

Spectral Dynamic Analysis of Buckling Restrained Brace (BRB) Configurations in an Irregular Building

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Abstract - This research covers a comparison between different configurations for the application of Restricted Buckling Brace (BRB) through the dynamic analysis of an irregular building that does not comply with the maximum drifts in one of its directions and is reinforced with the different distributions. The reinforcement with BRB was achieved with the three distributions analyzed and the guidelines of the Peruvian standard E.030 2018 were met. In that sense, the reduction of the maximum inelastic story drifts with the BRB V configuration was 25.64%. The reduction of maximum inelastic story drifts with the Inverted BRB V configuration was 27.92%. While the reduction of maximum inelastic story drifts with the BRB X configuration was 28.71%. Thus, the configuration with the best results was the BRB in X.

Keywords: BRB, dynamic analysis, BRB configurations, inelastic drifts, structural reinforcement, buckling restrained brace, reinforced concrete, Latin America

1. Introduction

Buckling restraint braces are seismic strengthening devices that emerged as an alternative to conventional steel braces, since their main weakness is buckling deformation when subjected to compression loads. This structural reinforcement mechanism is used mainly in countries such as Japan and the United States, which have a greater amount of literature on the matter. On the contrary, in Latin America, studies on BRB are very scarce and, consequently, its use in the reinforcement of buildings as well. The deficiencies of the E.030 Seismic-Resistant Design regulations play an important role, as it closes the way to the progressive and accelerated technological development that a country in a highly seismic area like Peru should have.

Research developed by Hubdar and Dong-Keon presents an analysis of studies that develop new models and adaptations of BRB in the period from 2009 to early 2023 [1]. Of this range of literature, only 1% of research belonged to a Latin American country, Argentina. Likewise, articles by researchers in Chile, Colombia and Mexico have done the same, publishing studies on seismic performance of the BRB in a characteristic building of the country [2] and [3], multi-objective seismic design of these braces [4] and acceptance criteria and index of damage to them [5]. As for us, in Peru there is no record of scientific articles on the matter, which directly influences the poor updating of the National Building Regulations, which still does not contemplate any scope on the reinforcement of existing structures [6]. This scenario is similar in Chile, in which, despite having some research, Chilean standards have not yet introduced specific guidelines on the implementation of the BRB as structural reinforcement [7].

However, worldwide, few investigations have addressed the different configurations of Restrained Buckling Braces in frames. Of them, the most notable compares numerically the most common configurations and proposes a variant, adding a vertical brace to the center of the inverted V configuration. Although it covers 5 floors and uses SAP2000, it is limited to the analysis of 2D steel frames [8]. Therefore, in this research a comparison of the contribution of different reinforcement configurations with BRB in reinforced concrete frames of an irregular building is developed, modeled in the ETABS v21.1 software under the parameters of Peruvian regulations. With the main objective of being used in future research and opening the way to promoting its discussion and use in Latin countries.

In this sense, the methodology that was developed is shown concisely in Figure 1.

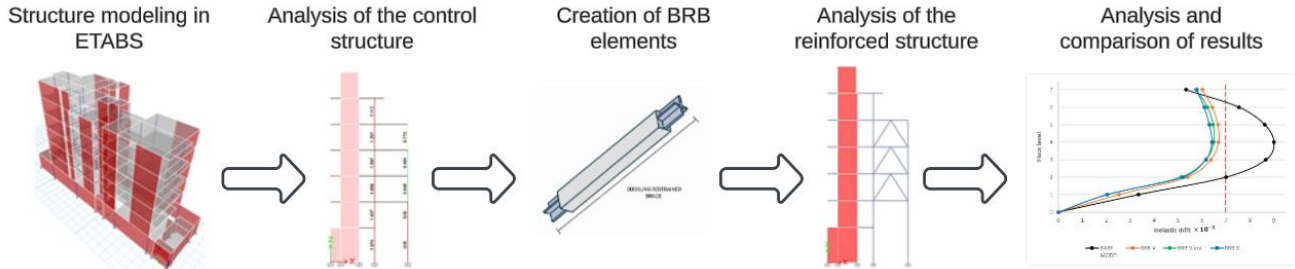


Fig. 1. Methodology of the research article

2. Study objects and tools

2.1. Irregular Building

A multi-family building with reinforced concrete walls and frames that has rigidity deficiencies in one of its directions and requires reinforcement has been taken as a case study. The main irregularity of the building in figure 2 is the torsion in the most flexible axis. In addition, it has a basement, 5 floors and a roof terrace. The structural elements of the building were modeled with a $f_c = 280 \text{ kg/cm}^2$ and grade 60 steel reinforcing bars.

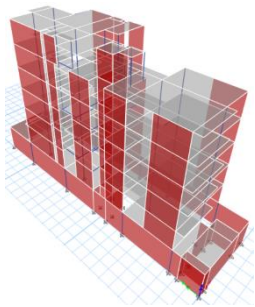


Fig. 2. 3D modeling of the case study

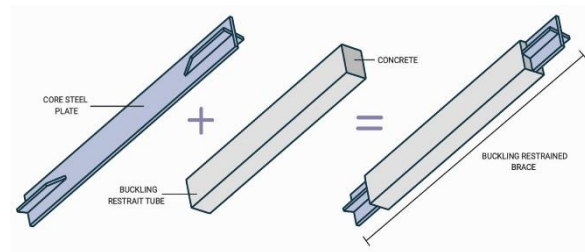


Fig. 3. Composition of a BRB

2.2. Buckling Restrained Braces (BRB).

Buckling Restrained Braces, as shown in figure 3, comply with the same ductile principle as conventional steel braces, with the difference of a concrete core that surrounds the main steel to restrict buckling, its main weakness.

The BRB profile used for each simulation was provided and modeled by the ETABS software, which is designated as STAR BRB_26.5. This profile belongs to the company Star Seismic, so it meets the necessary standards and codes.

3. Method

The research takes as its starting point the analysis of the current situation of the case study without additional reinforcement, as shown in figure 2, which is reinforced with 3 BRB configurations. The first is called BRB V (Figure 4b), the second is the Inverted BRB V (Figure 4c) and the third shown is the BRB X (Figure 4d).

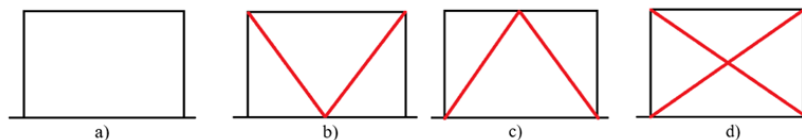


Fig. 4. BRB configurations in beam and column frames

3.1. Current situation of the multi-family structure

The modeling of the current situation in ETABS was carried out considering Frame elements for the columns and beams, beams, Membrane elements for the lightened slabs, Shell-Thin elements for the reinforced concrete slabs, and Shell-Thick Thick for the reinforced concrete walls. In addition, the intersections between beams and columns were considered as rigid rigid arms. The dynamic analysis of the structure was carried out without any reinforcement in the frames modeled in ETABS, as seen in Figure 2. From this, the maximum displacements and drifts of the stories were obtained. In addition, the vibration modes and fundamental periods were determined to visualize the flexibility of the structure with respect to the XX and YY axis. From this, the axes that need reinforcement in their most critical frames were analyzed; that is, in those that do not support the service loads of the structure, with overstressed columns. The study of the current situation resulted in the most flexible axis of the structure being the XX axis.

3.2. Frames evaluation

Through the analysis, it was determined that the maximum inelastic drift exceeded 7×10^{-3} . Likewise, it was found that the axes that do not support the service loads are axle 6 and 11, both in red and pink colors, as shown in figure 5. The vertical elements that are being overstressed are evident, which are they occur on all floors on axis 6 and on floors 1, 2, 3 and 4 of axis 11, as seen in figure 5b.

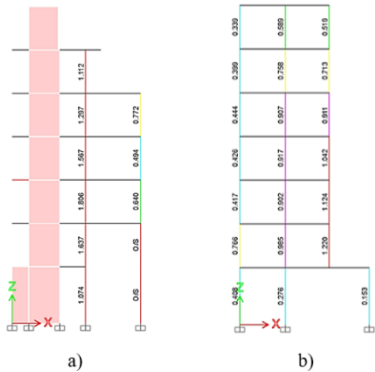


Fig. 5. Analysis of frames of axis 6 and axis 11 in direction XX

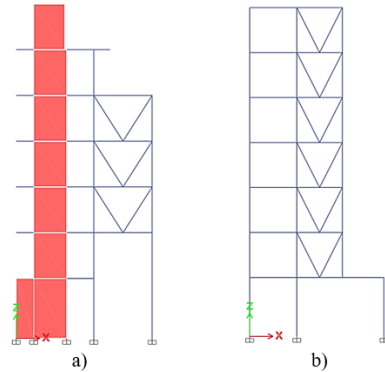


Fig. 6. Axis 6 and axis 11 frames reinforced with BRB V configuration in direction XX

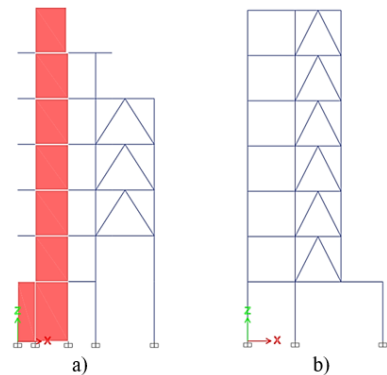


Fig. 7. Axis 6 and axis 11 frames reinforced with the BRB V Inverted configuration in the XX direction

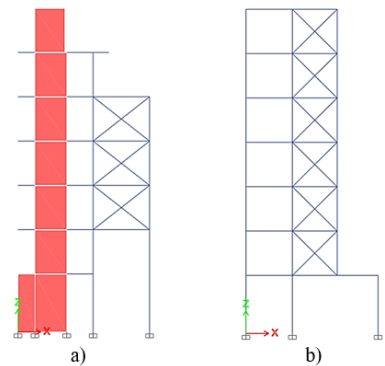


Fig. 8. Axis 6 and axis 11 frames reinforced with the BRB X configuration in the XX direction

This distribution was arranged due to limitations with installation, considering architectural aspects and mainly the efficient structural reinforcement. This configuration was maintained for the three models, with the objective that at the of comparison a standard is maintained and what was obtained is the result of different cases under the same conditions.

4. Results and results analysis

The results were measured in terms of inelastic drifts at each level. Thus, Table I shows the results obtained from the dynamic analysis of the structure without reinforcement and with the three BRB configurations. To process the results, floor 1 was considered the basement and floor 7 was considered the roof.

The results of the current situation were poor from the 2nd to the 6th level, thus obtaining a maximum drift of 8.996×10^{-3} in the 4th level. Thus, the maximum drifts did not comply with the maximum permissible parameter of 7×10^{-3} established in the Peruvian standard E.030.

On the other hand, the BRBs in their different configurations managed to reduce the maximum drift to a value less than the maximum allowable of 7×10^{-3} . This variation is demonstrated in figure 9.

TABLE I. Numerical comparison of inelastic drifts

STORY	ELEVATION (m)	LOC.	INELASTIC DRIFT ($\times 10^{-3}$)			
			BARE MODEL	BRB V	BRB V inv.	BRB X
7	19	Top	5.323	6.010	5.753	5.779
6	16.4	Top	7.537	6.427	6.223	6.090
5	13.8	Top	8.615	6.669	6.458	6.307
4	11.2	Top	8.996	6.689	6.484	6.413
3	8.6	Top	8.665	6.367	6.144	6.158
2	6	Top	6.995	5.382	5.119	5.200
1	3.4	Top	3.335	2.532	2.022	2.037
0	0	Top	0.000	0.000	0.000	0.000

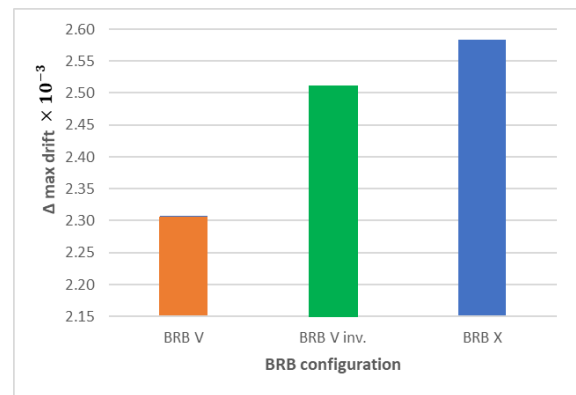


Fig. 9. BRB Configuration vs. Maximum drift reduction

Regarding the V-shaped structure reinforced with BRB, a maximum drift of $6,689 \times 10^{-3}$ was obtained at the 4th level. When compared to the control analysis without reinforcement, a reduction of 2.3070×10^{-3} in drift was obtained (Figure 10).

Regarding the structure reinforced with BRB in the shape of an inverted V, a maximum drift of 6.4840×10^{-3} was obtained at the 4th level. When compared to the control analysis without reinforcement, a reduction of 2.5120×10^{-3} in drift was obtained (Figure 11).

Regarding the X-shaped structure reinforced with BRB, a maximum drift of 6.4130×10^{-3} was obtained at the 4th level. When compared to the control analysis without reinforcement, a reduction of 2.5830×10^{-3} in drift was obtained (Figure 12).

Although all configurations complied with stiffening the building in the X axis and the results were similar, as shown in Figure 13, the reinforcement with the BRB the rest. This comparison is clearly shown in Figure 9.

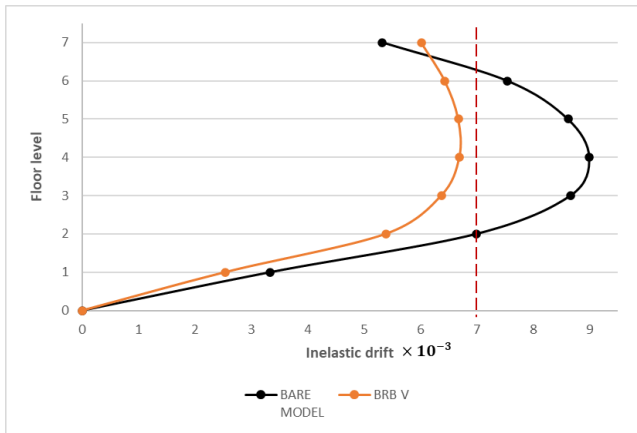


Fig. 10. Story drift vs. Floor level for the reinforced building with the BRB V configuration

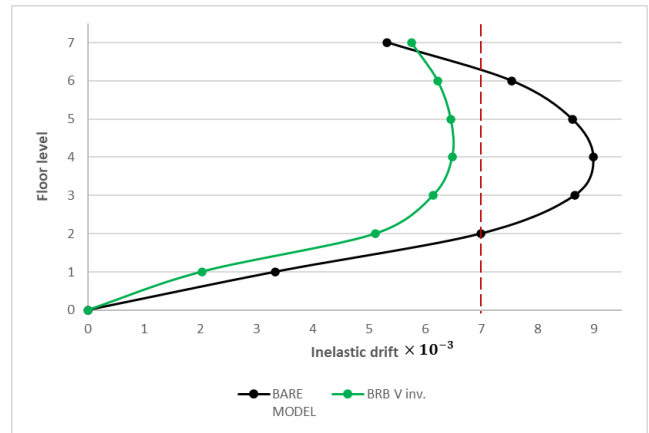


Fig. 11. Story drift vs. Floor level for the reinforced building with the BRB V Inverted configuration

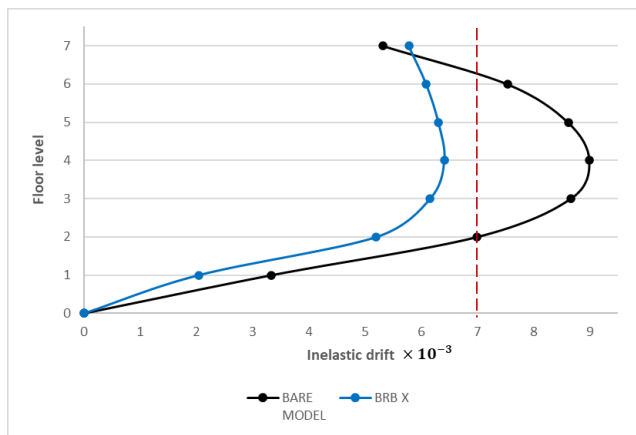


Fig. 12. Story drift vs. Floor level for the reinforced building with the BRB X configuration

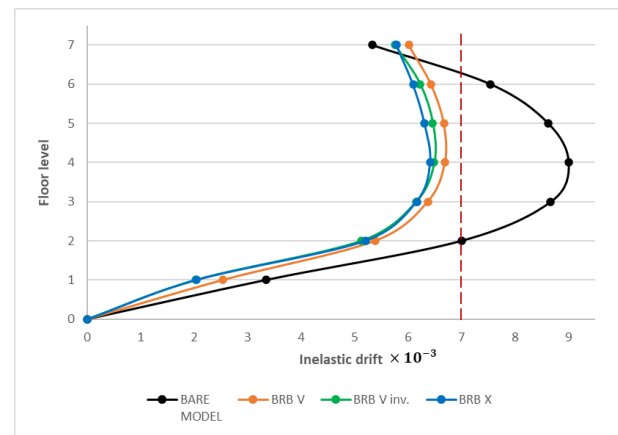


Fig. 13. Story drift vs. Floor level for reinforced building with all BRB configurations

Regarding the X-shaped structure reinforced with BRB, a maximum drift of 6.4130×10^{-3} was obtained at the 4th level. When compared to the control analysis without reinforcement, a reduction of 2.5830×10^{-3} in drift was obtained (Figure 12).

5. Validation

The results obtained are considered logical since they were compared with BRB literature developed by Deulkar, Modhera and Patil [8]. The basis was a comparative study of BRB configurations that, despite having different limitations and objects of study, obtained results that are similar in terms of the shape of the drift graph. Figure 14 shows the notable contribution of the braces compared to the unreinforced control model in a 2D steel frame, which highlights the new BRB configuration proposed by the study, with a reduction in the displacement of the upper level of 87.38%. and the Inverted V configuration, with a reduction in the displacement of the upper level of 87.12%. Furthermore, it shows that the configuration with the least reduction in displacements is the diagonal BRB forward with 64.84% and the Diagonal backward with 64.23%.

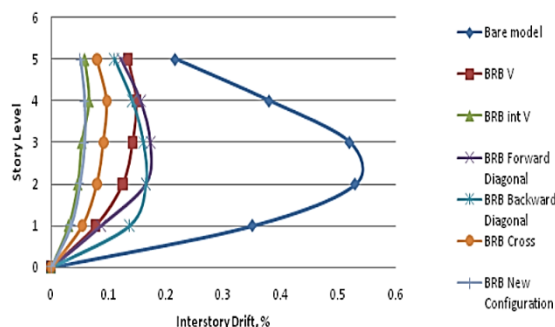


Fig. 14. Inter-story displacement versus floor level for a reinforced 5-story 2D frame for different BRB [8]

5. Conclusion

The BRB distribution was correct since the desired results were achieved by reducing the maximum drift to a value less than the maximum allowable of 7×10^{-3} . Likewise, all configurations evaluated performed satisfactorily. Below are the final observations extracted from the study:

- The reduction of maximum inelastic story drifts with the BRB V configuration was 25.64%.
- The reduction of maximum inelastic story drifts with the Inverted BRB V configuration was 27.92%.
- The reduction of maximum inelastic story drifts with the BRB X configuration was 28.71%.

It is important to highlight that the drift reduction was on average 27.43%, not like the study with which this research was validated, whose average drift reduction was 76.38%. This is because in this research a reinforced concrete building with irregularities and other variables that affect this value is reinforced; while the validation study is limited to the evaluation of completely regular frames and does not consider factors such as torsion.

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