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

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Abstract **-** This research covers a comparison between different configurations for the application of Buckling Restricted 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 configurations. Unlike other research, the factors considered take into account the seismic conditions of Peru and are evaluated under the national regulation E.030 2018. In addition, it seeks to promote research into unconventional structural reinforcement methods in Latin America. The reinforcement with BRB was achieved with the four distributions analyzed: BRB V, Inverted BRB V, BRB X and 2-story BRB X. These configurations were applied to the weakest frames of a building with a basement, 5 floors and a roof terrace. In that sense, the configuration that had better performance was 2-story BRB X, with a reduction of the maximum inelastic story drifts of 28.71%.

Keywords: Buckling restrained brace, Dynamic analysis, Structural reinforcement, Latin America, Inelastic drifts.

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]. From 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], [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 Reglamento Nacional de Edificaciones (RNE), which still does not contemplate any scope on the reinforcement of existing structures [6]. This scenario is

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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, buckling restrained braces continue to evolve. Some investigations cover the comparison with different configurations of BRB-RC frame structures under near-fault ground motions [8].

Probabilistic studies evaluated the seismic performance of BRB frames in 4, 8 and 12 story buildings. In this sense, it was shown that all frames remained at an optimal performance level during an earthquake with a return period of 475 years. The result was that the reliability of the frames with BRB not to violate the state of the safety performance level was greater than 86%. In addition, the BRB dissipated 98.5% of the energy exerted on the structure [9].

Another study analysed the influence that the configuration of the BRB and the height of the structure has on the seismic behaviour of buildings. They used probabilistic seismic assessment methods in four, six and ten story buildings with BRB V and inverted V reinforcement. The most relevant results were that the inverted BRB V had better structural performance and a lower probability of fragility than the BRB V. In addition, they concluded that, an increase of the height of structures, increases the fragility probability [10]. In addition to configurations, other variables that are involved in BRB-reinforced composite structures have also been studied [11], giving results in the form of a reduction of the drift ratio between floors by around 85-90% for C-shaped and L-shaped structures.

Despite this, few investigations have addressed the different configurations of Buckling Restrained Braces in irregular buildings. 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 [12]. 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.

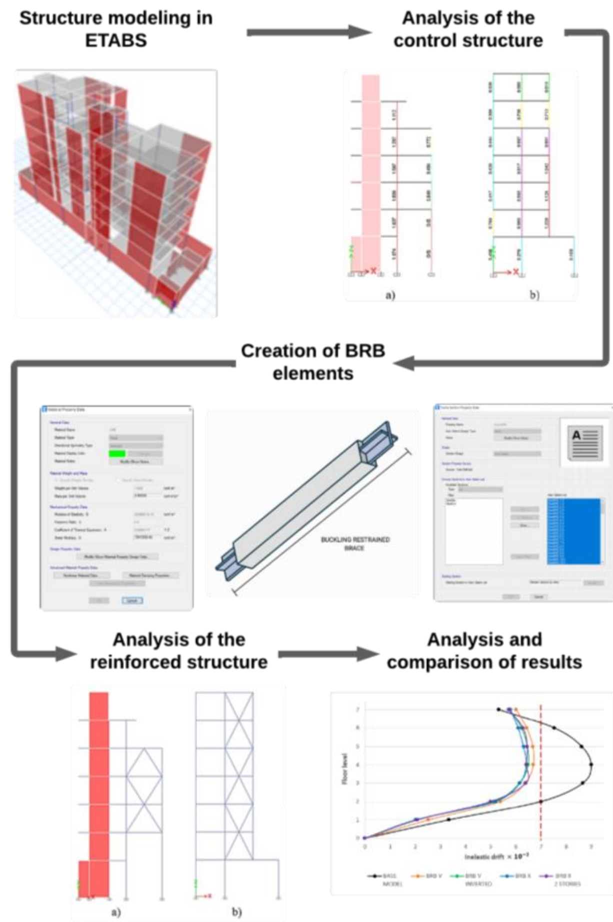

Figure 1. Methodology of the research article.

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 kg/cm2 and grade 60 steel reinforcing bars.

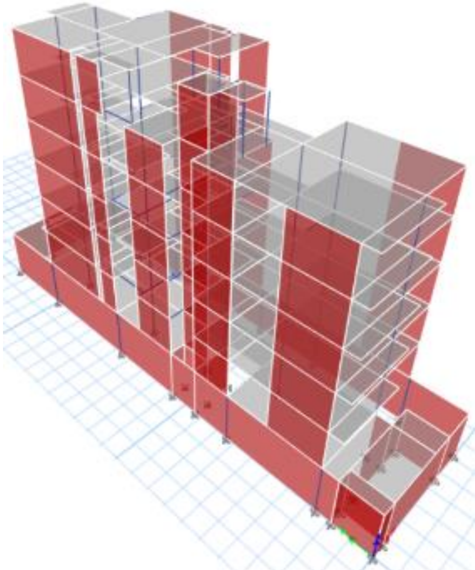

Figure 2. 3D modeling of the case study

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.

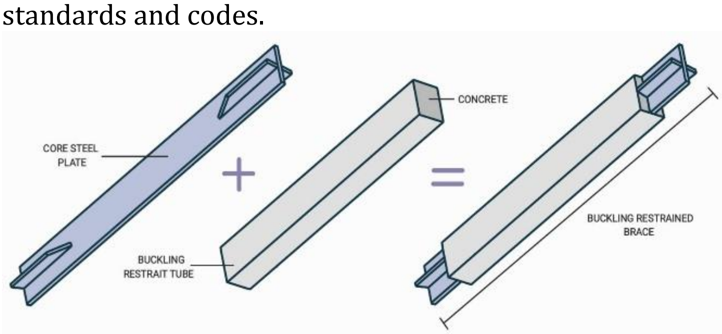

Figure 3. Composition of a BRB

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 4 BRB configurations. The first is called BRB V (Figure 4b), the second is the Inverted BRB V (Figure 4c), the third shown is the BRB X (Figure 4d) and the fourth is the 2-story BRB X (Figure 4e).

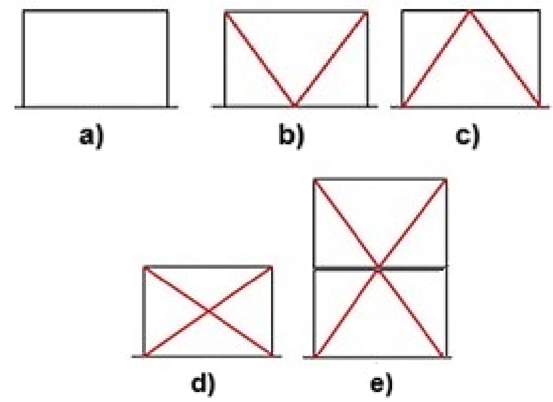

Figure 4. BRB configurations in beam and column frames

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, Membrane elements for the lightened slabs, Shell-Thin elements for the reinforced concrete slabs, and Shell-Thick for the reinforced concrete walls. In addition, the intersections between beams and columns were considered as 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 $7x10^{-3}$ indicated by the Peruvian standard E.030. Likewise, it was found that the axis that do not support the service loads are axis 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 presented on all floors on axis 6 and on floors 1, 2, 3 and 4 of axis 11, as seen in Figure 5b.

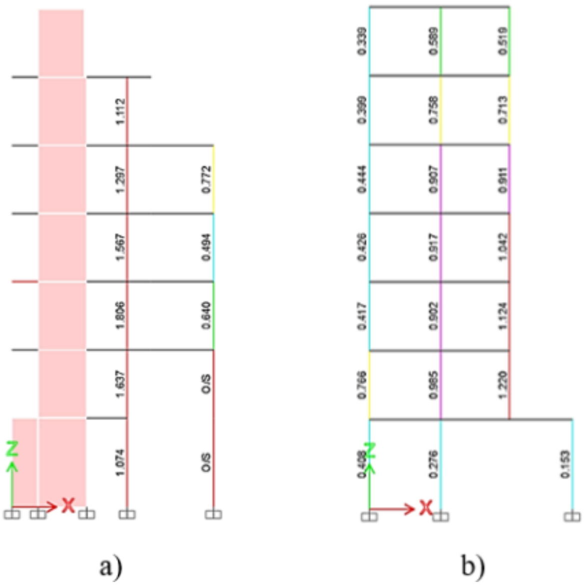

Figure 5. Analysis of frames of axis 6 and axis 11 in direction XX

Figures 6, 7, 8 and 9 show the distribution of the different BRB configurations implemented in the case study. This distribution was arranged due to limitations with installation, considering architectural aspects and mainly the most efficient structural reinforcement. This distribution was maintained for the four models, with the objective of maintaining a standard and obtaining results from the different configurations under the same conditions.

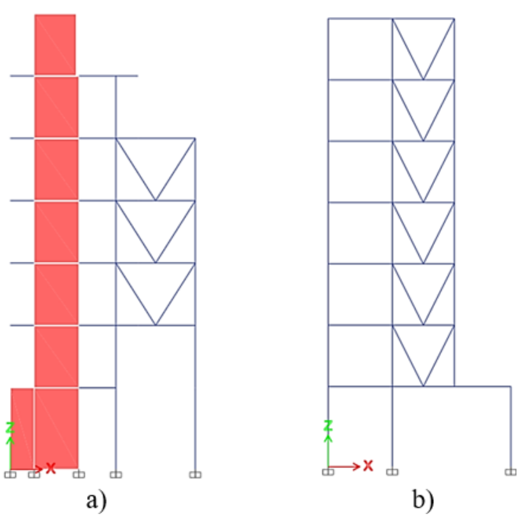

Figure 6. Axis 6 and axis 11 frames reinforced with BRB V configuration in direction XX

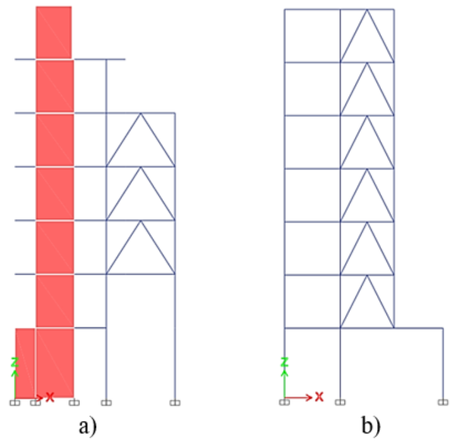

Figure 7. Axis 6 and axis 11 frames reinforced with the BRB V Inverted configuration in the XX direction

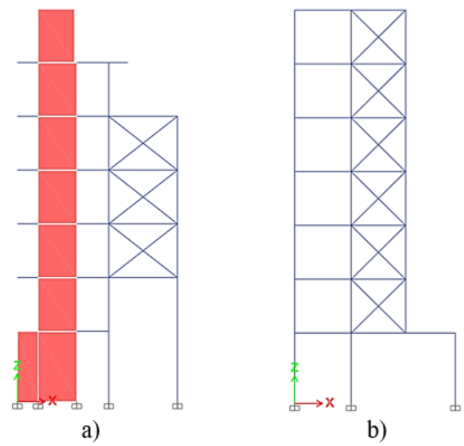

Figure 8. Axis 6 and axis 11 frames reinforced with the BRB X configuration in the XX direction

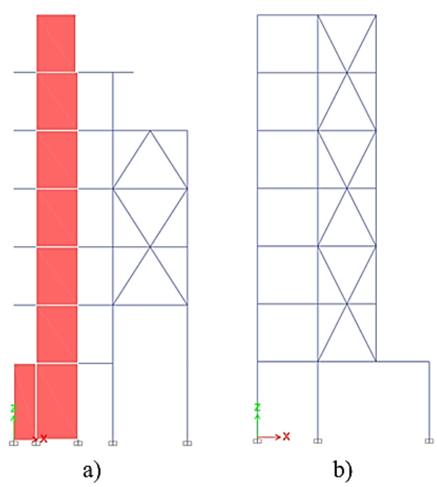

Figure 9. Axis 6 and axis 11 frames reinforced with the 2-story BRB X configuration in the XX direction

4. Results and results analysis

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

The results of the case study were low from the 2nd to the 6th level. The maximum drift was 8.996 x10^{-3} in the 4th level. In this way, the maximum drifts did not comply with the maximum permissible parameter of 7 x10^{-3} established in the Peruvian standard E.030.

On the other hand, the BRBs in their different configurations were able to reduce the maximum drift to a value less than the maximum allowed of 7 x10^{-3}. This variation is demonstrated in Figure 10.

Table 1. Numerical comparison of inelastic drifts

STORY	ELEVATION (m)	INELASTIC DRIFT $(\times 10^{-3})$				
		BASE MODEL	BRB V	BRB V INVERTED	BRB X	BRB X 2 STORIES
7	19	5.323	6.010	5.753	5.779	5.709
6	16.4	7.537	6.427	6.223	6.090	6.286
5	13.8	8.615	6.669	6.458	6.307	6.450
4	11.2	8.996	6.689	6.484	6.413	6.411
3	8.6	8.665	6.367	6.144	6.158	6.399
2	6	6.995	5.382	5.119	5.200	5.001
1	3.4	3.335	2.532	2.022	2.037	2.079
0	0	0.000	0.000	0.000	0.000	0.000

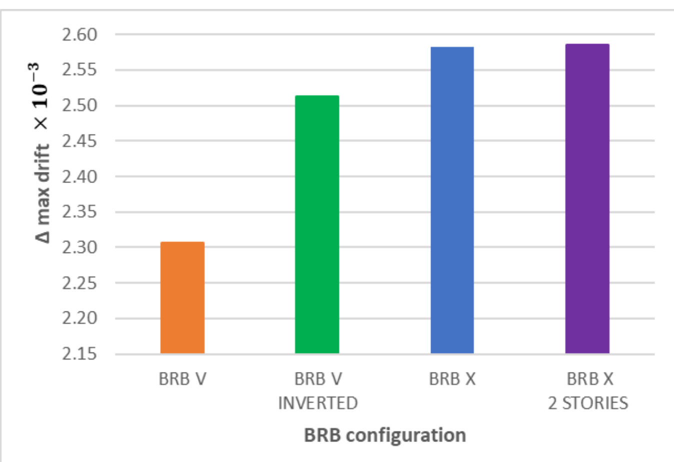

Figure 10. BRB Configuration vs. Maximum drift reduction

Regarding the structure reinforced with BRB V, a maximum drift of 6,689 x10^{-3} was obtained at the 4th level. Compared to the control analysis without reinforcement, a reduction of 2.3070 x10^{-3} in drift was obtained (Figure 11).

Regarding the structure reinforced with BRB in the shape of an inverted V, a maximum drift of 6.4840 x10^{-3} was obtained on the 4th level. Compared to the control analysis without reinforcement, a reduction of 2.5120 x10^{-3} in drift was obtained (Figure 12).

Regarding the BRB X reinforced structure, a maximum drift of 6.4130 x10^{-3} was obtained on the 4th level. Compared to the control analysis without reinforcement, a reduction of 2.5830 x10^{-3} in drift was obtained (Figure 13).

Regarding the structure reinforced with 2-story BRB X, a maximum drift of 6,411 x10^{-3} was obtained at the 4th level. Compared to the control analysis without reinforcement, a reduction of 2.5850 x10^{-3} in drift was obtained (Figure 14).

Although all configurations complied with stiffening the building on the X axis and the results were similar, as shown in Figure 13, the reinforcement with the BRB X and 2-story BRB X configurations were superior, since a greater angular distortion was reduced compared to the others. This comparison is clearly shown in Figure 9 and 15.

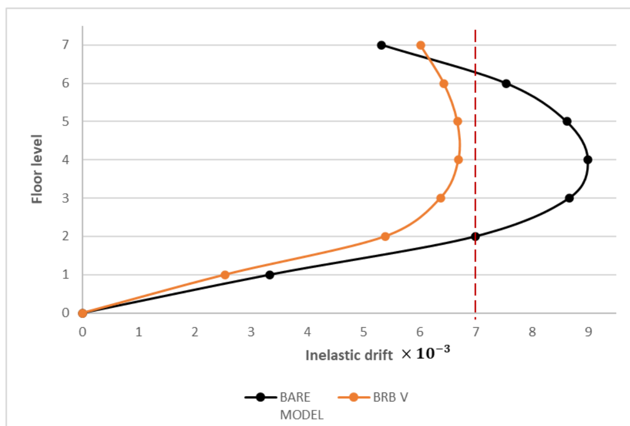

Figure 11. Story drift vs. Floor level for the reinforced building with the BRB V configuration

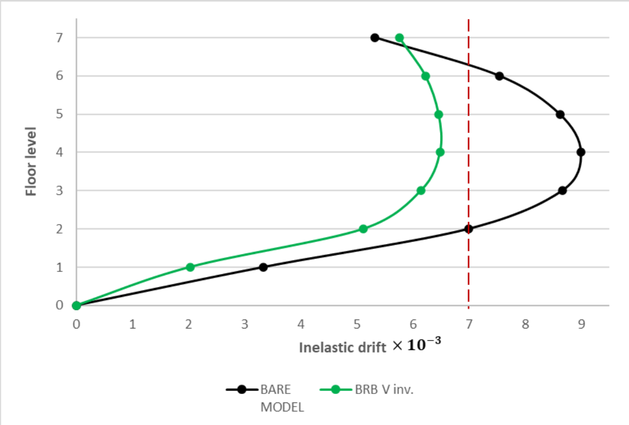

Figure 12. Story drift vs. Floor level for the reinforced building with the BRB V Inverted configuration

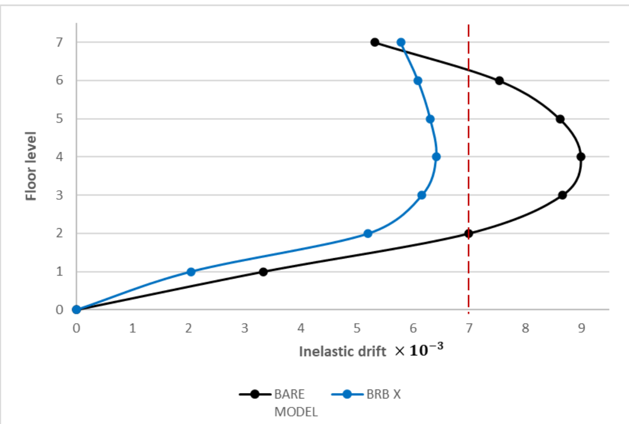

Figure 13. Story drift vs. Floor level for the reinforced building with the BRB X configuration

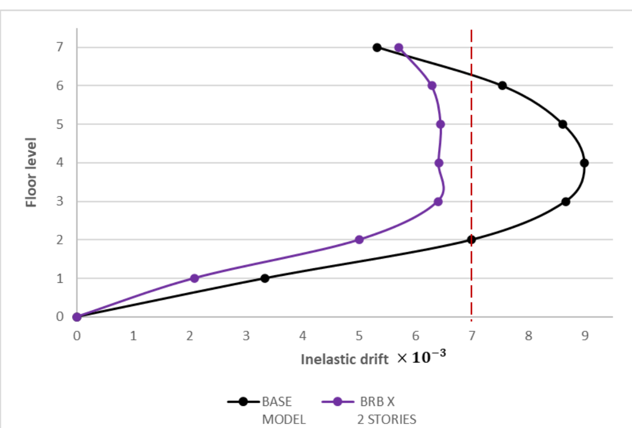

Figure 14. Story drift vs. Floor level for the reinforced building with the BRB X configuration

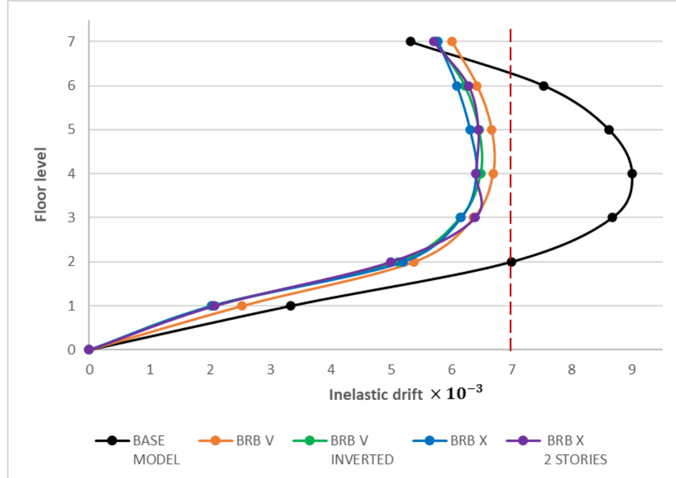

Figure 15. Story drift vs. Floor level for reinforced building with all BRB configurations

5. Validation

The results obtained are considered logical since they were compared with BRB literature developed by Deulkar, Modhera and Patil [12]. 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 16 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%.

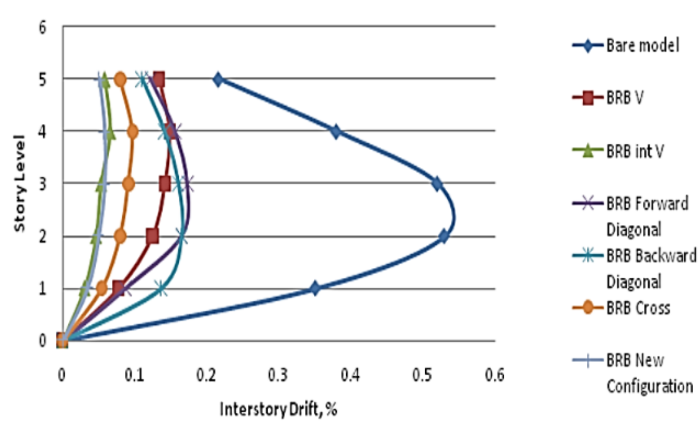

Figure 16. Inter-story displacement versus floor level for a reinforced 5-story 2D frame for different BRB [12]

6. Conclusion

The distribution of BRB was correct, as the desired results were achieved by reducing the maximum drift to a value lower than the maximum allowable value of $7x10^{-3}$. Likewise, all the 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%.
- The reduction of maximum inelastic story drifts with the 2-story BRB X configuration was 28.73%.

It is important to highlight that the reduction of drift was on average 27.75%, unlike the study with which this research was validated [12], whose average reduction of drift 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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