*Proceedings of the 10th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2025)*
*July, 2025 | Imperial College London Conference Center, London, United Kingdom*
*Paper No. 272*
*DOI: 10.11159/iccste25.272*

# Comparative Spectral Dynamic Analysis of Reinforcement with Buckling Restrained Braces and Fluid Viscous Dampers for an Irregular 11-Story Building

**Marco Antonio Ccota Olivares [1], Renzo Nino Tomás Dueñas[2], Franz Emmanuel Estrada Porras[2]**
[1]School of Civil Engineering Peruvian University of Applied Sciences
Lima, Perú
U202022020@upc.edu.pe ; U20181D804@upc.edu.pe
[2]School of Civil Engineering Peruvian University of Applied Sciences
Lima, Perú
pccifest@upc.edu.pe Conference on Civil, Structural and Transportation Engineering (ICCSTE 2025)

***Abstract -*** This study presents a comparative spectral dynamic analysis between the use of Buckling Restrained Braces (BRB) and Fluid Viscous Dampers (FVD) in a configuration, applied to an irregular 11-story building. The effectiveness of both systems in reducing inelastic drifts and torsions was examined, considering the irregularities in height and plan. The results indicated that, without reinforcement, the building exhibited inelastic displacements that exceeded the permissible limit established by the Peruvian standard E.030. The implementation of BRB and FVD significantly reduced these displacements, improving the seismic response of the structure. This analysis allowed for the determination of which damping system provides better results in stiffness and seismic energy dissipation.

***Keywords*:** Buckling-Restrained Braces (BRB), Fluid Viscous Dampers (FVD), structures, steel, seismic risk, energy dissipation, dampers, high-rise buildings, seismic.

## 1. Introduction

Braced frames and moment frames are the most used structural systems in steel construction for areas prone to seismic activity. Braced frames can generally be categorized into concentrically braced frames (CBF) and eccentrically braced frames (EBF). Figure 1 illustrates examples of concentric bracing arrangements.[1]

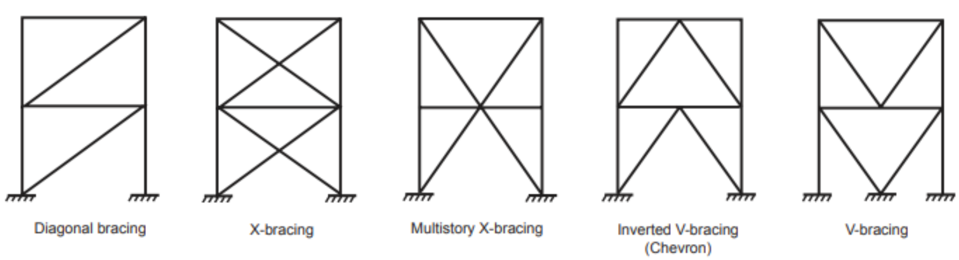


Fig. 1: Examples of concentric bracing arrangements

Since brace buckling is not effective for energy dissipation, a different approach to the standard CBF system that eliminates brace buckling has been developed. This system, referred to as the buckling-restrained braced frame (BRBF), is becoming increasingly popular in both Japan and the United States.[2]

The majority of BRBs created so far are proprietary, though the underlying concepts are generally the same. Figure 2 illustrates the design of one type of BRB. The brace consists of a ductile steel core, which is intended to undergo yielding in both tension and compression.[3]

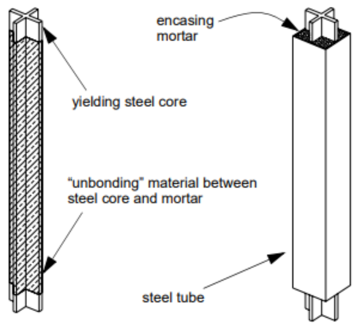


Fig. 2: Concept of a type of buckling-restrained brace

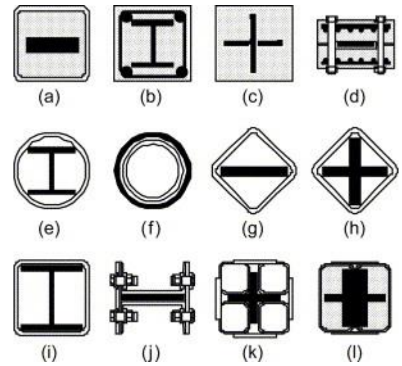


Fig. 3: Cross sections of various buckling-restrained braces developed

The advantage of BRBFs would be that they demonstrate high elastic lateral stiffness under low-level seismic motions. BRBFs allow for cost-effective installation via bolted or pinned connections to gusset plates. BRBFs provide design flexibility, as both the strength and stiffness of the braces can be easily adjusted. And the disadvantages include the possibility that, if not properly managed, the steels typically used to create the restrained yielding segment may exhibit a wide variation in yield strength. There needs to be clear criteria for identifying and replacing damaged braces.[4]

Fujimoto et al. (1988) examined the behaviour of a BRB type featuring a steel core enclosed in a steel casing filled with mortar. Meanwhile, Nagao and Takashi developed a BRB consisting of a wide flange section encased in a reinforced concrete member. Figures 3a through 3h display various BRB types created by researchers in Japan during the 1990s. Figure 3c depicts a cruciform steel core surrounded by concrete reinforced with steel fibers, while figure 3d illustrates a steel core plate confined by two precast concrete panels bolted together. The steel cores shown in figures 3c to 3h were all confined solely by an HSS casing.[5]

Syrakos et al. (2018) conducted an experimental study on gap-type fluid viscous dampers (FVDs) using two specimens with identical dimensions (50 mm length, 80 mm outer diameter, 0.30 mm gap) but different silicone fluid viscosities: 600,000 cSt and 80,000 cSt. Each damper was equipped with pressure sensors (up to 160 MPa, ±1.6% accuracy) and temperature strips to monitor internal pressure and thermal behavior. The study aimed to validate the testing method and analyze how simultaneous temperature and pressure variations affect damper performance. Complementary tests examined the viscosity–temperature dependency and rheological behavior of the fluids. [6]

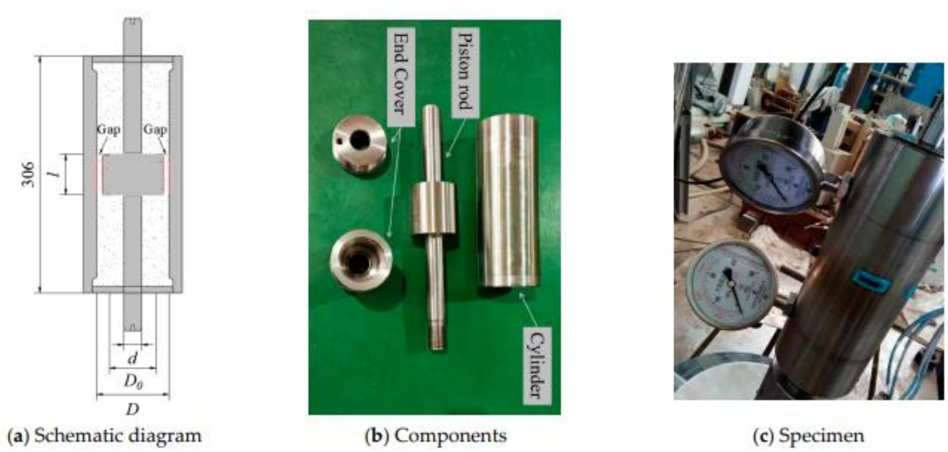


Fig. 4: Illustrative layout and constituent elements of the viscous fluid damper prototype

Fluid Viscous Dampers (FVD) optimize the structural response, although their damping coefficient remains fixed, limiting their effectiveness to a specific range. Since external loads, such as earthquakes and strong winds, are unpredictable and variable, these devices do not have the ability to modify their performance under different conditions or displacements of the structure, which restricts their ability to dissipate energy efficiently and protect the building.[7]

In this scenario, the proposal consists of comparing the performance of Buckling-Restrained Braces (BRBs) and Viscous Fluid Dampers in an 11-story building to determine which one provides better results in terms of reducing inelastic drifts and torsion. The goal is to ensure a more controlled and safer response of the building by minimizing lateral deformations at each level and reducing damage to the main structural elements, such as connections and columns.

## 2. Methodology

In this research, an 11-story building located in the department of Lima was evaluated. Additionally, according to the Peruvian standard E0.30, the following seismic coefficients for the acceleration spectrum were used:

Table 1: Seismic Coefficients in the Building

| **Seismic Coefficients** | **In "X"** | **In "Y"** |
|---|---|---|
| Seismic Zone | Z4 | Z4 |
| Building Category | C | C |
| Soil Profile | S2 | S2 |
| R | 6 | 6 |
| Acceleration of Gravity | 9.81 m/s² | 9.81 m/s² |
| Plan irregularities | 1 | 1 |
| Vertical irregularities | 0.60 | 0.75 |

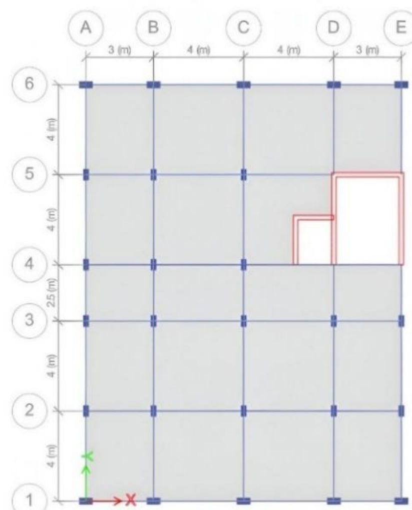

Fig. 4: Typical slab structural plan

First, the BRB and viscoelastic fluid dampers were designed along the X and Y axes. Additionally, according to the architecture, there is greater stiffness along axis 11, which causes torsion in the building. Moreover, the X axis has fewer plates.

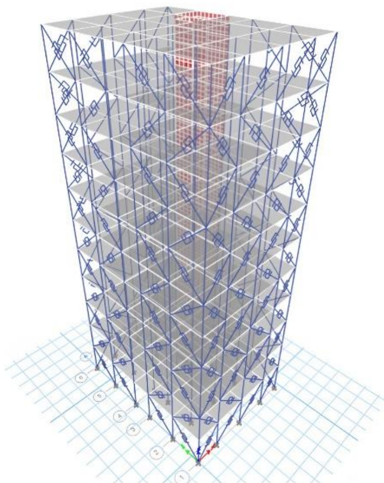

Fig. 5: Structure reinforced with BRB

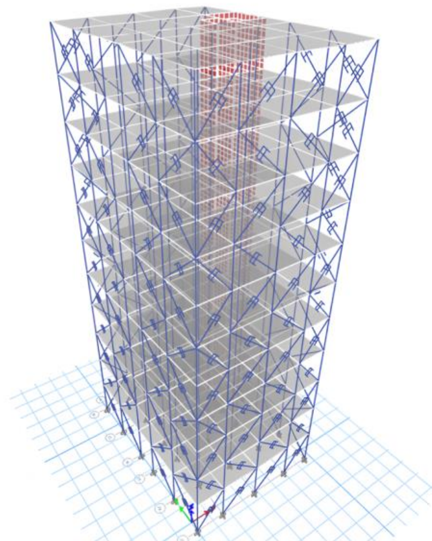

Fig 6: Structure reinforced with viscous fluid dampers

For the pre-dimensioning of the buckling-restrained braces (BRB), 25% of the maximum dynamic shear force is taken.

$$V_{BRB} = 25\% V_{dynamic} \tag{1}$$

Considering the number of dampers per axis:

$$Pu = \frac{V_{BRB}}{n \times \cos(\theta)} \tag{2}$$

Where n represents the number of braces per axis, and θ is the angle between the height and the length of the panel. The core area (plastic zones) is calculated using:

$$A_{pmin} = \frac{P_u}{0.9 \times f_{ymin}} \tag{3}$$

Where $f_{ymin}$ is 2530 kg/cm². The nominal resistance of the BRB is calculated as:

$$P_y = 0.9 \times f_{ymin} \times A_p \tag{4}$$

Where $A_{min}$ is the area of the BRB. The expected resistance of the BRB is:

$$P_{ye} = R_y \times f_{ymin} \times A_p \tag{5}$$

For the BRB, $R_y$ = 1.1 is used. Additionally, the stiffness correction factor KF depends on the sections. The calculation of stiffness for each axis is:

$$K_{bwp} = KF\left(\frac{E \times A_P}{L_{bwp}}\right) \tag{6}$$

Where $L_{bwp}$ is the total length of the BRB.

The relationship between force and displacement of a FVD primarily depends on the relative velocity between the ends of the device. As the displacement velocity increases, the force of the damper also increases, and the relationship between force and velocity is defined by.

$$F_{damper} = CV^{\propto}$$

The coefficient $\propto$ varies between 0.4 and 0.5 for buildings.

For the pre-dimensioning of the Viscoelastic Dampers, 25% of the shear force is also taken, similar to the BRB. The participating mass of the structure, generalized mass, and displacement are considered to calculate the drifts and periods of the structure:

Participating mass: $Ln = \emptyset_1^T \times M \times i$ (7)
Generalized mass: $Mn = \emptyset_1^T \times M \times \emptyset_1$ (8)
Displacement: $d = \emptyset_1 \times F_{o1} \times S_{di}$ (9)

Also, to calculate the stiffness of the brace damper, the damping calculation is determined:

$$C = \frac{\beta_{visc} \times 2\pi \times D_{roof}^{1-\alpha} \times \omega^{2-\alpha} \times (\emptyset_1^T \times M \times \emptyset_1)}{\lambda \times \emptyset_r^{1+\alpha} \times cos^{1+\alpha}(\theta)} \tag{10}$$

## 3. Results

The results were measured in terms of inelastic drifts at each level. The table provided shows the results obtained from the spectral dynamic analysis of the irregular 11-story building, both without reinforcement and with the implementation of BRB and viscoelastic dampers in a chevron configuration. In the case without reinforcement, significant inelastic drifts were observed, reaching a maximum of 15.025 x $10^{-3}$ in the X direction on the 3rd floor, thus exceeding the maximum allowable limit of 7 x $10^{-3}$ established by the Peruvian standard E.030.

Table 2: Inelastic drifts in X.

| | Inelastic drifts in X (x$10^{-3}$) | | |
|---|---|---|---|
| PISOS | Inelastic drifts Δ without reinforcement | Inelastic drifts Δ with BRB | Inelastic drifts Δ with FVD |
| 11 | 4.0706 | 3.3350 | 3.5198 |
| 10 | 5.4038 | 3.6431 | 4.0210 |
| 9 | 6.6997 | 3.9739 | 4.5503 |
| 8 | 7.8096 | 4.1041 | 4.8538 |
| 7 | 8.7624 | 4.3956 | 5.2930 |
| 6 | 9.6572 | 4.2116 | 5.2773 |
| 5 | 10.6931 | 4.4843 | 5.6433 |
| 4 | 11.5008 | 3.8622 | 5.1996 |
| 3 | 12.0202 | 4.0585 | 5.3896 |
| 2 | 11.7697 | 2.9040 | 4.4104 |
| 1 | 8.1503 | 2.8362 | 3.9535 |

In the case without reinforcement, significant inelastic drifts were observed, reaching a maximum of 9.816 x $10^{-3}$ in the Y direction on the 3rd floor, thus exceeding the maximum allowable limit of 7 x $10^{-3}$ established by the Peruvian standard E.030.

Table 3: Inelastic drifts in Y.

| Story | Inelastic drifts in Y (x$10^{-3}$) | | |
|---|---|---|---|
| | Inelastic drifts Δ without reinforcement | Inelastic drifts Δ with BRB | Inelastic drifts Δ with FVD |
| 11 | 3.4901 | 2.7426 | 3.0658 |
| 10 | 4.2658 | 3.0028 | 3.4743 |
| 9 | 5.0598 | 3.3166 | 3.9474 |
| 8 | 5.7644 | 3.4553 | 4.2567 |
| 7 | 6.3574 | 3.7836 | 4.6917 |
| 6 | 6.8652 | 3.6280 | 4.7281 |
| 5 | 7.3963 | 3.9624 | 5.0715 |
| 4 | 7.7313 | 3.3466 | 4.6681 |
| 3 | 7.8529 | 3.5988 | 4.7438 |
| 2 | 7.5059 | 2.3518 | 3.6865 |
| 1 | 5.1791 | 2.2579 | 3.0332 |

The table presents the maximum inelastic drifts (in millimeters, multiplied by $10^{-3}$) for the 3rd, in two directions (X-axis and Y-axis), under the influence of two damping systems: Buckling-Restrained Braces (BRB) and Fluid Viscous Dampers (FVD).

Table 4: Maximum Inelastic Drift.

| Maximum Inelastic Drift ($x10^{-3}$) | | | | |
|---|---|---|---|---|
| Axis | Story | Without reinforcement | BRB | FVD |
| X | 3 | 12.0202 | 4.0585 | 5.3896 |
| Y | 3 | 7.8529 | 3.5988 | 4.7438 |

Table 5: Base Shear due to Dynamic Forces without Dampers.

| Base Shear | |
|---|---|
| Vx(tonf) | Vy(tonf) |
| 223.325 | 268.782 |

Table 6: Base Shear due to Dynamic Forces with Dampers.

| Type | BRB | | FVD | |
|---|---|---|---|---|
| Axis | X | Y | X | Y |
| Total | 441.604 | 326.200 | 433.877 | 460.080 |
| Dampers | 269.390 | 166.945 | 94.346 | 151.492 |
| % Dampers | 61.00% | 51.18% | 21.74% | 32.93% |

Table 6: Base Shear due to Dynamic Forces with Dampers.

| | Torsional Irregularity Ratio | | | | | |
|---|---|---|---|---|---|---|
| Type | Without reinforcement | | BRB | | FVD | |
| Story | X | Y | X | Y | X | Y |
| 11 | 1.08 | 1.02 | 1.02 | 1.02 | 1.02 | 1.03 |
| 10 | 1.18 | 1.01 | 1.03 | 1.01 | 1.02 | 1.01 |
| 9 | 1.25 | 1.01 | 1.05 | 1.01 | 1.06 | 1.02 |
| 8 | 1.30 | 1.01 | 1.03 | 1.01 | 1.06 | 1.01 |
| 7 | 1.33 | 1.03 | 1.07 | 1.03 | 1.10 | 1.03 |
| 6 | 1.36 | 1.02 | 1.02 | 1.02 | 1.08 | 1.01 |
| 5 | 1.41 | 1.05 | 1.10 | 1.05 | 1.14 | 1.05 |
| 4 | 1.46 | 1.03 | 1.01 | 1.03 | 1.11 | 1.02 |
| 3 | 1.52 | 1.09 | 1.15 | 1.09 | 1.21 | 1.09 |
| 2 | 1.59 | 1.03 | 1.03 | 1.05 | 1.18 | 1.06 |
| 1 | 1.66 | 1.29 | 1.24 | 1.20 | 1.44 | 1.32 |

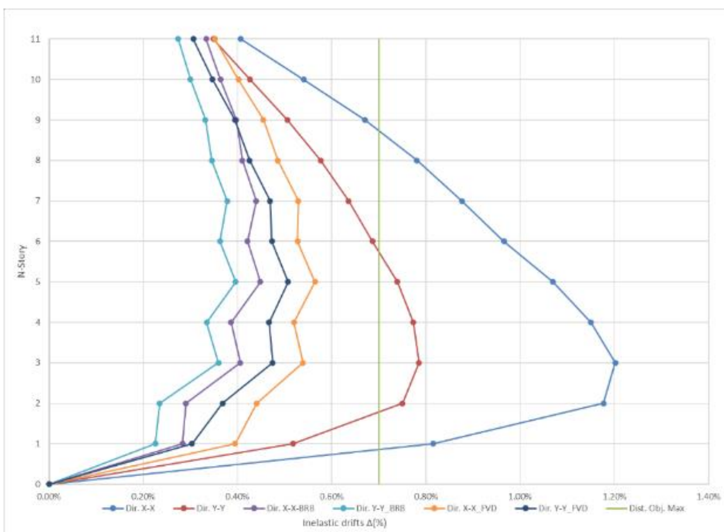


Fig 7: Graph of Inelastic Drifts

## 4. Conclusion

**- Inelastic Drifts**: By implementing Buckling-Restrained Braces (BRB) and Fluid Viscous Dampers (FVD), inelastic drifts were reduced in both directions, complying with the E0.30 standard, as shown in Figure 7, since the inelastic drifts remained below $7x10^{-3}$, as shown in Tables 2 and 3. The highest inelastic drifts were recorded on the third floor, with $12.02x10^{-3}$ in the X-axis and $7.853x10^{-3}$ in the Y-axis. The implementation of the BRBs led to a significant improvement, as they provided greater stiffness compared to the FVD. Likewise, the base shear of the structure was absorbed to a greater extent by the BRBs compared to the FVD, as shown in Table 6.

**- Irregular Building**: Initially, the structure exhibited irregularities in the X direction due to extreme torsion and in the Y direction due to torsion, in accordance with the E0.30 standard. However, as shown in Table 6, after the implementation of Buckling-Restrained Braces (BRB), it was observed that only the X direction retained the torsional irregularity, while torsion was no longer present in the Y axis. On the other hand, after incorporating Fluid Viscous Dampers (FVD), although improvements were achieved, both directions continued to exhibit torsional irregularities.

**- Use The BRB**: The use of Buckling-Restrained Braces (BRBs) is appropriate for reinforced concrete structures that require increased stiffness and a significant reduction in lateral displacements, while also helping to reduce structural torsion. In contrast, Fluid Viscous Dampers (FVDs) are a suitable alternative for structures that exhibit inelastic drifts exceeding the 7/1000 limit established by the E.030 standard. However, FVDs do not help reduce structural torsion, unlike BRBs, which do.

## Financing

Universidad Peruana de Ciencias Aplicadas / UPC-EXPOST-2025-1

## Acknowledgements

To the Research Directorate of the Peruvian University of Applied Sciences for the support provided through the UPC-EXPOST-2025-1 incentive.

I sincerely thank Professors Esquivel and Estrada for their guidance, support, and dedication, which were key to the development and success of this project.

Finally, special thanks to the parents of both authors, whose love, unwavering support, and values provided the environment needed for the development of this project.

## References

[1] C-M Uang and M. Nakashima Steel Buckling-Restrained Braces Frames. Y. Bozorgnia & V. Bertero (Eds.), Earthquake Engineering from Engineering Seismology to Performance-Based Engineering, ICC, 2004.

[2] C-M Uang, M. Bruneau, AS. Whittaker and Tsai K.-C, Seismic design of steel Structures. F. Naeim, (Ed.), Seismic Desing Handbook, Van Nostrand Reinhold, New York, 2001.

[3] P. Clark, I. Aiken, K. Kasai, E. Ko and I. Kimura, Desing procedures for buildings incorporating hysteretic damping devices, Proc. 69th Annual Convention of SEAOC, Sacramento, CA, 1999.

[4] C. Shuhaibar, W.A. Lopez and R. Sabelli, Buckling-restrained braced frames, Proceedings, Seminar on Response Modification Technologies for Performance-Based Seismic Design, ATC-17-2, ATC and MCEER, pp. 321-328, 2002.

[5] M. Fujimoto, A. Wada, E. Saeki, A. Watanabe and Y. Hitomi, A study on the unbonded brace encased in buckling-restraining concrete and steel tube, Journal of Structural Engineering, 034B,249-258,1988.

[6] A. Syrakos, Y. Dimakopoulos and J. Tsamopoulos, "Theoretical Study of the Flow in a Fluid Damper Containing High Viscosity Silicone Oil: Effects of Shear-Thinning and Viscoelasticity," *in* Y. Bozorgnia & V. V. Bertero (Eds.), *Earthquake Engineering: From Engineering Seismology to Performance-Based Engineering*, ICC, 2018.

[7] CoreBrace. Author. (2020, November). Brace Stiffness Calculations [Online]. Available: B