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Analytical Investigation of Buckling Restrained Braced Frame Subjected To Non-Linear Static Analysis

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Abstract— ***Buckling-Restrained Braces (BRB) is the advanced methods of seismic force-resisting system used in latest building design. The lateral displacement of the structure is minimized by the efficient seismic vibration control system. In Present research, Pushover analysis was done for a six storey 2D frame for unbraced frame, diagonal bracing and the buckling restrained bracing frame using sap2000. The behavior of various constraints used to appraise structural response are lateral displacement, Interstory drift and base shear. The length and the area of yielding core for modeling the exact behavior of BRB are evaluated. Based on the analytical investigation, the results and graphs shows BRB controls the lateral displacement over the unbraced and diagonal braced***

Keywords: Buckling restrained braces, displacement, hinge formation

I. INTRODUCTION

There is a great concern all over the world about the catastrophic Earthquake, which affects the structures and creates a big human loss. Due to earthquakes or ground motion the structures are easily influenced to collapse or large lateral displacements, so there should be special care taken to limit these displacements [1-4]. Braced frames are usually utilized in structures to give seismic mitigation. Like different sorts of Braced frame BRB uses the axial strength and stiffness of the bracing to resist lateral forces. Lateral forces tend the structures to displacement [5]. To limit this displacement ductility should be provided to the structures. BRB have do not buckle in compression, BRB yield in both in tension and compression, to prevent flexural failure in axial compression. BRB is designed to inelastic deformation where steel core plate as a load carrying member. Outer surface of the core is covered by a restraining member to prevent flexural buckling. In order to escape friction forces extreme in the middle of the plates and the outer surface a clearance or unbounded material is used [6]. BRBs are installed in frame structure to perform as energy dissipation members; it can be called as Seismic controlled members. BRBs are developed to exhibit inelastic behavior, as a result Plastic deformation in beams and columns is reduced and they survive the structure from strong Earthquake ground motion compared to the conventional one. BRBs provide some techniques to control this lateral displacement. The conventional inclined members or braces own limited ductility capacity under cyclic loading. Large quantity of Kinetic energy is fed in to the construction during Earthquake. The position of damage is found by the manner in which the Energy dissipated. Inside the elastic ability of the material, the seismic codes represent that it is not capable to dissipate the seismic. The Yielding in structure happens at controlled area and ductile way. The ideal ductile structure is one in which yielding happens in Structural Fuses. Frank Lloyd Wright received a patent for using roller at foundation using talc powder. Ka R used roller and sliding system in building constructed using isolation [7]. Kelly proposes an innovative control hybrid control approach comprise of base isolation with controlled actuator. Kimura initiated the idea of BRB and conducted tests which proved BRB has better energy dissipation. Suzuki analyzed the diameter and thickness ratio for a double steel tube BRB and the clearance of the inside and outside steel tube [8]. Xie worked on the important BRB configuration on gap configurations and the removing process between the core and casing members.

II. BRB OVERVIEW

BRB frames have been introduced in alternative for the conventional braced frame, where in BRB buckling of braces is prevented compared to the conventional braces. BRBs cross section core and the steel casing where inside concrete is filled is shown in fig1. A steel core withstands the axial stresses and the external cement filled steel tube opposes buckling stresses, and the casing prevents the steel core from buckling and by that resulting very nearly uniform axial strains in compression and tension [9]. Between the core and the surrounding concrete BRB provides a slip surface (gap). Different parts of the BRB are shown in the fig 2.

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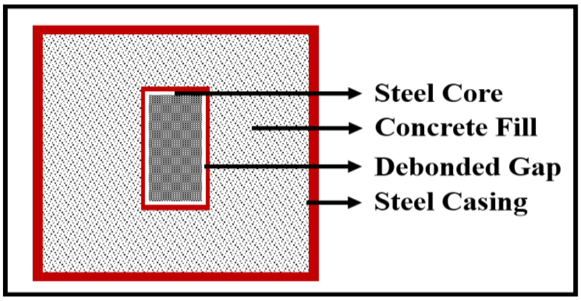

Fig. 1. Cross section of BRB

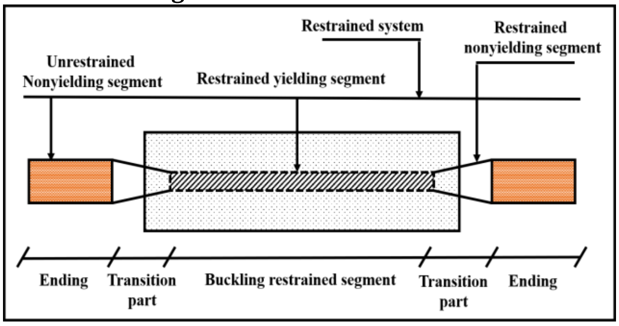

Fig. 2. Parts of BRB Hysteresis loop of BRB

BRBF have full, balanced hysteresis loops with compression yielding similar to tension yielding behavior shown in fig 3. Due to this uniform tension and compression capacities BRBs eliminate the post buckling load imbalance inherent in the conventional braced frames such as building code designated special concentric frames system. BRB is constructed to endure stretches during the seismic reaction and all the seismic damages (yielding) that occurs inside the braces [10]. The concrete and steel tube respond as a composite action and provides sufficient flexural strength to prevent local buckling of the brace.

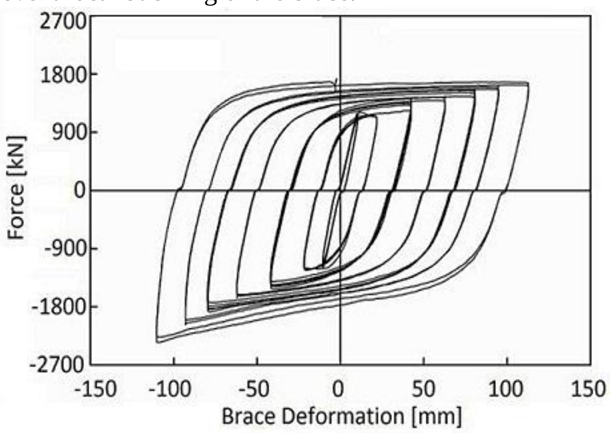

Fig. 3. Hysteresis loop of BRB

III. Design of BRB

BRB are has a proposed structured utilizing equivalent lateral force method as a result of this method, the static load is generated and applied to rigid diaphragms or vertical column, which can carry determined forces. Every code proposes explicit impediments utilizing such strategy. Most basic confinements are structure consistency and its tallness. in Conventional prop casing to decide the edges required quality and solidness a diminished seismic burden is connected to a straight versatile model. For BRBF with supports proportioned by this technique, the distinction between the versatile and inelastic distortion modes is considerably less sensational than for CBF. To give a better brace ductility inelastic analysis is done. In normal buildings, bracings are believed to buckle in compression. The beam – column connections should be fully restraint. The brace connections can be fixed or pinned to the gusset plate. Braces should possess enough ductility to resist the seismic loading and recommended provisions are available but there is no building code governs BRBF design. More number of BRBs types has developed by researchers and manufactures. Cores are in different shapes like Single plate and rod. Sleeves can be bare steel, concrete or a composite of the both. To prevent the stress transfer to the Sleeve (outer plate) many ideas have been researched. BRBF have many brace configurations. Because brace yielding in tension and compression, strengths are almost equal. The stability between bracing compression and tension strength the beam is required only modest load. To reduce large beam displacement deflection limit. deflection limit is also imposed. BRB used in latest construction to reduce ductile, stiffness and energy dissipation is needed [11-12].

The required brace stiffness is then calculated as

$$K_{br} = \frac{p}{\Delta}$$

Where, K_br is brace stiffness and P is the Seismic mass of the building calculated from benchmark problem

Ly is the length of yield and

$$\Delta \sim \frac{P\,L_Y}{AE}$$

$$L_y = 0.5 - 0.8\,L \quad \text{(L-Length of brace)}$$

Ultimate load $P_u = \dfrac{F}{\cos\theta}$

For ultimate load calculation if the system has to bracings then there will be slight variation in the formula,

$$P_u = \frac{F}{2\cos\theta}$$

Depending on brace type and configuration brace stiffness varies. Since the stiffness of the diagonal brace is calculated as

$$k_{br} = 1.3 - \frac{As\,E}{L}$$

The required cross-sectional area of the yielding portion calculated as

$$A_{sc} \geq \frac{P_u}{\emptyset F_{YSC}}$$

Where, F_y is yield strength of the brace steel material.

BRB Adjusted Strength for compression and tension depends upon over strength and strain hardening.

IV. Pushover Analysis

Pushover analysis is a static nonlinear analysis has been developed over the last two decades. For Seismic evaluation and design, Pushover analysis is considered to be the best method. As the method is easy to handle, it considers post elastic behavior, as the method is no difficult. A pattern of force is given to a structural model that comprising nonlinear properties and the whole load is delineated against reference deformation to characterize a limit curve known as capacity curve.

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This can be joined with a demand curve. Single degree of freedom (SDOF) is reduced by this method. Performance based design brought nonlinear pushover analysis as famous one. The magnitude of the structural loading is regularly increased in a manner conforming to a specific pattern established in advance. Feeble connections and failure method of the structure is found with increment in the loading. The force is monotonic with the impacts of the cyclic performance and inversions being evaluated by utilizing an altered force-displacement and with damping approximations. Push over analysis helps structural engineer to find out the real strength of the structure and it is compelling for Performance based structure. The ATC-40 and FEMA-273 codal provisions have created demonstrating methods in modeling, acknowledgment criteria and investigation techniques for push over analysis. These archives clarify the force – displacement rules for pivots utilized in push over investigation. Load - displacement is noted as A B C D and E. IO, LS, CP are utilized to characterize the acknowledgment criteria for the pivot. IO (Immediate inhabitance), LS (Life security), and CP (Collapse counteractive action). This paper introduces the means utilized in push over investigation of 2-D structure where diagonal bracing and buckling restraint bracing is designed and analyzed using SAP2000. Where weak links and failure modes (hinge formation) of the structure are found. Displacement of the structure also found out by this sap push over analysis, which is the main objective of this paper. This research concerns about comparative analytical value between three similar two-dimensional frame 1) bare frame, 2) braced frame, 3) buckling restraint braced frame. Building is located in seismic zone IV soil type is considered as of type II. Properties of all the three frames, seismic zone and soil types are same. Detailed description about the building and its components is as follows:

Table 1. Six storey structure details

Storey height	18 m
Floor height	3 m
Bay width (x – dir)	5 m
Beam size	0.25m X 0.45m
Column size (1)	0.60m X 0.60m
Column size (2)	0.55m X 0.55
Column size (3)	0.65m X 0.65m
Live load	2 KN/m2
Seismic zone	IV
Soil type	II

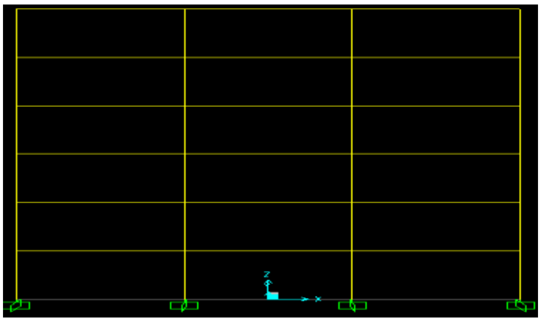

Fig. 4. Six Storey 2D frame

In this paper modeling of bare frame, conventional diagonal braces and BRB is modeled using SAP 2000. Columns are given fixed support in the bottom. Braces were modeled as pin-ended members. A conventional diagonal brace element is prismatic and the BRB are modeled as non-prismatic element. Compared to the end offset the central yield portion of the BRB has lesser cross-sectional area. So different sections were first defined using Sap section designer and then assigned to form the non-prismatic section to perform as a BRB.

V. RESULTS AND DISCUSSION

The results in this work are divided into three parts. First part shows results of the correct modeling of BRB. Second part shows results of the hinge formation. Third part is about the displacement and base shear of the three frames. Section designer is used while modeling BRB, we cannot model BRB as a single member, it has to be divided and modeled into three divisions, two ends are classified as end offset and there is a kernel yielding portion. Conventional braced frame is modeled using ISMB 350. Comparison is made between the three types is to find out the suitable bracing.

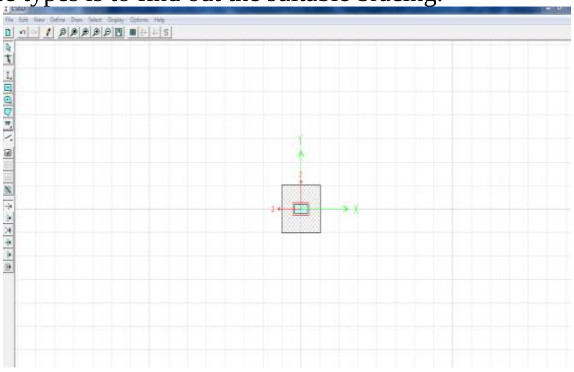

Fig. 5. BRB Design in SAP 2000

While modeling in section designer materials properties can be given. Such as Concrete mix design, steel sections properties and deboning gap dimensions can be given.

Deformation or Hinge formation of the three types of frames is analyzed and the results are given below. (1) Bare frame deform shape (2) Conventional diagonal brace deform shape and (3) BRB frame deform shape. The Hinge formation or the deformed shape for the three frames is compared. Results show that deformation in 1st mode for all the three frames. Based on the results BRB has a good behavior and all the hinges started forming in the BRB and it prevent the system from seismic response with all the other two frames .

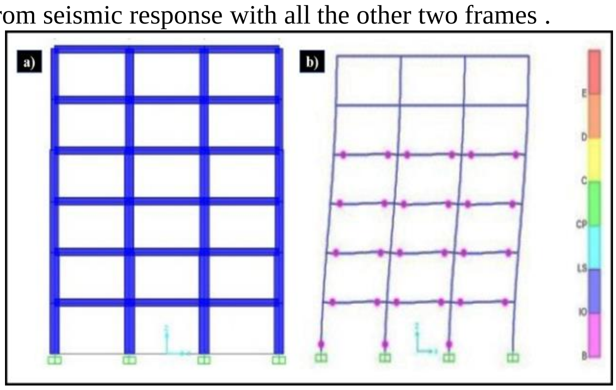

Fig. 6. a) Bare frame, b) deformed shape

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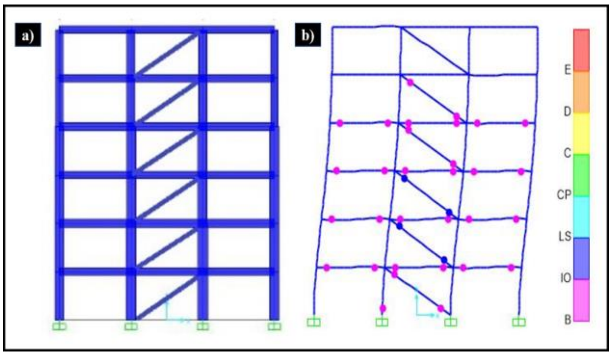

Fig. 7. a) Braced frame, b) deformed shape

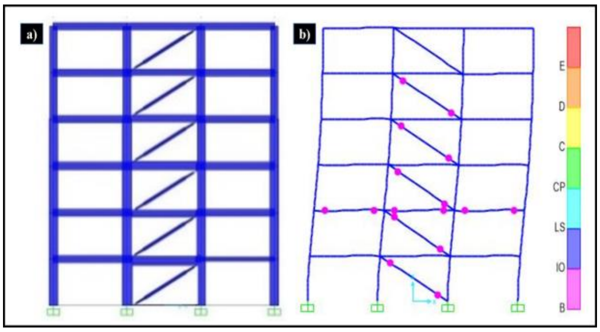

Fig. 8. a) BRB, b) deformed shape

The displacement for all the three frames is determined and presented in a tabular column format. As compared to the bare frame, Conventional diagonal braced frame has less displacement and BRB has less displacement compared to the conventional braced frame. Literature shows that BRB is most economical; hence an attempt was made to BRB for the same frame. To rely upon the results of BRB frame. It was necessary to model the BRBs correctly. Modeling of BRB is based on its yielding zones appropriate lengths and its cross-sectional dimensions. Figure 11 shows the displacement of the BRB and other frames.

Table 2. Displacement of frames

	Buckling restrained braced frame	Conventional diagonal braced	Bare frame
IO	0.0045	0.01213	0.147688
PP	0.017	0.034	0.1287
LS	0.02295	0.07352	0.188343
CP	0.06324	0.2189	0.3587
UL	0.2378	0.264	0.2996

During modeling, central yielding zone length of BRB is varied from 33% to 100% of total length by keeping the area of yielding and end offset constant.

This comparative graph shows that the displacement for bare, braced and buckling restrained brace is shows. From this graph, it is observed that BRB system is found to be most effective of all the other two types.

The Spectral acceleration obtained from the analysis are plotted against Spectral displacement to define "Capacity spectrum", which is combined with demand spectrum or response spectrum (from Turkish code) to determine performance point. The spectral displacement and spectral acceleration values which were used to plot capacity spectrum for models with bare, braced and buckling restrained braces are shown in fig 10. In following figures, Pushover curves based on Capacity spectrum method are given.

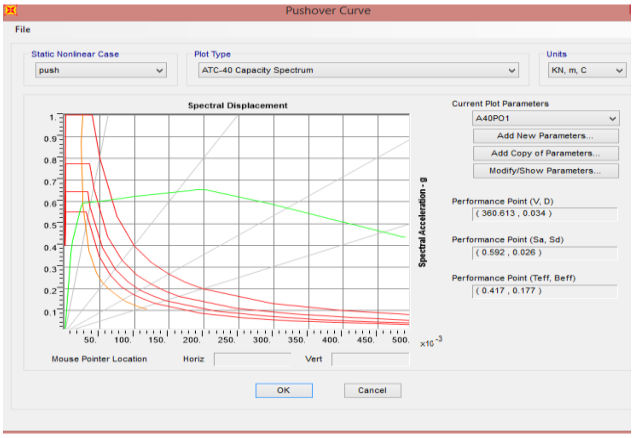

Fig. 9. Capacity curve for bare frame

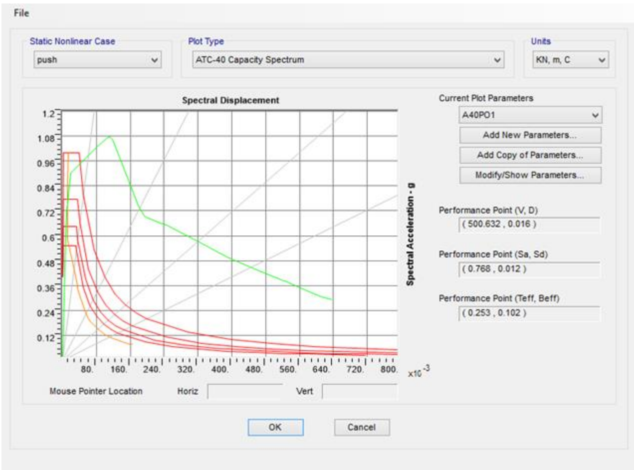

Fig. 10. Capacity curve for BRB frame

CONCLUSION

The behavior of buckling restrained braces subjected to seismic response has been studied. Modeling of BRB and its important parameters such as yield zone and end offset are found out. The analytical investigation shows that BRB has good control over displacement and Hinge formation forms slowly than the other types of frames by keeping the cross-sectional area of the end offset more than the central steel core. Capacity curve poses a good value compared to the other braces.

REFERENCES

1. Sabelli, R., Mahin, S., & Chang, C. (2003). Seismic demands on steel braced frame buildings with buckling-restrained braces. *Engineering Structures*, 25(5), 655-666.
2. Cameron, J. (2004). Component testing, seismic evaluation and characterization of buckling-restrained braces. *Journal Of Structural Engineering*, 880-894.

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3. Park, Junhee, Junho Lee, and Jinkoo Kim. "Cyclic test of buckling restrained braces composed of square steel rods and steel tube." *Steel & Composite Structures* 13, no. 5 (2012): 423-436.
4. Tremblay, R., M. Dehghani, L. Fahnestock, R. Herrera, M. Canales, C. Clifton, and Z. Hamid. "Comparison of seismic design provisions for buckling restrained braced frames in Canada, United States, Chile, and New Zealand." *In Structures*, vol. 8, pp. 183-196. Elsevier, 2016.
5. Takeuchi, Toru, J. F. Hajjar, R. Matsui, Kohji Nishimoto, and Ian D. Aiken. "Local buckling restraint condition for core plates in buckling restrained braces." *Journal of Constructional Steel Research* 66, no. 2 (2010): 139-149.
6. Kersting, R. A., Fahnestock, L. A., & López, W. A. (2015). Seismic Design of Steel Buckling-Restrained Braced Frames. NIST GCR, 15-917.
7. Kim, J., & Choi, H. (2004). Behavior and design of structures with buckling-restrained braces. *Engineering Structures*, 26(6), 693-706.
8. Kim, J., & Seo, Y. (2004). Seismic design of low-rise steel frames with buckling-restrained braces. *Engineering structures*, 26(5), 543-551.
9. Takeuchi, T., Hajjar, J. F., Matsui, R., Nishimoto, K., & Aiken, I. D. (2010). Local buckling restraint condition for core plates in buckling restrained braces. *Journal of Constructional Steel Research*, 66(2), 139-149.
10. Hoveidae, N., & Rafezy, B. (2012). Overall buckling behavior of all-steel buckling restrained braces. *Journal of Constructional Steel Research*, 79, 151-158.
11. Usami, T., Ge, H. B., & Kasai, A. (2008). Overall buckling prevention condition of buckling-restrained braces as a structural control damper. *In Proceeding of the 14th world conference on earthquake engineering*, Beijing, China.
12. Usami, T., Wang, C., & Funayama, J. (2011). Low-cycle fatigue tests of a type of buckling restrained braces. *Procedia engineering*, 14, 956-964.

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