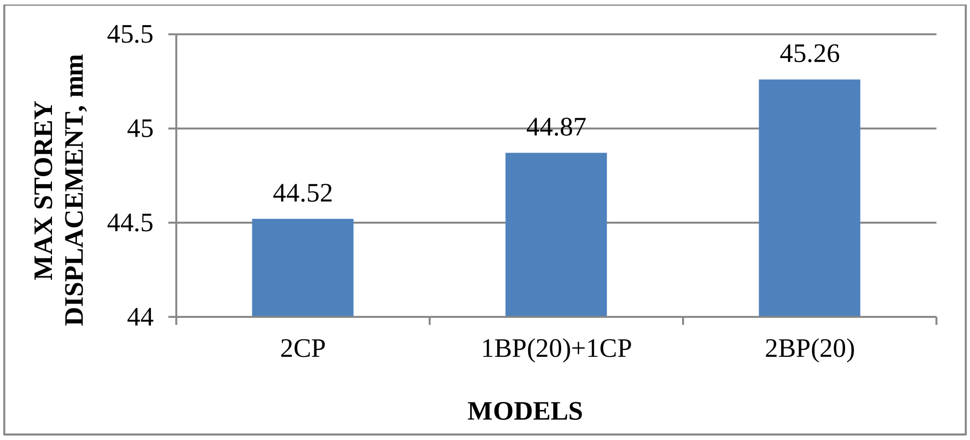

Fig.4.8 Effect of Replacement by BRBs on Max Storey Displacements for Response Spectrum Force along X- Axis

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Table.4.2 summarizes maximum storey displacement results of all the models. The maximum storey displacements of all models of buildings are approximately nearer. But along Y axis have 4.91% and 3.66% less maximum storey displacement than conventional brace system models. This result shows higher percentage of BRB of 100% yielding core length are more effective in reducing maximum storey displacement.

4.3 Max. Storey Drift

Table.4.3 Results of Max Storey Drift

MODEL	YIELDING CORE LENGTH (%)	MAX. STOREY DRIFT				MODEL TYPE
		ESX	ESY	RSX	RSY	
2CP	—	0.001	0.0011	0.0008	0.0008	Models of multi-storey building with conventional brace system
1BP(100)+1CP	100	0.001	0.001	0.0008	0.0008	Models of multi-storey buildings with partial BRB system of different yielding core length
1BP(80)+1CP	80	0.001	0.001	0.0008	0.0008	
1BP(60)+1CP	60	0.001	0.001	0.0008	0.0008	
1BP(40)+1CP	40	0.001	0.0011	0.0008	0.0008	
1BP(20)+1CP	20	0.001	0.0011	0.0008	0.0008	
2BP(100)	100	0.001	0.001	0.0008	0.0008	Models of multi-storey buildings with BRB system of different yielding core length
2BP(80)	80	0.001	0.001	0.0008	0.0008	
2BP(60)	60	0.001	0.001	0.0008	0.0008	
2BP(40)	40	0.001	0.001	0.0008	0.0008	
2BP(20)	20	0.001	0.001	0.0008	0.0008	

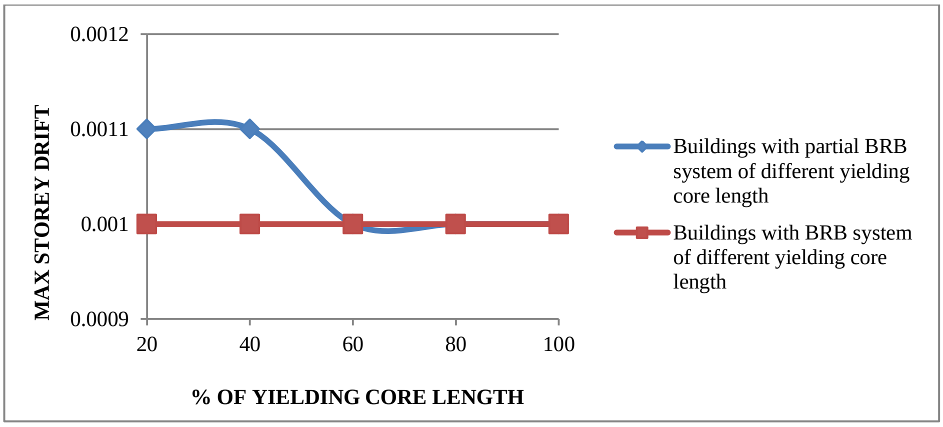

Fig.4.9 Effect of Yielding Core Length on Max Storey Drifts for Equivalent Static Force along Y- Axis

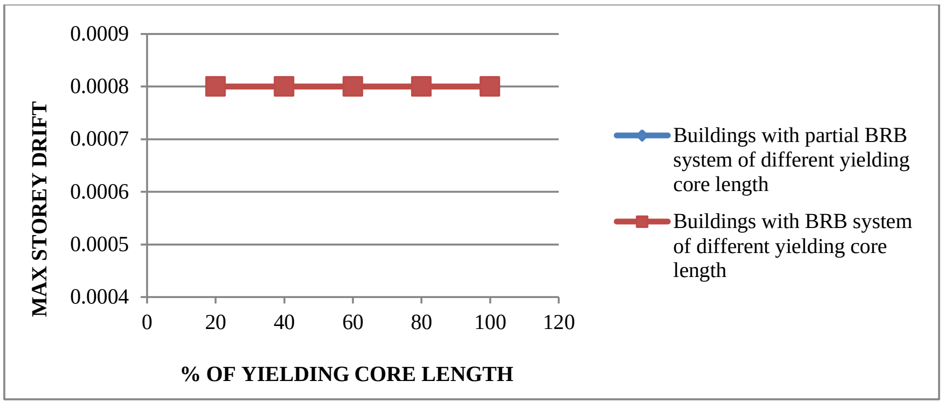

Fig.4.10 Effect of Yielding Core Length on Max Storey Drifts for Response spectrum Force along X- Axis

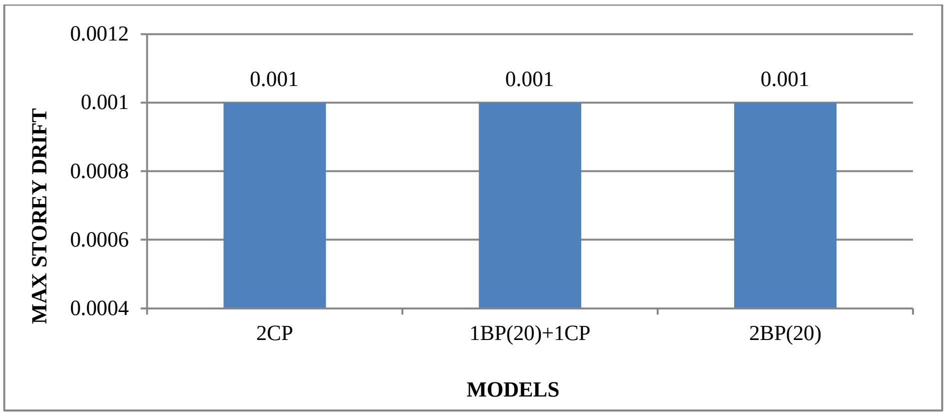

Fig.4.11 Effect of Replacement by BRBs on Max Storey Drifts for Equivalent Static Force along X- Axis

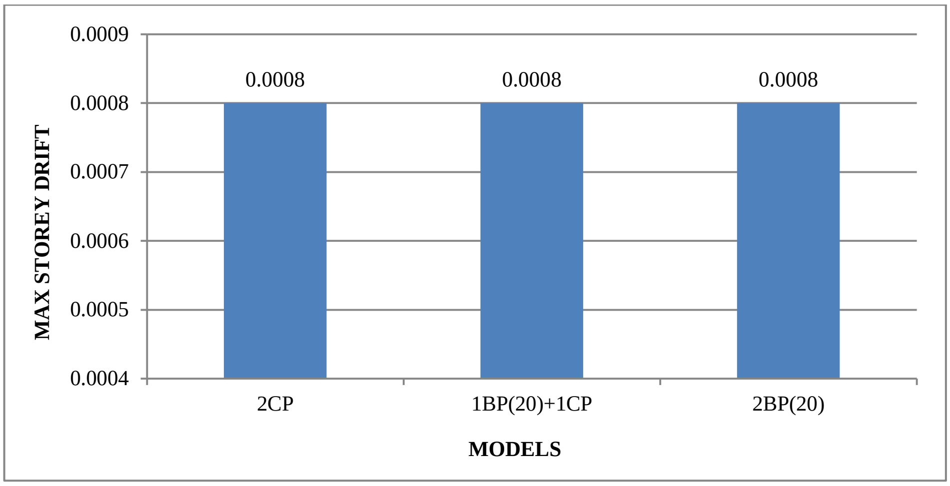

Fig.4.12 Effect of Replacement by BRBs on Max Storey Drifts for Response Spectrum Force along X- Axis

Table.4.3 summarizes maximum storey drift results of models. The maximum storey drifts of all building models are similar except along Y axis under equivalent static force. Maximum storey drift along Y axis for equivalent force has less value up to 9.09% than conventional brace system building model. This result shows BRBs are more effective in reducing drift when higher numbers of BRBs are used.

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4.4 Time Period

Table.4.4 Results of Time Period

MODEL	TIME PERIOD (sec)
2CP	2.012
1BP(100)+1CP	2.04
1BP(80)+1CP	2.046
1BP(60)+1CP	2.054
1BP(40)+1CP	2.069
1BP(20)+1CP	2.088
2BP(100)	2.068
2BP(80)	2.081
2BP(60)	2.098
2BP(40)	2.128
2BP(20)	2.166

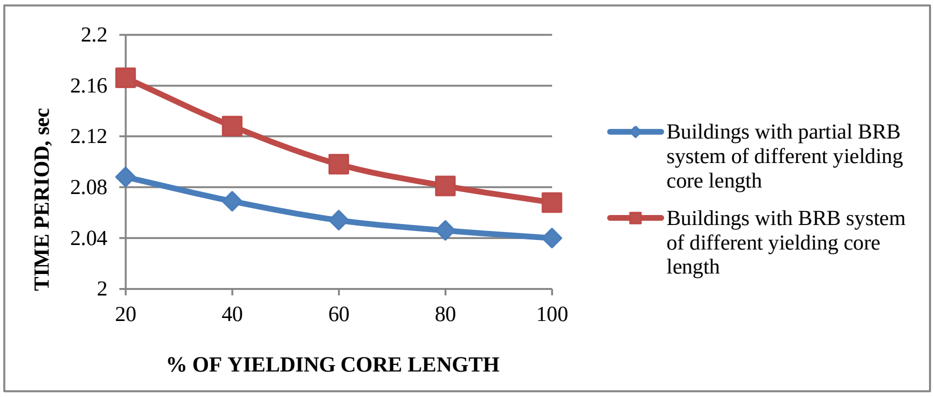

Fig.4.13 Effect of Yielding Core Length on Time Period of Buildings

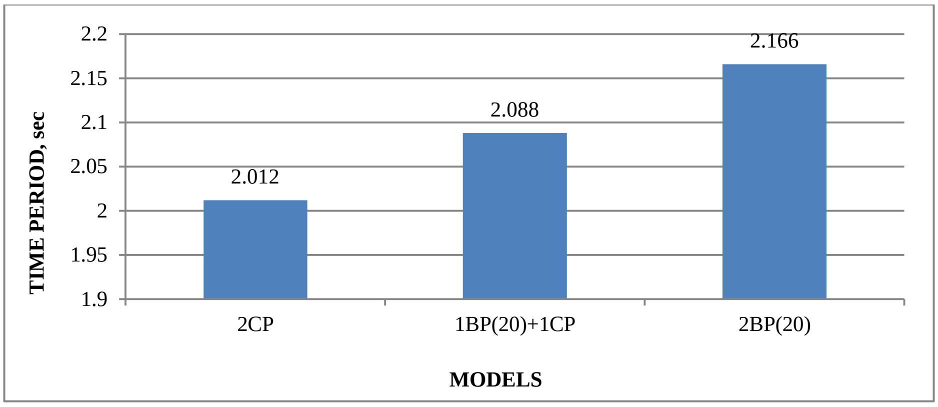

Fig.4.14 Effect of Replacement by BRBs on Time Period of Buildings

Table.4.4 summarizes time period results of all the models. The time period of partial replaced BRBs system and complete replaced BRBs system models of buildings are significantly higher than the conventional braces system models of buildings. Model 2CP has 2.012 sec time period.

Models of partially replaced BRBs system with varying yielding core length have more time period than conventional up to 3.78%. Fig.8.25 shows concave up that shows rate of increasing increases with decreasing the yielding core length. Effect of yielding core length on partial replaced BRBs system is not much significant in controlling or altering time period.

Models of completely replaced BRBs system or Models of BRBs system with varying yielding core length have more time period than conventional up to 7.65%. The time period also more than partial replaced BRBs system. Fig.8.25 shows concave up that shows rate of increasing increases with decreasing the yielding core length. Effect of yielding core length on BRBs system is significant in controlling or altering time period.

4.5 Axial Force

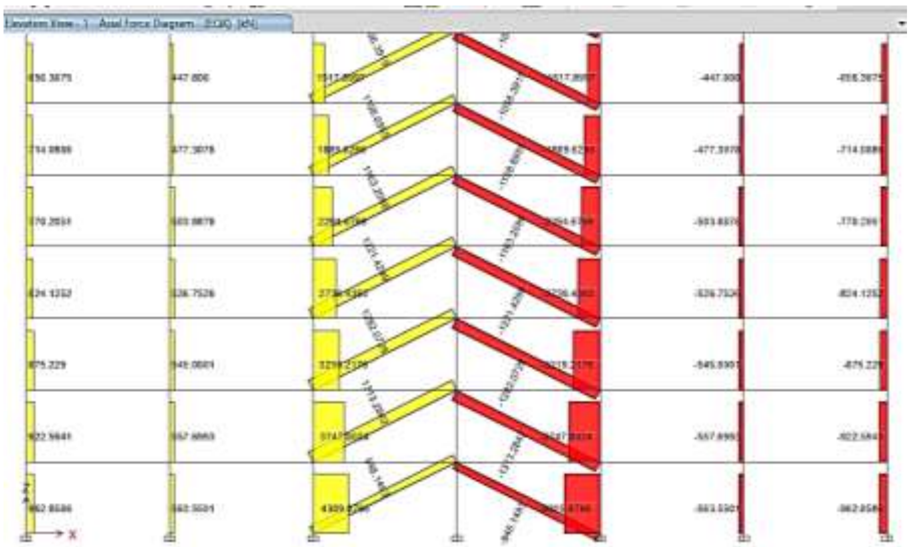

Fig.4.15 Axial Force Diagram of 2CP Model (Elevation-1)

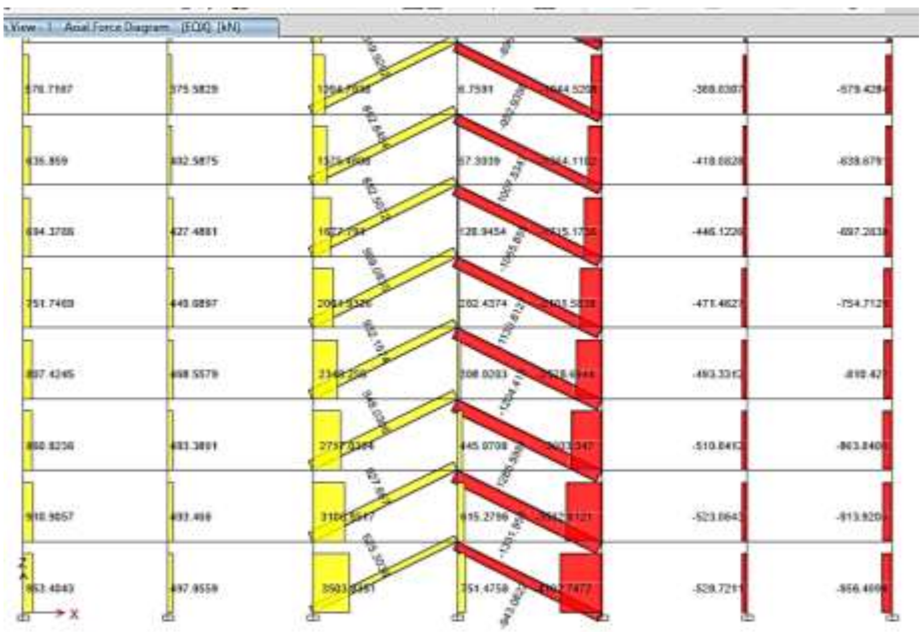

Fig.4.16 Axial Force Diagram of 1BP(20)+1CP Model (Elevation-1)

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Fig.4.17 Axial Force Diagram of 2BP(20) Model (Elevation-1)

Fig.4.15 to 4.17 illustrates axial force diagrams. The result shows as BRBs are effective in reducing axial force for column and footing. Columns associated with BRBs have got up to 22.71% and 23.77% less axial force than columns associated with conventional steel braces along X and Y direction respectively.

5. CONCLUSION

Numerical studies of eleven models were carried out by using ETABS software. The numerical tests were carried out for different scenarios, i.e. building model with conventional brace system, building models with partial BRBs system and building models with BRBs system. The main findings are listed below:

- The value of base shear decreases with decreasing of yielding segment length of BRBs. Building with BRB system of yielding segment length equals to 20% in total length has 10.13% and 12.14% less base shear than building with conventional steel brace system along X and Y direction respectively.
- Buildings with partial replaced BRBs system are not showing significant result. It is nearer to 50% performance of fully replaced BRBs for conventional steel brace system.
- Maximum storey drifts of all building models are similar except along Y axis under equivalent static force. Maximum storey drift along Y axis for equivalent force has lesser by 9.09% than conventional brace system building model. This result shows BRBs are more effective in reducing drift when higher numbers of BRBs are used.
- Effect of yielding core length on partial replaced BRBs system and BRBs system buildings are significant in controlling or altering base shear, maximum storey displacement and storey drift, and time period.
- BRBs are effective in reducing axial force for column and footing. In this work, columns associated with BRBs have got up to 22.71% and 23.77% less axial force than columns associated with conventional steel braces along X and Y axis respectively.

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