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Analysis of Seismic Performance of an RC Building Retrofitted with Buckling Restrained Braces

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Abstract: **-- According to recent earthquake histories, damages and collapses in structures caused greater loss in life and property. So, it is very important to develop an alternate method to enhance the earthquake resistance of building by more realistic approaches to seismic retrofitting after examining the current building codes. The main aim of seismic retrofitting is increasing lateral strength, strength and ductility. Buckling restrained braces (BRBs) is used for retrofitting with the property to yield both in tension and compression and also increases strength and stiffness. This study presents, analysing G+6 storey RC building seismically retrofitted with BRBs having storey-height 3m for gravity and seismic loads for desired parameters such as storey-displacement relation, base shear, inter storey drift etc. The configurations of BRB used in this study are inverted V, V bracing, cross, forward and backward diagonal configuration. The comparative study between building with and without BRBs is done.**

Index Terms: **-- Buckling restrained braces, RC frame, time history analysis, roof displacement, storey drift**

I. INTRODUCTION

Framed systems have been extensively used for building structures in earthquake-prone regions because of their seismic performance. However, a number of existing reinforced concrete (RC) framed building structures were designed for gravity loads only and hence do not possess adequate lateral stiffness and resistance; seismic details are also lacking as observed during surveys carried out in the aftermath of recent earthquakes worldwide[1]. According to recent survey, it is clear that earthquakes in Nepal and Gujarat adversely affected the areas. The earthquake in Nepal 2015, with magnitude 7.8Mw killed over 8,000 humans and injured greater than 21,000 and made thousands of human beings homeless with entire villages flattened, across many districts of the country.

The Bhuj earthquake in 2001, Gujarat with value 7.7Mw killed about 12,300 people. Considerable damage additionally took place in Bhachau and Anjar with hundreds of villages flattened in Taluka of Anjar, Bhuj & Bhachau. Over a million structures were destroyed, inclusive of many historic buildings and traveller attractions [2]. While observing the buildings after these latest earthquakes it's been observed that those existing reinforced concrete framed buildings had been designed most effective for gravity loads and not for earthquake loads, so such buildings do not possess adequate lateral stiffness and resistance. Many existing reinforced concrete buildings need retrofitted to overcome deficiencies to resist seismic loads. The use of steel bracing systems for strengthening seismically inadequate reinforced concrete frames is a viable solution for enhancing earthquake resistance. Steel bracing is economical, easy to erect, occupies less space and has flexibility to design for meeting the required strength and stiffness.

The most common structural configurations for bracings are concentrically braced frames (CBFs), which possess a lateral stiffness significantly higher than that of unbraced frame. Frames with BRBs are used for new and existing structures, particularly for damaged controlled structures. Buckling restrained braces (BRBs) have gained quality within the U.S. and different countries around the world recently owing to their basic property of yielding both in tension and compression. Another advantage of BRBs is that they add stiffness to the structure, leading to attainable reduction in the framed member sizes whereas achieving constant performance level [3].

II. BUCKLING RESTRAINED BRACE FRAMED SYSTEM

Buckling restrained braces are modified from concentrically braced framed systems. Buckling-restrained braces (BRBs) do not exhibit any unfavorable behavior characteristics of conventional braces. BRBs have full, balanced hysteretic behavior with compression yielding similar to tension-yielding behavior. They achieve this through the decoupling of the stress resisting and flexural-buckling resisting aspects of compression strength. The steel core resists axial stresses. Because the steel core is restrained from buckling, it develops almost uniform axial strains across the section. Thus it is an innovative method of seismic retrofitting in existing buildings.

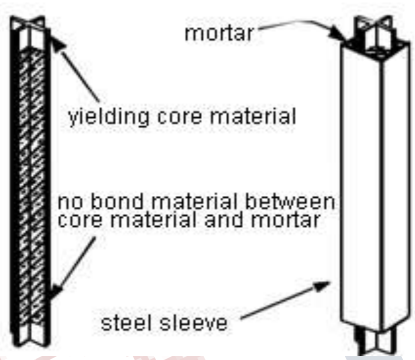

Figure 1: Schematic diagram of buckling restrained brace [4]

The buckling restrained brace (BRB) was invented in the 1970s, and active research has been conducted since then to improve its performance. While its purpose is mainly to provide stiffness to framed structures, only limited research on the structural dynamic response of buckling restrained braced frames (BRBFs) has been performed until recently to fully exploit the benefits of having BRBs installed. This research attempts to better understand the behavior of BRBFs when subjected to seismic loading. The schematic diagram of buckling restrained brace is shown in Figure 1.The components of BRBs are core steel, steel tube casing, confined infill concrete.

Seismic Retrofitting Strategy Using BRBd Building

The design of new and existing structures with hysteretic buckling restrained braces generally comprises the following:

- ❖ The estimation of the optimum parameters for the dissipative braces by using implied methods.
- ❖ The application of capacity design checks for all members of the braces, e.g. the yielding force of the BRBs.
- ❖ The verification of the design performance, preferably through time history analysis.

Modelling of BRB

Buckling restrained braces can be used in new construction as well as for upgrading the existing buildings with poor ductility where additional stiffness, strength and energy dissipation is needed.

Deulkar W. N. et. al. designed BRB element is as follows:

- ❖ Determine the design seismic base shear V_B with critical damping 5% according to IS 1893:Part I 2002
- ❖ Distribute the seismic horizontal forces along the height of the building based on the formula

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2} \qquad (1)$$

, where W is the seismic weight and h is the storey height with respect to the ground level

- ❖ Determine the axial forces (F_{br}) in the diagonal braces assuming that the existing frame has pinned beam-to-column and base-column connections

$$F_{br} = \frac{1}{n} \frac{V_i}{\cos\alpha} \qquad (2)$$

,where V_i is the seismic storey shear at the ith floor , n the number of storeys and α is the angle of the braces with respect to the horizontal beams which is taken as 45°

- ❖ The required cross sectional area of the brace is A_{br}

$$A_{br} = \frac{F_{br}}{f_y} \qquad (3)$$

,where f_y is the yield stress of steel used
The dimensions is then formulated and the design procedure is done

III. MODELLING AND ANALYSIS OF BUILDING

A. *Building Description*

The (G+6) RCC multi storey building considered for analysis to know the realistic behavior during

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earthquake with the general form of plan and elevation is shown in Figure 2 and Figure 3. The building is proposed in Kadakkal, Kollam. Building is modeled for Indian seismic zone III IS:1893- 2002. Plan dimension in X and Y direction is 17.6 m and 16m respectively.

The buildings has following dimensions,
Columns size 200mmx500mm and 200mm x600mm,
Beam size. 200mmx500mm and 200mm x600mm
Floor slabs are taken as 120mm thick.
The height of all floors is 3m.
Soil type is medium.
Modal damping 5% is considered.
Material concrete grade is M25
Steel Fe415 is used.

For given structure, loading which applied includes live load, earthquake load and dead load are according to IS 875 part I, Part II and IS 1893:2002 respectively.

Live load on Staircase – 3 kN/m^2
Live load on floor slab – 2 kN/m^2
Live load on terrace floor - 4 kN/m^2

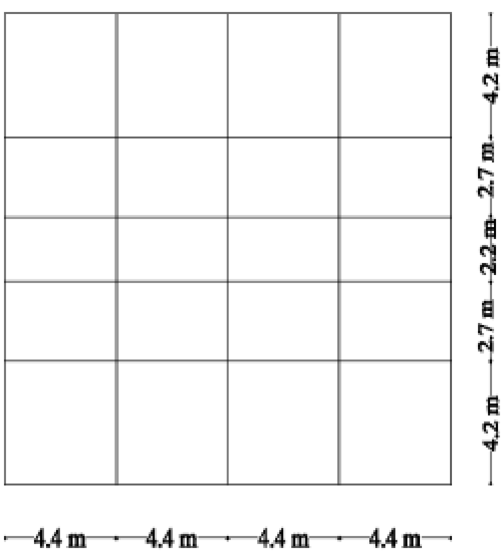

Figure 2: Plan of the building

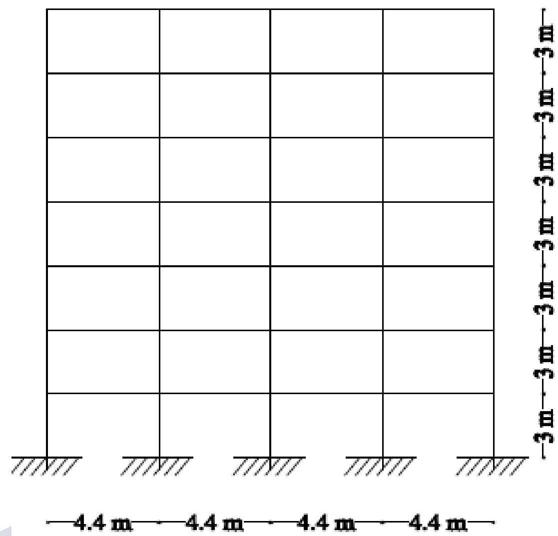

Figure 3: Elevation of the building

B. BRB details

After analyzing the building the base shear is found out. From this the force acting on individual BRB s calculated and the dimensions of the BRB specimen are decided using specifications. The geometric properties of the BRB elements are summarized in table 1

Table 1: Geometry properties of BRBs

BRB name	Dimensions of cross-section (mm)	Area of yielding zone (mm^2)
CEW 800	20×40	800
CEW 825	15×55	825

Seismic Analysis

Total 6 models are analyzed in this study.
- One bare frame model.
- One model of backward diagonal bracing
- One model of forward diagonal bracing
- One model of V bracing
- One model of cross diagonal or X bracing
- One model of inverted V bracing

Modeling and Analysis of the Bare Frame

Analysis of building with DL, LL, seismic load and wind load is done and results are obtained.

Wind load Analysis

Wind analysis is done according to IS 875: Part(3) 1987 . According to clause 5.3.2 and the design wind pressure,

P_z= 824.7N/mm^2

The wind loads is assigned to the building using SAP2000 and analysis is done. The maximum top storey displacement is found to be 34.907mm at joint 182

Seismic load analysis

El-Centro 1940 time history function is used for the time history analysis of the building subjected to seismic loads in SAP2000. The maximum top storey displacement is found to be 62.23mm at joint 193.

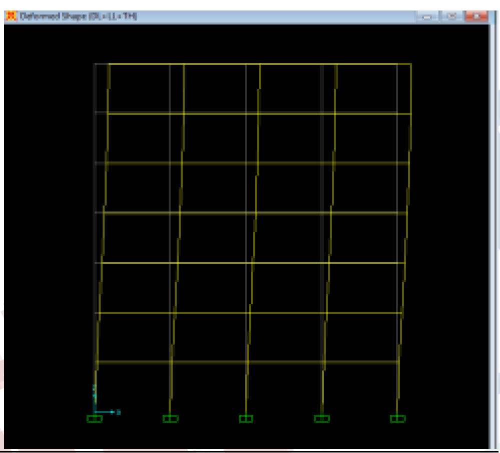

Figure 4: Deformed shape of the building

Results

The graph is plotted for roof displacements vs. storey level for 7-storey 2D bare frame as shown in Figure 5.

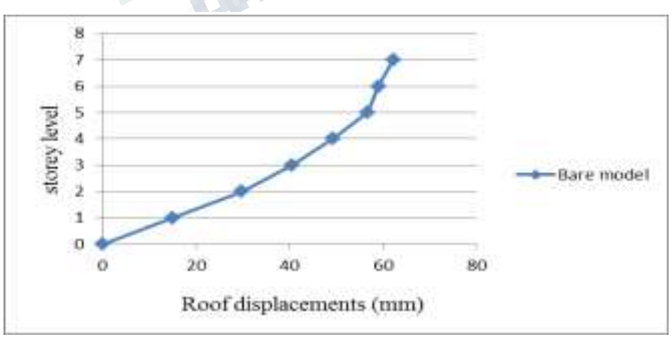

Figure 5: Roof displacements vs. storey level for 7-storey 2D bare frame

Modelling and Analysis of Frame with different BRB Configuration

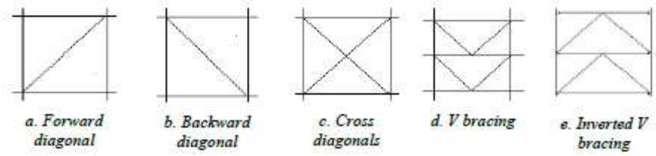

Figure 6: Bracing configuration [16]

The seismic analysis of buildings with different types of bracing configuration is done. Diagonal, V type, Inverted V type, X type or cross type bracing configurations are commonly used. The bracing is provided for peripheral columns and any two parallel sides of building model. Figure 6 shows the bracing configuration used in building.

IV. RESULT AND DISCUSSION

The seismic response of RC frames braced with buckling restrained braces (BRB) has been studied. The important parameters associated are displacements, inter-storey drift, base reactions and the energy dissipation capacity of the building. The time history analysis using El-Centro 1940 earthquake is done for six cases using SAP 2000 software. The study presents the results of response of unbraced and braced frames with different BRB configurations.

A. Storey Displacements and Inter-storey Drift for Unbraced Frame and Frame Braced with BRBs

The storey displacements of the unbraced frame and frame braced with BRBs are studied and shown in Figure 7. It can be seen that the building with inverted V bracing shows less storey displacement, which in turns increases the stiffness and strength of the structure. The roof displacements vs. storey level for 7-storey 2D frame braced with for different BRB is shown in Table 2.

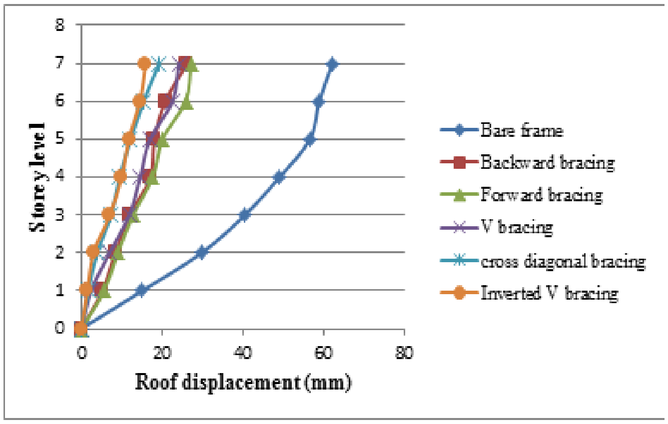

Figure 7: Roof displacements vs. storey level for 7-storey 2D frame braced with for different BRB

Table 2: Storey displacement (mm) of frame with different BRB configuration in storey level

Storey level	Displacements (mm)					
	Bare frame	Backward bracing	Forward bracing	V bracing	cross diagonal bracing	Inverted V bracing
7	62.23	26.21	27.21	24.19	19.25	14.15
6	59.02	24.81	25.84	23.05	18.53	13.82
5	56.68	18.106	20.1	17.03	12.16	11.77
4	49.181	17.09	17.71	14.55	9.45	10
3	40.55	12.02	12.8	11.86	7.34	7.03
2	29.82	8.37	9.02	6.96	3.88	2.97
1	15.08	5.21	5.56	2.37	1.72	1.46
0	0	0	0	0	0	0

Table 3 shows the reduction in roof displacement with respect to bare frame for different BRB configuration and it can be concluded that the ductility of the building is increased; hence the displacements are decreased for braced frames.

Table 3: Reduction in roof displacement with respect to bare frame for different BRB configuration

Different BRB configuration	**Reduction in roof displacement with respect to bare frame**
Backward bracing	57.88%
Forward bracing	56.27%
V bracing	61.12%
Cross diagonal bracing	69.06%
Inverted V bracing	77.26%

A comparison of inter-storey drift obtained for original and braced frames for five different configurations, number of storeys is shown in Figure 8. The inter-storey drifts are generally expressed as ratios δ/h of displacements, where δ is the difference in displacements of consecutive floors and h is the storey height. The addition of steel bracings reduces maximum inter-storey drift and distributed more uniformly along the height of structure.

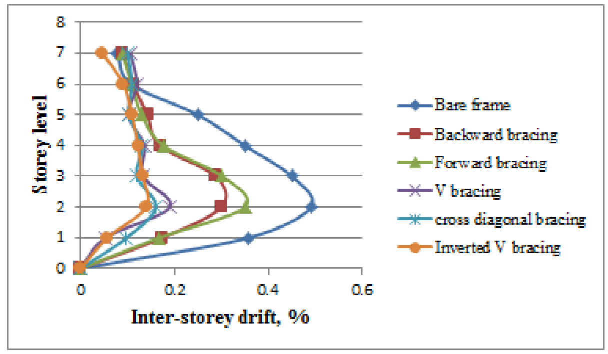

Figure 8: Inter-storey drift vs. storey level for7-storey 2D frame braced withfor different BRBs

Table 4 shows the inter-storey drift values obtained for each storey of the building. The values of inter-storey drifts of retrofitted buildings are within limits, 0.5% (ACI-318-08: Clause 21.13.6).

Table 4: Inter-storey drift (%) of frame with different BRB configuration in storey level

Storey level	Inter-storey drifts (%)					
	Bare frame	Backward bracing	Forward bracing	V bracing	cross diagonal bracing	Inverted V bracing
7	0.107	0.046	0.045	0.038	0.024	0.011
6	0.078	0.09	0.191	0.200	0.212	0.068
5	0.24997	0.1421	0.13	0.1021	0.103	0.1093
4	0.3502	0.1689	0.1763	0.1353	0.13	0.1221
3	0.4501	0.288	0.302	0.132	0.12	0.132
2	0.49133	0.3001	0.35	0.19	0.16	0.1401
1	0.357	0.1736	0.167	0.053	0.098	0.057
0	0	0	0	0	0	0

Table 5 shows the reduction in inter-storey with respect to bare frame for different BRB configuration and it can be noted that there is large variation and hence BRBs are effective in retrofitting the structure seismically.

Table 5: Reduction in inter-storey with respect to bare frame for different BRB configuration

Different BRB configuration	Reduction in inter-storey with respect to bare frame
Backward bracing	57.00%
Forward bracing	57.94%
V bracing	64.48%
Cross diagonal bracing	77.57%
Inverted V bracing	89.71%

The buckling restrained bracing effectively limits the response and inter-storey drifts in the building and provides an adequate safety against collapse by reducing the floor displacements. The result also shows that inter-storey drift decreased with increased height of frames. Therefore it can be noted that the buckling restrained braces are more effective to reduce the effect of ground motion due to earthquake forces.

B. Time History Plots of Roof Displacement v/s Time

The time history plots of the roof displacement v/s time is shown in the Figures 9 a,b,c,d which is obtained for El-Centro 1940 earthquake for buildings both with BRBs and without BRBs

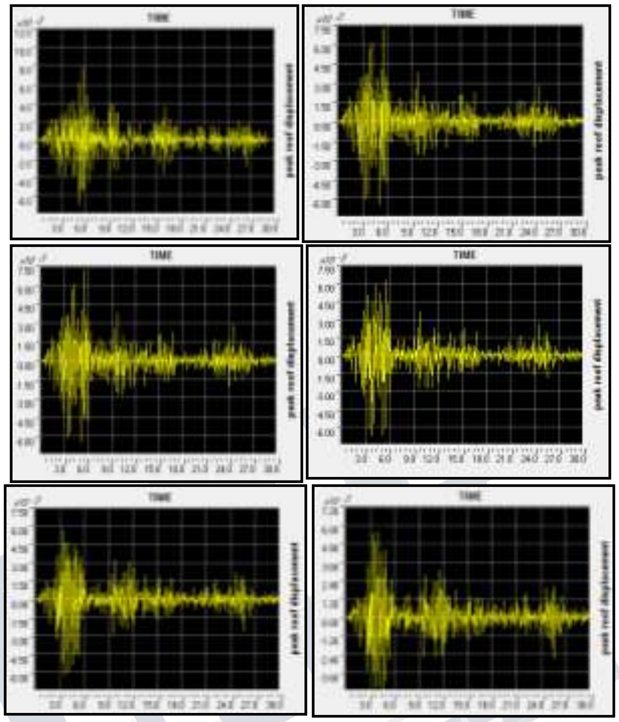

Figure 9: Roof displacement time histories in mm v/s sec for El-Centro 1940 time history functions for a G+6 story building (a) without BRBs(b) with backward diagonal BRBs (c) with forward diagonal BRBs (d) with V BRBs (e) with cross diagonal BRBs (f) with inverted V BRBs

From the above graphical results (Figures 11 a,b,c,d,e,f,) we can get to know that the peak roof displacement values for buildings with BRBs are less than for building without BRB. This suggests that as the stiffness increases the top story displacement reduces due to the effect of buckling restrained braces.

C. Base Reactions obtained after Time History analysis for Unbraced and Braced Bildings

The variation of base reaction is studied for the frames with different bracings. Figure 10 shows the base reaction force of frames with different BRB configurations. The strength defines the capacity of a member or an assembly of members to resist actions. If the base reactions in the building are high, the strength of the building reduces. . The most obvious effect of bracings is the increase in ultimate strength of the system. Adding bracing itself will be accompanied with increased strength and stiffness, but according to research done, the type and structural configurations of the bracing system is also important. The capacity of braced building is

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increased when compared to the bare frame, which in turn reduces the base reactions.

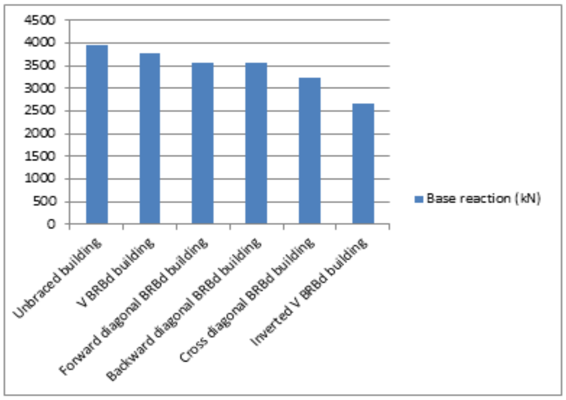

Figure 10: Comparison of different BRB configuration vs. base reactions

Table 6: Base reactions after time history analysis

Name of the model	Base reaction (kN)
Unbraced building	3967.01
V BRBd building	3769.656
Forward diagonal BRBd building	3558.307
Backward diagonal BRBd building	3558.238
Cross diagonal BRBd building	3244.127
Inverted V BRBd building	2664.582

After studying Figure 12 and Table 6, it can be concluded that the base reactions are reduced for braced building than unbraced buildings, which enhances the strength of the building by rigid support.

V. CONCLUSION

By studying and comparing the results gained from El-Centro time history analysis of the G+6 story building with and without buckling restrained braces, the following conclusions can be drawn.

1. The roof displacement v/s storey level for El-Centro function for buckling restrained braced (BRBd) buildings is less. This suggests that as the buckling restrained brace stiffness increases the top story displacement reduces and it can be concluded that inverted V configuration is more effective, i.e. 77.26% is reduced than the bare frame.

2. The results of drifts show that the inter-storey drift values because of El-Centro function for BRBd buildings are comparatively less. The drift values for all types are within the permissible value of drift and it can be concluded that inverted V configuration is more effective, i.e. 89.71% is reduced than the bare frame.

3. From the time history plots of roof displacement v/s time, it can be noted that the roof displacement with BRBs are less which indicates buckling restrained braces helps in reducing the effects of earthquake in high rise buildings.

4. The base reactions obtained after time history analysis for unbraced and braced buildings are compared and the base reactions are less for braced building, thus helps in the effective retrofitting of the building seismically.

Thus, buckling restrained bracings provides good control for the roof displacement as compared to the bare frame. The frames with insufficient stiffness can be retrofitted with addition of such bracing to control the roof displacements and resist the lateral loads. The BRBs are also the reliable and practical alternative to enhance the earthquake resistance of existing and new structures. Bracings are capable of providing both the rigidity needed to satisfy structural drift limits, as well as a stable and substantial energy absorption capability.

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