

Supplemental Viscous Damping Combined with Seismic Isolation – A Practical Case Study

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1 ABSTRACT

The recent increase to the seismic hazard throughout much of New Zealand has made it difficult to design and achieve an isolated building with bearings that are within practical limitations. Adding fluid viscous dampers in parallel with a conventional base-isolation system can reduce the displacements across the isolation plane. This paper compares the seismic performance of a conventionally isolated building to an equivalently isolated building combining supplemental viscous dampers (located within the isolation plane and with added damping in the superstructure).

A prototype building has been developed for this study, located in a high seismic zone in New Zealand – the isolation system and superstructure are designed in accordance with the NZSEE Base Isolation Guideline, representing current industry practice. The same building is then located in a higher seismic zone (50% higher, representing either a different location or change in seismic hazard for an existing structure), and the isolation system is redesigned incorporating viscous dampers located within the isolation plane. Both isolated buildings are intended to have comparable isolator and superstructure geometries (minor variations are discussed in the paper). Nonlinear dynamic analyses have been performed on both isolated structures to demonstrate that supplemental viscous damping can be used reduce seismic displacements across the isolation plane, resulting in bearings with smaller (more practical) dimensions to what would otherwise be required without dampers. The trade-off in adding supplemental damping within the isolation plane, is an increase to the demands in the superstructure (drifts, storey shears, accelerations) via the stiffening effect that comes with such devices. This paper presents the results of several analytical studies to investigate how supplemental damping located within the isolation plane, and within the superstructure may be used to arrive at a solution to control (and strike a balance between) competing structural responses quantities.

2 PROTOTYPE STRUCTURE DESCRIPTION

A 6-storey steel moment-frame building (IL4) has been designed for two types of base isolation: Lead Rubber Bearings (LRB), and a Friction Pendulum System (FPS). The prototype building is intended to reflect a generic hospital building comprising of two levels of podium (i.e. Acute-Services/ICU/Imaging),

with two 4-storey towers above (wards, outpatients etc). The steel superstructure comprises of concrete metal deck slab, structural steel framing, isolated over a concrete sub-structure (beams, columns perimeter basement walls). The isolation plane is located at the top of cantilever ground-floor columns (refer to Figure 1 below).

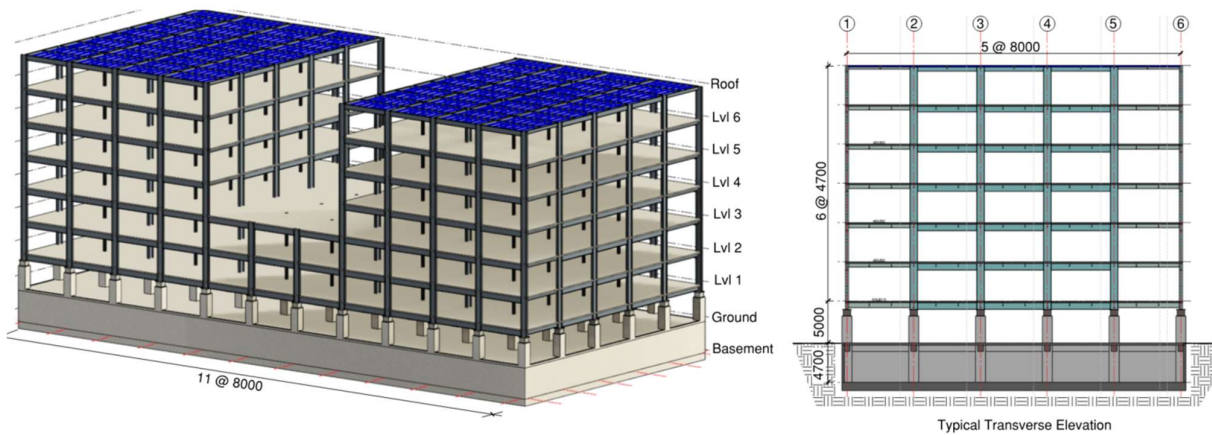


Figure 1: Prototype isolated building.

The prototype isolated structure is located in Whakatane, and has been designed in accordance with TS1170.5:2025, and the 2017 NZSEE Base Isolation Design Guide. The structure was designed as an IL4 building for SLS2, ULS and CALS objectives, corresponding to a 1/500, 1/2500 and 1.3 times the 1/2500 hazard level, respectively.

As part of this study, the as-designed prototype building was then re-located in a new hazard location, having a 50% higher hazard level (a generic location). The purpose of relocating the structure was two-fold:

1. If supplemental damping is introduced within the relocated-building, can the demands within the isolation plane and superstructure be reduced to levels that are comparable to that of the structure situated in the as-designed location. That is, can the introduction of damping “neutralise” a seismic hazard increase for a new design.
2. From an existing isolated building perspective which has seismic performance less than that of a new building, to what extent can supplemental damping reduce the demands on the isolation plane and superstructure to achieve a relative increase in seismic performance.

3 SEISMIC HAZARDS

The baseline seismic hazard, and location of the prototype building is shown in Figure 2 below. The results presented and discussed herein are specific to a single TS1170.5:2025 IL4 hazard level - CALS (1.3x 1/2500 hazard). The site is classified as a “High” seismic risk area ($Z=0.3$), per the current New Zealand Building Act. It is acknowledged that not all engineering parameters presented herein may be of interest in design at the CALS hazard level; however, the CALS hazard is used to present and discuss general trends in observed structural response.

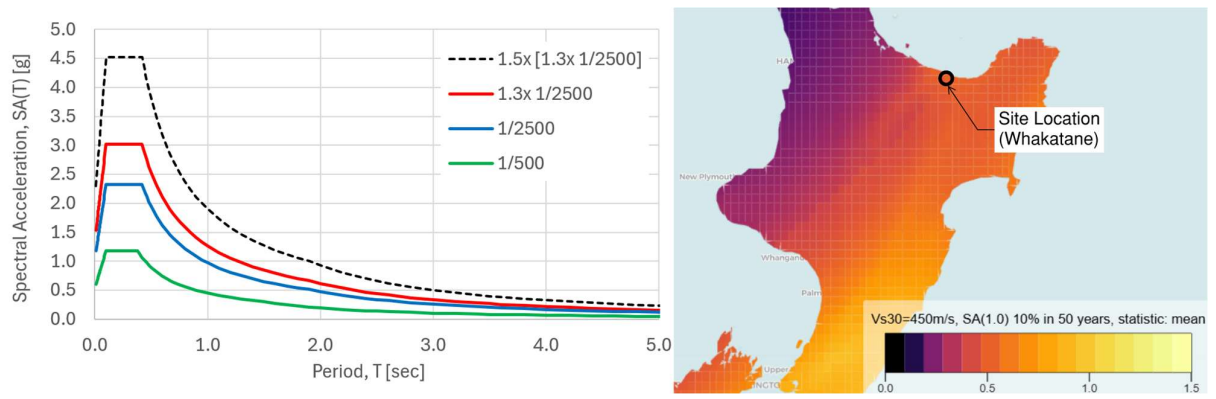


Figure 2: Seismic hazard, and location of the prototype building, Left: TS1170.5:2025 elastic design response spectra for Site Class II, $\mu=1$, $S_p=1$; Right: GNS 2022NSHM hazard plot, $SA(T=1.0)$, 1/500yrs and $V_s=450\text{m/s}$.

A suite of 11 amplitude-scaled ground motions were selected and scaled to the target response spectrum.

4 PARAMETRIC STUDY RESULTS

The following structural response metrics were explored to compare the impact of each parameter variation to the benchmark prototype structures:

- Storey (floor level) Displacements (including at the isolation plane)
- Storey Drifts above the isolation plane
- Storey Shears

Table 1 summaries each parametric variation and corresponding sections in this paper to guide the reader.

Table 1. Summary of Parameter Variations

Paper Section	Hazard	Isolation Type*	Dampers at Isolation Plane		Distributed Damping in Superstructure	
			Total Damping, ΣC (kN.s/m)	Velocity Exponent, α	Total Damping per Story, ΣC (kN.s/m)	Velocity Exponent, α
4.1	100%, 150%	LRB, FPS	0	N/A	N/A	N/A
4.2	150%	LRB	2,400 – 24,000	0.7	N/A	N/A
4.3	150%	FPS	5,000 – 20,000	0.3, 1.0	N/A	N/A
4.4	150%	LRB	14,200 – 18,500	0.3 – 1.3	N/A	N/A
4.5	150%	LRB	16,800	0.7	4,000 – 48,000	0.4

* See Section 4.1 for quantification of isolation parameters used to represent LRB and FPS systems

The seismic design and response of supplemental damped isolation buildings is not a new concept, and previous studies have focused on the behaviour of the isolation plane, SDOF systems, and limited MDOF

systems (Makan et al 2023), (Makan et al 2025), and (Whittaker 2025), including general-purpose design procedures for combined hysteretic-viscous dissipation (Marriott 2009). This paper studies the complete isolation-superstructure response, representative of a traditional building configuration, using common construction materials.

4.1 Benchmark Performance

The storey drift, floor displacement and storey shear are shown in Figure 3 below for the two benchmark isolated structures. Only the mean results of the suite-maxima NLRHA response quantities at the CALS hazard are presented throughout this paper. The response of the LRB Benchmark ($Q_d/W_t=0.086$, Yielded Period, $T_2=4.9\text{sec}$) is presented at the 100% and 150% CALS hazard to indicate the general increase in structural demand considering a 50% increase in hazard (70%-80% increase in displacements, 20-30% increase in superstructure drifts and storey shears). Results for the FPS Benchmark ($Q_d/W_t=0.045$, Yielded Period, $T_2=5.7\text{sec}$) are shown at the 150% CALS hazard level – the FPS is reflective of a “softer” isolation design (20%-30% larger displacements, 30%-40% lower superstructure drifts, and 10-20% lower storey shears than the LRB benchmark). While not presented or discussed in this paper, the superstructure drift demands were less than 0.4% for the LRB benchmark building at the SLS2 hazard (100% hazard).

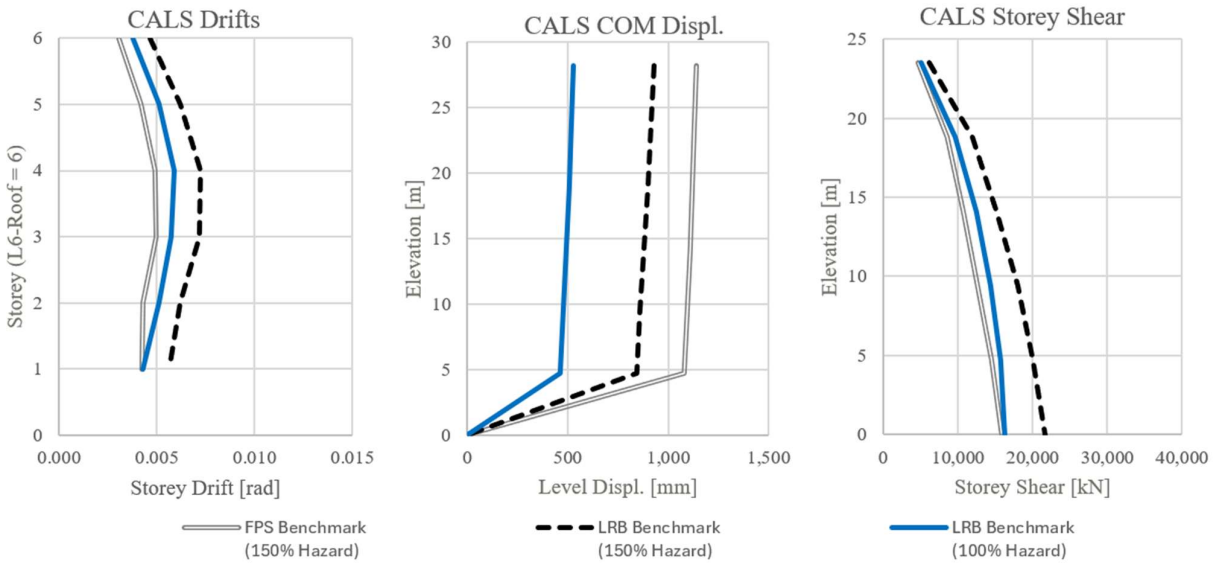


Figure 3: Structural response plots for the LRB and FPS benchmark buildings – no supplementary damping.

4.2 Varied Damping at Isolation Plane; LRB Isolation System

The addition of damping was studied in the LRB benchmark at the 150% CALS hazard by varying the amount of supplemental damping introduced within the isolation plane. Comparisons are made against the undamped LRB benchmark building at 100% and 150% CALS. In Figure 4 below supplemental damping increments of 2,400, 4,800, 12,000, 16,800 and 24,000kN.s/m are investigated ($\alpha=0.7$), which correspond to an elastic ($T=0.5\text{sec}$) damping ratio of 1%, 2%, 4%, 6%, 8% of critical damping¹.

¹ Relating the damping ratio increments to an elastic period of $T=3.0\text{sec}$ (reflective of displacement-based design approaches that utilise the secant period of an equivalent SDOF system) yields ratios of 5%, 9%, 24%, 33% and 47% of critical damping, respectively.

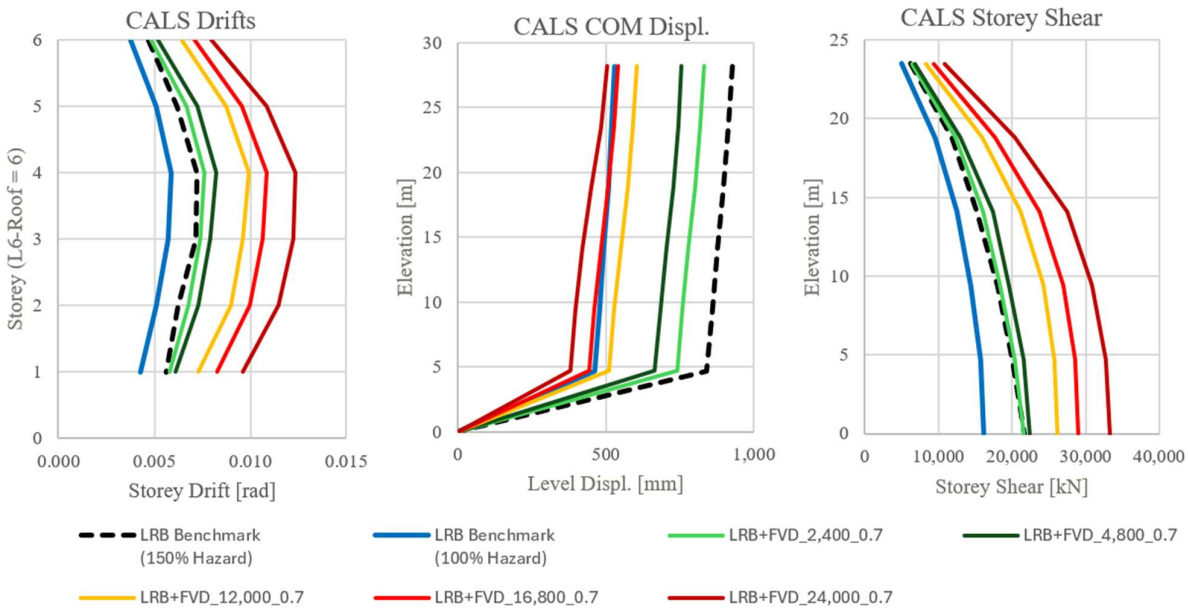


Figure 4: Structural response plots for the LRB benchmark isolated building with varying levels of supplemental damping located at the isolation plane.

Generally, as the amount of supplemental damping within the isolation plane increases, the isolation displacement reduces at the expense of increased storey drifts and storey shears in the superstructure. The trend is not linear - a nominal amount of damping introduced to the isolation plane (4,800kN.s/m) equated to a ~20% reduction in isolation displacement, combined with a ~10% increase in storey drifts and storey shear. It is evident from this study that simply adding supplemental damping into the isolation plane is unable to neutralise a 50% hazard increase. To reduce the isolation demands of the undamped LRB benchmark (150% hazard) to be comparable to the 100% hazard demands, supplemental damping needs to reduce the isolation displacement by 40%-50%. The amount of supplemental damping to achieve this reduction in isolation displacement increases storey drifts by 50%-60% and storey shear by 40-50% relative to the undamped LRB benchmark (150% hazard). Supplementary damping at the isolation plane introduces a “stiffening effect” at the base of the structure – the work done by the dampers corresponds to shear resistance that is additive to the bearings within the isolation plane – this additional shear resistance (stiffening) manifests its way up through the structure, increasing superstructure demands (in general).

4.3 Varied Damping at Isolation Plane; FPS Isolation System

In the next two sub-studies, the isolation damping was investigated on a FPS isolated building ($Q_d/W_t=0.045$, Yielded Period, $T_2=5.7$ sec). The intention was to investigate a system that had a better “balance” in shear resistance (energy dissipation) provided between a “softer” isolation system and non-linear dampers.

4.3.1 Velocity Exponent, $\alpha = 0.3$

The addition of non-linear damping ($\alpha=0.3$) was studied in the FPS benchmark building by varying the amount of supplemental damping introduced within the isolation plane. Of interest was to understand if it is possible for the FPS system (with added damping) at 150% CALS to achieve comparable demand parameters to the undamped LRB benchmark at 100% CALS. In Figure 5, supplemental damping increments

of 5,000, 10,000, and 15,000kN.s/m are investigated, which correspond to an elastic ($T=0.5\text{sec}$) damping ratio of 2%, 3%, and 5% of critical damping².

As with the LRB isolation system, as the amount of supplemental damping in the isolation plane increases, the isolation displacement reduces at the expense of increased storey drifts and storey shears in the superstructure - nonlinear damping in the isolation plane alone could not neutralise a 50% hazard increase. The introduction of 5,000kN.s/m of damping into the isolation plane (at 150% hazard) reduced the undamped FPS isolation displacements by almost 30%. The amount of supplemental damping to reduce the isolation displacements to be comparable to the undamped LRB benchmark at 100% hazard was three times this amount (15,000kN.s/m). This case increased the storey drifts by 30-50% and storey shear by 20-70% relative to the undamped LRB benchmark (150% hazard).

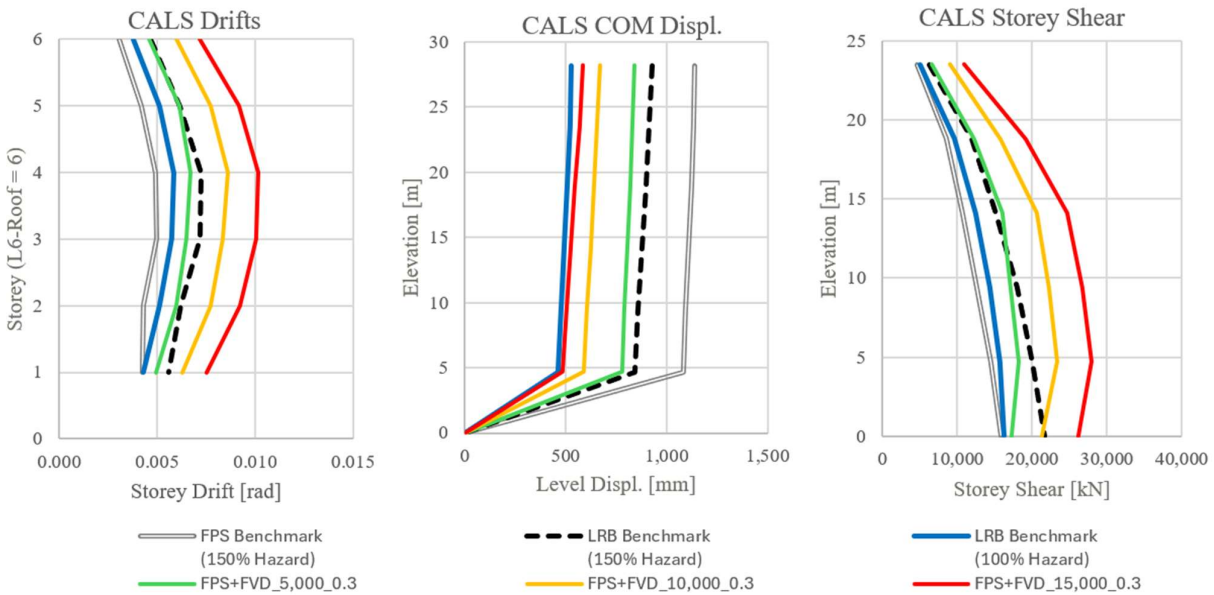


Figure 5: Structural response plots for the FPS benchmark isolated building with varying levels of supplemental damping located at the isolation.

4.3.2 Velocity Exponent, $\alpha = 1.0$ with force-limit

The addition of linear damping ($\alpha=1.0$) was studied in the FPS benchmark building by varying the amount of supplemental damping introduced to the isolation plane and also included a force-limit on the damper devices. A force-limiting behaviour can be achieved in FVDs by adding a mechanical relief-valve internally or by having the FVD installed in series with a friction or yielding engineered device. Both cases limit the load that can be resisted by the damper assembly. In Figure 6, supplemental damping increments of 10,000, 15,000, and 20,000kN.s/m are investigated, which corresponds to an elastic ($T=0.5\text{sec}$) damping ratio of 3%, 5%, and 7% of critical damping³. Additionally, a force-limit of 0.05 and 0.075 times the weight of the building was investigated – approximately equal to 1.0 and 1.5 times the yield strength (Q_d/W_i) of the FPS bearing system.

Compared to the undamped FPS isolation system, the reduction in isolation displacement was relatively insensitive to the damping coefficients investigated (10,000-20,000kN.s/m), returning a 30-40% reduction in

² Relating the damping ratio increments to an elastic period of $T=3.0\text{sec}$ (reflective of displacement-based design approaches that utilise the secant period of an equivalent SDOF system) yields ratios of 10%, 20%, 30% of critical damping, respectively.

³ Relating the damping ratio increments to an elastic period of $T=3.0\text{sec}$ (reflective of displacement-based design approaches that utilise the secant period of an equivalent SDOF system) yields ratios of 20%, 30%, 30% and 39% of critical damping, respectively.

isolation displacement when the damper force-limit was set to $0.05W_t$. A further reduction (40-50%) could be achieved if the force-limit was increased to $0.075W_t$. A combination of damper coefficient and force-limit was not able to “neutralise” the hazard increase to the undamped LRB benchmark (100% hazard); however, a coefficient and force-limit of $15,000\text{kN.s/m}$ and $0.075W_t$ (respectively) reduced the undamped FPS isolation displacement by more than 40%. This amount of damping increased the storey drift by 5-15% and storey shear by 5-15% and by -10-25% relative to the undamped LRB benchmark (150% hazard).

A linear damper solution combined with a force-limit appeared to be a means to control the undesirable increase in superstructure response while still reducing the displacement at the isolation plane. That is, there appeared to be greater dependence on the force-limit, rather than the damper coefficient (for the parameters studied, at least). A damper plot and base shear plot for one ground motion for the FPS isolation system having a total damping of $C=15,000\text{kN.s/m}$ and a force-limit of $0.05W_t$ is shown in Figure 7. This figure shows the clear force-limit being routinely met by the damper, limiting the velocity-dependant spikes in damper-force being transmitted through the isolation system.

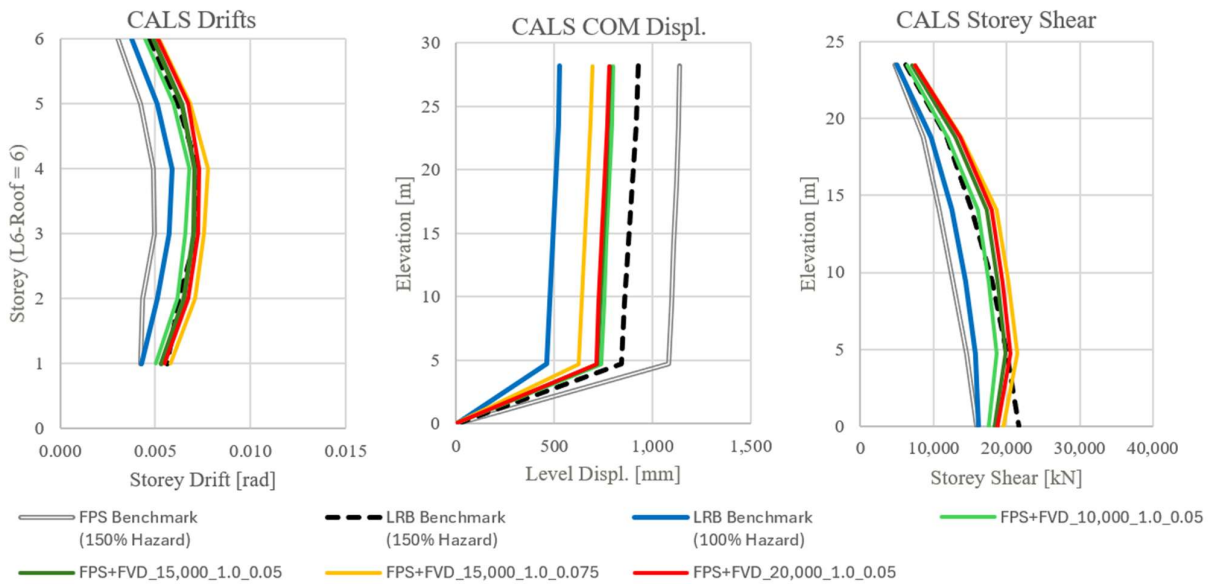


Figure 6: Structural response plots for the FPS benchmark isolated building with varying levels of supplemental damping, including a damper force-limit, located at the isolation plane.

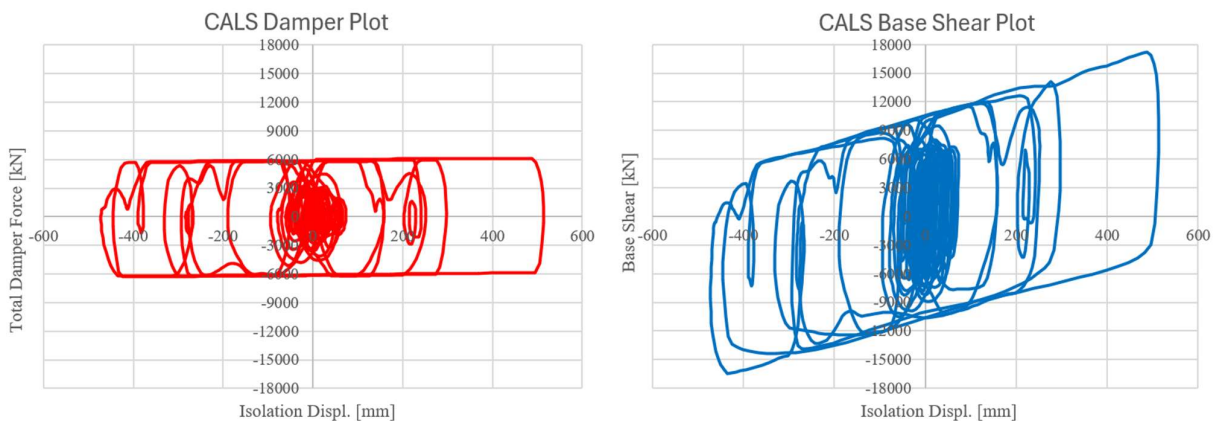


Figure 7: Damper response plot (left) and combined base shear response (right) for a damped FPS isolation system (FPS+FVD_15,000_1.0_0.05) subjected to one ground motion (150% CALS)

4.4 Varied Velocity Exponent at Isolation Plane Damper; LRB Isolation System

This sub-study focused on the impact of the velocity exponent on the isolation plane displacement and superstructure behaviour. The benchmark building with LRB isolators and a cumulative damping coefficient of 16800 kN.s/m with a velocity exponent of 0.7 was used as the base design. Changing the velocity exponent shifts the shape of the FVD hysteretic loops as shown in Figure 8. Damping constants, C , were adjusted along with the change in velocity exponent to achieve equal energy dissipation at a velocity and deformation which was near the peak value for one of the chosen ground records.

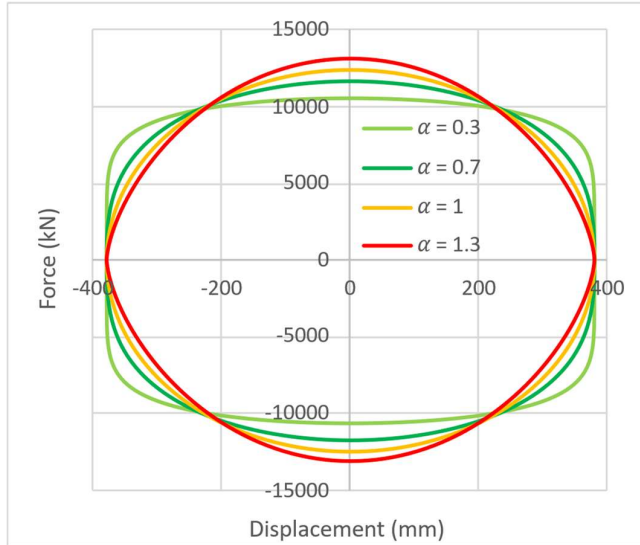


Figure 8: Hysteretic Loops for FVDs with varying velocity exponents but equal area (energy dissipation)

Figure 9 shows the structural response results from varying the velocity exponent for the dampers in the isolation plane. By using dampers with approximately equivalent energy dissipation, the reduction in displacement at the isolation plane remained approximately constant. Superstructure responses improved as the velocity exponent in the dampers at the isolation plane increased (i.e. lower storey drift and shear), but the superstructure responses still remained higher than the benchmark building at the 100% and 150% hazards without dampers at the isolation plane. Based on these results, linear dampers would be better to use at the isolation plane than nonlinear dampers with a velocity exponent less than 1.0.

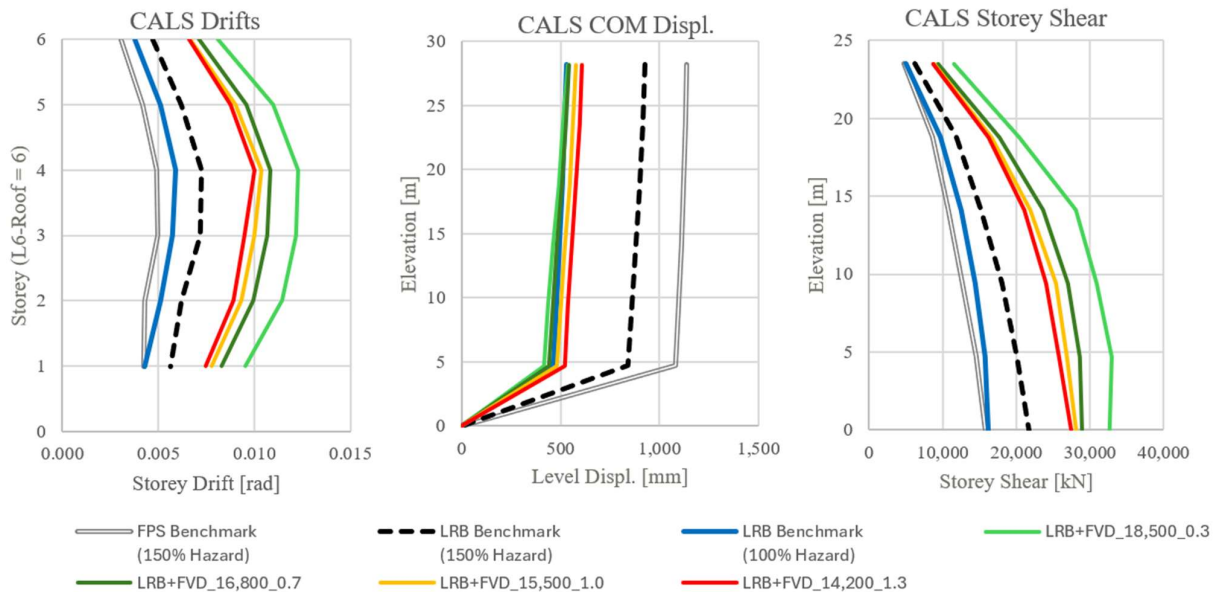


Figure 9: Structural response plots based on variation in velocity exponent in dampers at the isolation plane

4.5 Damping at Isolation Plane and Distributed Damping in Superstructure; LRB System

This sub-study investigated the effects of damping in the isolation plane combined with distributed damping in the superstructure. The properties of the isolators and dampers in the isolation plane are the same as those used in Section 4.2, Model ID “LRB+FVD_16800_0.7.” Four dampers were placed in each principal direction at each floor in the superstructure, totalling 48 dampers. The damping coefficient, C , was kept the same for all superstructure dampers and was varied to investigate the impact of increased damping above the isolation plane. All the superstructure dampers used a velocity exponent, α , of 0.4.

Figure 10 shows the results at the 150% CALS hazard level. The presence of dampers at the isolation plane continued to reduce the isolator displacements and the addition of distributed damping in the superstructure reduced the structural responses, even reducing the storey drift below the original isolated benchmark building at the 100% CALS hazard. Higher levels of damping in the superstructure corresponded with lower structural responses, although the decrease in storey shear seemed to reach a lower limit even when more damping was added – though, the actual proportion of total storey shear that is resisted by the steel moment frame (versus dampers) is not presented here.

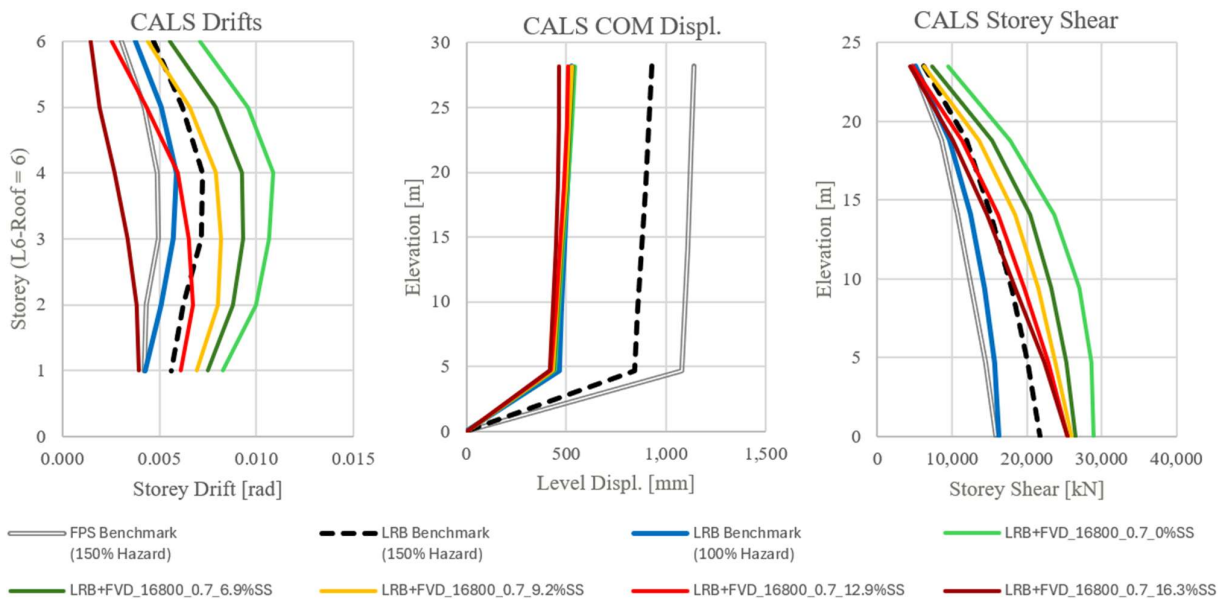


Figure 10: Structural response plots based on variation in damping constant in the superstructure

5 CONCLUSIONS

The recent increase to the seismic hazard in New Zealand is placing significant demand on designing practical base isolated buildings. A prototype isolated building has been designed to study the influence of supplemental damping located within the isolation plane, and with added damping in the superstructure.

Dampers located within the isolation plane alone were unable to neutralise an increase in seismic hazard across all structural response parameters studied. That is, generally a reduction of isolation displacements came at the expense of increased superstructure drifts and storey shears – a balance between bearing and damper resistance (energy dissipated) can produce a good outcome provided the trade-off in response parameters are understood. Supplemental dampers that incorporate a force-limit were able to provide good control of superstructure drift and storey shear.

The combination of supplemental dampers located within the isolation plane and throughout the superstructure offered the greatest strategy to “neutralise” a majority of the isolator and superstructure

response quantities studied – it was found that as the level of damping within the superstructure increased beyond 10%, limited reduction in storey shear was observed.

6 REFERENCES

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