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Case Study of a 22 story building using Hybrid Coupling Beams Equipped with Buckling Delayed Shear Links

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Abstract

This study presents a parametric seismic performance evaluation of a 22-story reinforced concrete building with five basement levels in Quito, Ecuador. The structure features two rigid concrete cores connected by coupled shear walls using hybrid coupling beams (HCBs) with Buckling Delayed Shear Links (BDSL) dissipators. In coupled wall systems, coupling beams are key for energy dissipation and to control the degree of coupling and axial loads in the walls. Since concrete performs poorly in shear, traditional designs require heavy diagonal reinforcement. BDSL devices, like the SLB used here, offer improved stiffness and ductility, dissipating energy effectively through shear and accommodating large lateral displacements.

The building's final seismic design was based on eleven nonlinear time-history analyses using site-specific ground motion records representing a 2475-year return period (collapse-level events). For the parametric study, five representative records were selected to approximate the average structural response. The analysis focuses on the performance of BDSL-equipped coupling beams by examining interstory drifts, critical structural sections, and overall system behavior. The study explores different levels of wall coupling and concludes that optimal performance is achieved when all levels are fully coupled with a consistent yield strength (Fy). Additionally, reducing Fy leads to a significant reduction in base shear forces.

Keywords: Hybrid Coupling Beam, Buckling Delayed Shear Link, Energy Dissipator, SLB, NonLinear Time history Analysis, Performed Base Design.

1 Introduction

High seismic risk areas demand buildings to employ efficient lateral load-resisting systems that ensure structural integrity during strong ground motions. A widely adopted strategy involves the use of dual-core reinforced concrete walls, where coupling beams serve a vital function in transferring forces between the cores and enhancing the overall lateral stiffness of the structure. Coupled shear wall systems are recognized for providing substantial rigidity to high-rise buildings under seismic loading (ACI, 2019; ASCE, 2017). However, these coupling beams are inherently vulnerable due to the large stiffness differences between the beams and the connected boundary elements, especially under seismic shear demands. This vulnerability results in stringent code requirements that increase beam dimensions, complicate reinforcement detailing, and elevate construction costs.

Traditional concrete coupling beams present notable design and construction challenges. They primarily resist shear forces, necessitating heavy diagonal reinforcement that penetrates the boundary elements of the shear walls. These boundary elements must be heavily confined and reinforced to maintain ductility, further complicating construction and increasing the risk of errors. Furthermore, conventional concrete beams are prone to extensive cracking after seismic events—as observed in recent earthquakes (El-Tawil et al., 2004)—which often leads to expensive repairs and sometimes irreparable damage.

The use of Buckling Delayed Shear Links (BDSL) in Hybrid Coupling Beams (HCB) enhances seismic performance by improving shear resistance. These steel dissipators outperform concrete in energy dissipation and eliminate the need for heavy diagonal reinforcement, simplifying construction and avoiding reinforcement congestion in wall boundary zones. Additionally, being replaceable components, BDSLs allow for easier post-earthquake repairs, reducing costs and increasing overall structural resilience (Chen et al., 2019).

2 Methodology

This study investigates the seismic performance building under construction equipped with BDSL in hybrid coupled beams. The aim of the study is to analyze the effect of different BDSL in the overall performance of the structure and the coupling degree of the walls they connect. The first part of the study uses the original building, keeping the same structural elements as well the HCB and compares it with two variations of the yielding force (Fy) in the BDSL. The first variation reduces the Fy for the upper half of the building in half (0.5Fy) while keeping the bottom half with the same Fy, the second variation divides the building and the Fy in 3 proportional parts (0.33Fy; 0.66Fy;Fy).

The second part of the study also uses a variation in the Fy of the BDSL. However, in this part the Fy remains the same in each model and the variation is compared for each structure with different Fy. The range of study goes from 160kN to 1113kN Fy divided in 10 different models. The main focus of both parts of the study is to assess and compare the lateral drift response for each configuration under seismic loading in order to compare the different coupling degrees of the HCB with the core walls.

Nonlinear dynamic analysis simulates a structure's response to seismic loads by applying ground motion records at its base and integrating the motion equations step by step. This method captures displacements, deformations, and internal forces while accounting for the nonlinear behavior of structural elements.

The selection and scaling of the accelerograms used in this study were carried out in accordance with ASCE standards (ASCE 7-16, 2017), considering the seismicity of the site. The average demands of five earthquake records, adjusted to the site-specific response spectrum, were evaluated. The original model was analyzed through eleven nonlinear time-history analyses; however, for this parametric study, the five most representative signals were used to reduce computational cost. These records were selected based on the site-specific seismic hazard assessment conducted for the "Luz Apartamentos" project in Quito, Ecuador, as detailed in the technical report *Caracterización de la Peligrosidad Sísmica: Proyecto Edificio "Luz Apartamentos"* (Aguiar, Rivas, & Cagua, 2025).

To evaluate the configurations, 15 nonlinear analyses were performed to compare vertical variations of yield strength (Fy), and 50 additional analyses assessed wall coupling based on different uniform Fy values of BDSL along the height.

Both horizontal components of the ground motions were considered to act simultaneously in the principal directions of the structures. However, only one direction is studied for both shear and drift analysis as the HCB are only placed in one direction. The nonlinear behavior of the structural elements was accounted for in accordance with ASCE 41-17 standards.

3 Case Study

3.1 Linear Response Spectrum Analysis Model

The building under study, known as Luz, is located in Quito, Ecuador—a region classified as highly seismic. It is a 22-story reinforced concrete structure with five confined basement levels which are fully embedded in soil in all the perimeter of the building. The structural system is based on a dual configuration, composed of two main reinforced concrete cores formed by coupled shear walls and complemented by moment-resisting concrete frames. The cores are responsible for resisting over 75% of the total seismic demand. These behave as coupled wall systems in the X-direction, connected by energy dissipation devices—specifically Shear Link Bozzo dissipators—with a yielding force (Fy) of 558 kN for the real project, an initial stiffness

(K_1) of 9580 kN/cm, and a maximum force capacity (Fmax) of 966 kN, allowing controlled inelastic energy dissipation under strong ground motions.

The structure uses medium to high-strength concrete for walls, columns, and floors, with conventional Grade 60 reinforcing steel. A linear modal response spectrum analysis was performed in the preliminary design phase, considering local soil conditions and full compliance with the Ecuador building code. The analysis verified the building's strength and deformation limits under gravity and seismic loads, as well as the effectiveness of energy dissipators in improving seismic performance.

This preliminary modal analysis verifies strength and drift limits under gravity and seismic loads. Cracked stiffness was modeled per NEC-SE-DS (2015), and elements were designed per ACI 318-19. The analysis, performed in ETABS v21, used a site-specific spectrum calibrated to ASCE 7-22, with a seismic reduction factor R = 5, 5% accidental eccentricities, and included sufficient modes to capture 90% of the effective modal mass.

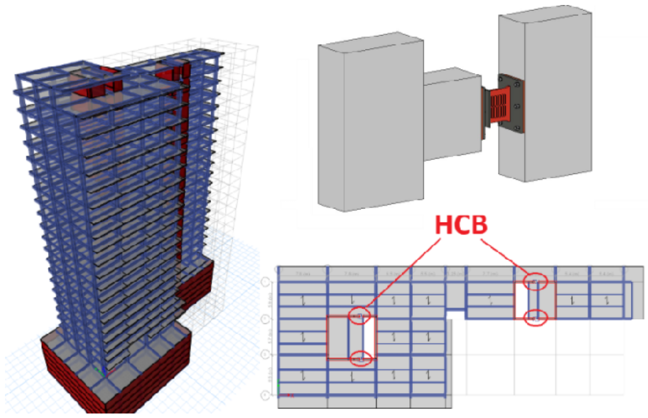

Figure 3.1. Isometric and plan view of the building.

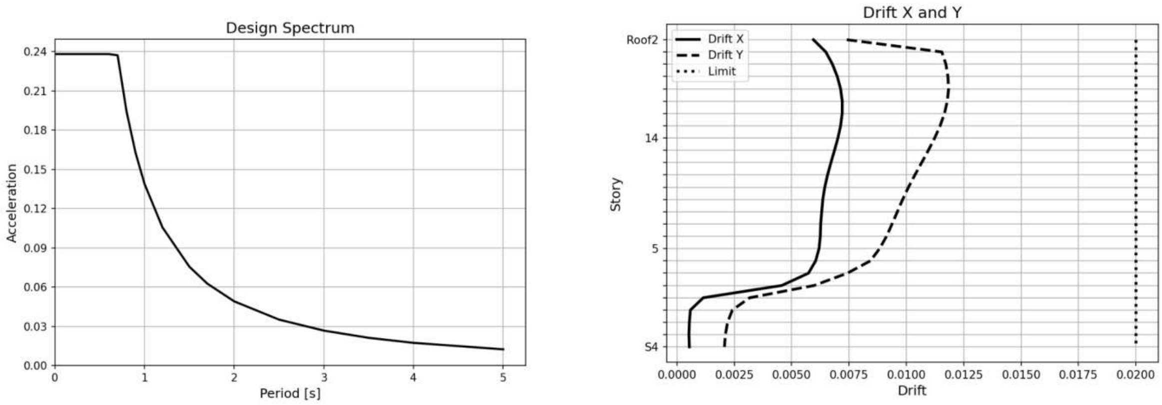

Figure 3.2. Design Response Spectrum (left); Drifts obtained from Modal Response Analysis (right)

Interstory drifts were assessed (see Figure 3.2 - right), applying an amplification factor of 0.75 R, as required for linear analysis models. The computed (amplified) story drift ratios remained in all stories well below the maximum drift limit of 0.02 specified in the Ecuadorian code provisions for ductile reinforced concrete and steel structures. This confirms an acceptable level of seismic performance within the assumptions of linear elastic analysis.

3.2 Nonlinear Time History Analysis

To carry out the Nonlinear Time History Analysis (NLTH), seismic records were selected that adequately reflect the tectonic characteristics of the environment and the dominant rupture mechanism in the region where the structure is located. These records were obtained from the Seismic Hazard Study specifically developed for the site (Aguiar, Rivas, & Cagua, 2025).

Eleven pairs of accelerograms were used, which were amplitude-scaled according to the demand level corresponding to the Maximum Considered Earthquake (MCE). The scaling procedure employed was the Weighted Average Method, which allowed the average spectral ordinates to match those of the Uniform Hazard Spectrum (UHS) for a return period of 2,475 years, taking into account the predominant periods of the structure.

3.2.1 Performance analysis of variable Fy dissipators distributed by height

Study of the structural performance based on the interstory drift by modifying the coupling degree of the walls along the height of the building. The coupling degree is modified by varying the yield strength (Fy) of the BDSL in the coupling beams with these three configurations:

Configuration 1 establishes a uniform setup where all BDSL (Buckling-Restrained Shear Link) devices are distributed evenly across the building’s height, each with the same yield strength (Fy). This configuration aligns with the original design outlined in Section 3, using consistent parameters for stiffness and strength. **Configuration 2** introduces a vertical variation in yield strength by dividing the building into two zones: the upper half uses dissipators with a reduced yield strength of 0.5Fy, while the lower half maintains the original Fy. This redistribution aims to obtain a more uniform distribution of average story drift ratios. **Configuration 3** takes this idea further by dividing the structure into three equal segments, with yield strengths set at 0.33Fy in the top, 0.66Fy in the middle, and Fy at the bottom. This more tailored distribution of strength in the HCB is intended to progressively enhance energy dissipation performance across the building’s height.

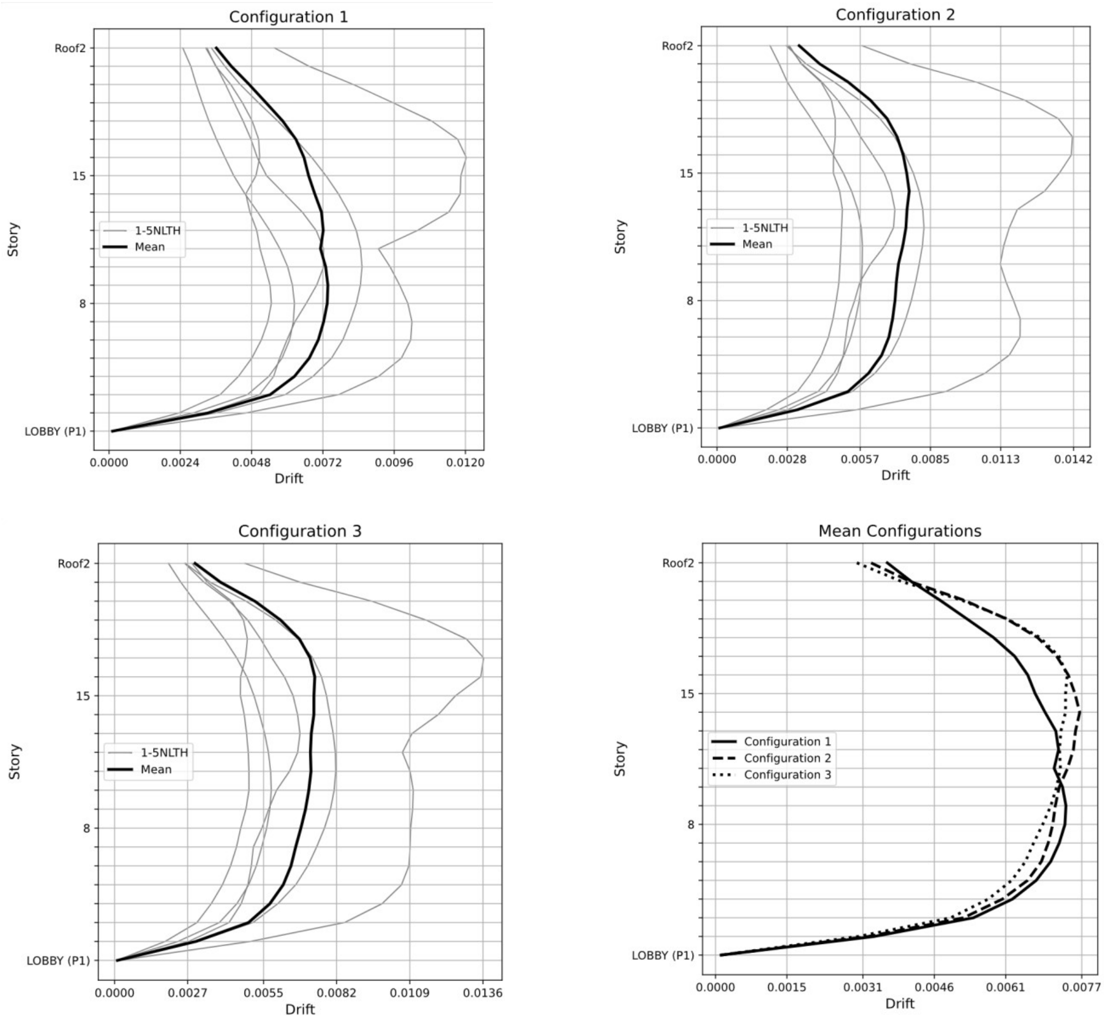

Figure 3.4. InterStory drift analysis for height-variable dissipator configurations.

Figure 3.4 shows the interstory drift variation for each of the 3 configurations studied. The bottom right figure shows the mean drift for each configuration. It is shown that as the Fy is reduced in height, the Drift in the upper part of the building increases. However, the results show that the overall mean story drift distributions in the three configurations are not significantly different from each other. This result suggests that Fy variation through height and regarding lateral displacements does not report significant advantages.

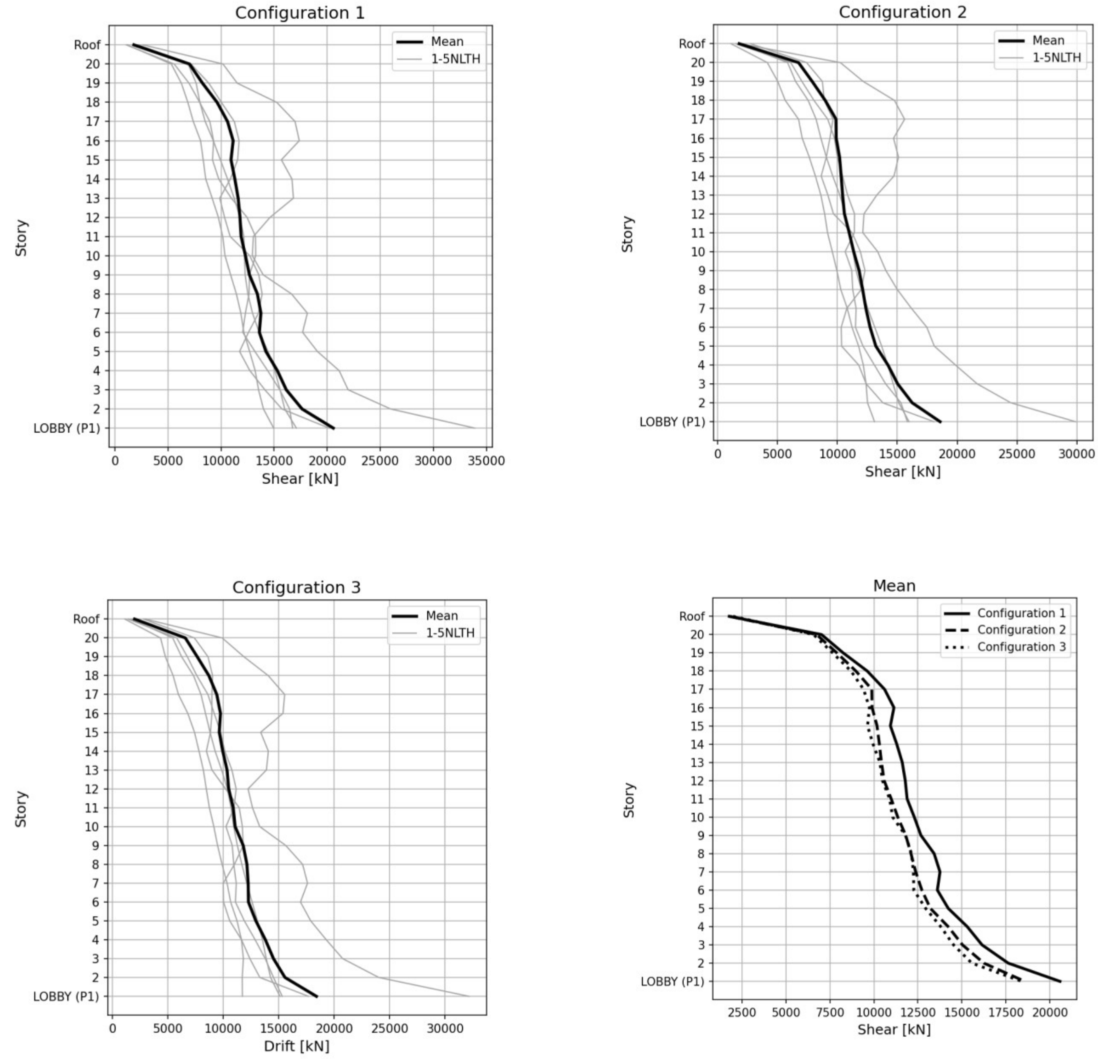

Figure 3.5. Shear demand in walls for each configuration

Figure 3.5 showcases the effect of varying in height the Fy of the BDSLs. It is shown the Shear results for the 3 configurations as well as the average comparison. Configuration 2 and 3 significantly reduce the shear along the height of the structure compared with configuration 1.

3.2.2 Performance analysis for Configuration 1 varying the Fy

This part of the study aimed to examine the degree of coupling offered by the HCBs when the BDSL has different Fy maintaining the principle of Configuration 1, in which the Fy is kept uniform along the height of the structure. The range of Fy was implemented from 160 to 1113 kN. Figure 3.6 shows the interstory drift for the maximum and minimum Fy considered as well as the Fy that displayed optimal drift. The optimal drift was considered as the minimum Drift max for the average of the 5 NLTH analysis carried out for each Fy.

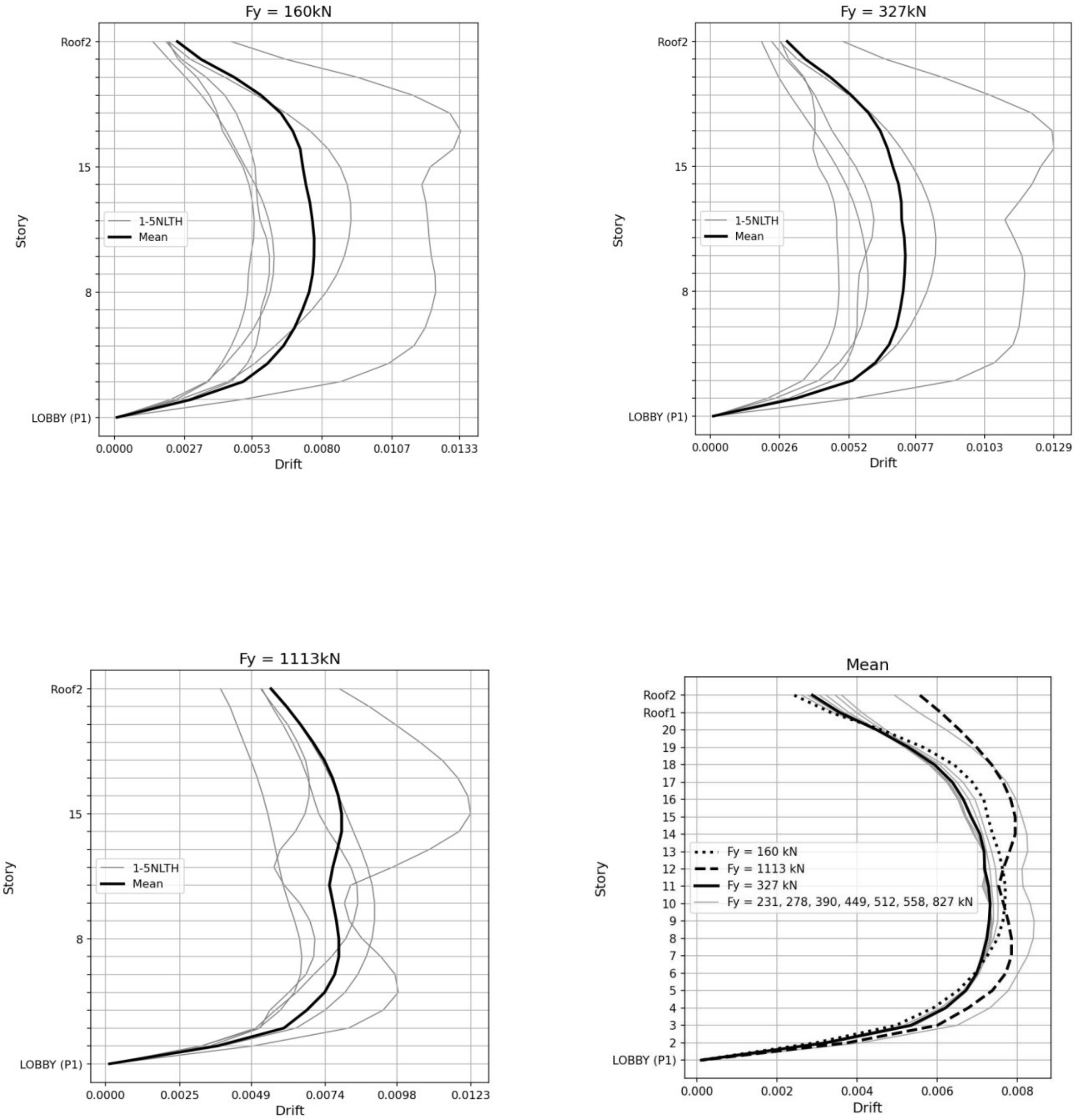

Figure 3.6. Interstory drifts results for the minimum, maximum and optimal Fy

Figure 3.6 shows that the interstory drift does not present a linear correlation with the value of the Fy as both for a high and a low value of Fy the interstory drift presents maximum values. The optimal value for the Fy is shown in the top right corner of the figure, showing the optimal result for Fy =327kN.

Figure 3.7 shows the correlation between the base shear force of the core walls for each seismic record studied and each Fy case in Section 3.2.2. The black line is the mean correlation for the 5 signals and illustrates how, as the HCB ratio — defined as Fy of the BDSL divided by the maximum shear of the cantilever — increases, the base shear also increases, and in a nearly quadratic line.

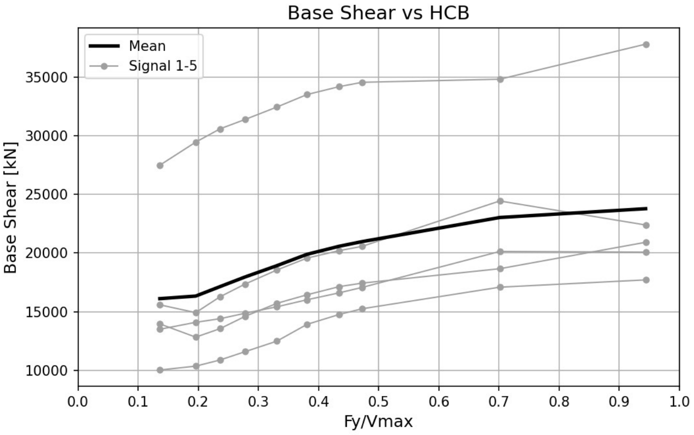

Figure 3.7. Variation of base shear with changes in normalized HCB strength

The displacements are not significantly affected by the yielding force of the devices, which is consistent with the observations from nonlinear spectra of single-degree-of-freedom systems (Newmark & Hall, 1982). Figure 3.8 shows little variation with respect to the yielding strength of the dissipators in the roof. An “optimal” strength can be observed where displacements are minimized, although, in general, the variation across all values is low.

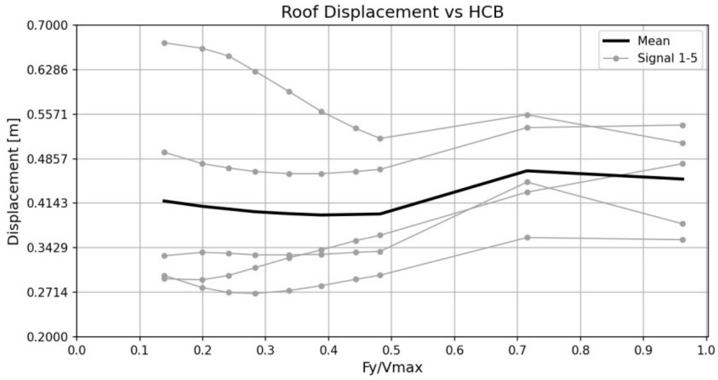

Figure 3.8. Variation of roof absolute displacement (m) with the HCB ratio

Figure 3.9 presents the hysteresis diagrams of the dissipators at Level 5 for both Wall Core 1 and Wall Core 2—the most highly demanded elements—in the optimal configuration (Configuration 1 with a yield strength of 327 kN). It is observed that the maximum displacement does not exceed 6 cm in the most heavily loaded dissipator, which is consistent with the displacement limits established by experimental tests.

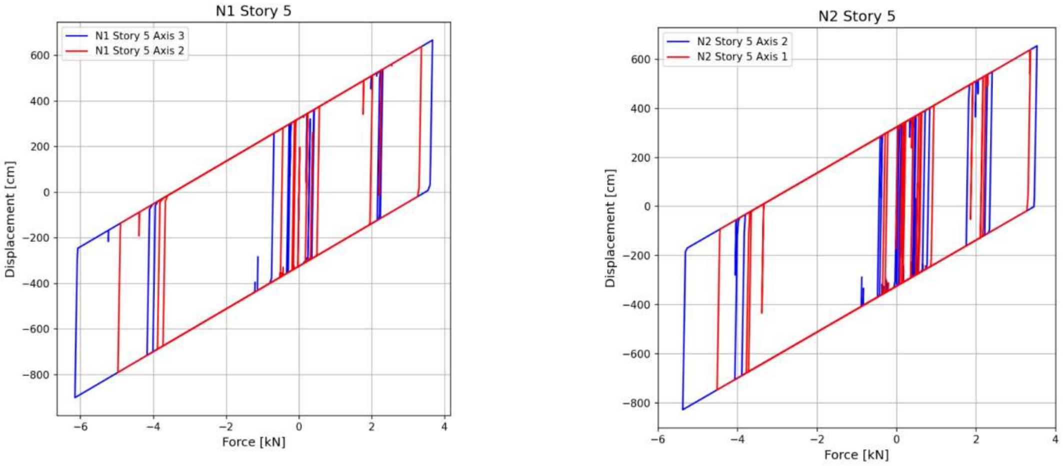

Figure 3.9. Hysteresis diagram of the BDSL at Level 5 for the most unfavorable ground motion in Configuration 1 with Fy = 327 kN.

The structure's seismic performance has also been verified by checking the formation of plastic hinges in the structural elements. Table 3.1 presents the number of plastic hinges that formed in the models with Fy values of 160, 1113, and 327 kN—representing the minimum, maximum, and the Fy value that showed the optimal interstory drift, respectively. The data shown in this table corresponds to the most unfavorable seismic record. All the plastic hinges for the 5 ground motions studied, if appeared, were Immediate Occupation (IO) type.

Table 3.1. Immediate Occupation Plastic Hinges

Fy (kN)	**Walls**	**Beams**	**Columns**
160	18	80	18
327	**12**	**64**	**14**
1113	24	111	22

4 Conclusions

4.1 Summary

- Parametric studies changes the variation of yielding strength of the hybrid coupling beams (HCB) indicate that maintaining uniform dissipator properties along the building height yields the best structural performance by effectively controlling floor drifts. In contrast, reducing stiffness at upper levels increases drift in higher stories, compromising structural behavior. A consistent damper distribution is therefore recommended to optimize seismic response.
- Results from nonlinear response history analyses indicate that an adequate, close to optimum, distribution of story drifts demands along the height of the building was achieved with a yield strength (Fy) of 327 kN, or 66% of the original design. This aligns with expectations, as a lower Fy triggers earlier energy dissipation, reducing seismic forces. However, reducing Fy beyond this point increases drifts due to weaker coupling between the walls, making the structure more flexible
- The hysteresis diagrams for the most demanded dissipators at Level 5 (Wall Cores 1 and 2) in the optimal configuration (327 kN yield strength) show that displacements remain below 6 cm, meeting experimental limits and confirming the design's effectiveness.
- Displacements are not significantly affected by the initial yielding forces of the devices while the base shear at the cores are reduced as the yiending forces decrease.
- SLB Devices provide a great solution for HCB, allowing optimal coupling level of the core walls while not exceeding their maximum displacement capacity.
- Through a series of parametric studies it was found that setting the yield strength Fy=327 kN not only results in the lowest peak interstory drift but also leads to the fewest plastic hinges. In other words, the Fy value of 327 provides the most effective coupling level, as it minimizes overall structural damage.

5 ACKNOWLEDGEMENTS

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