Comparing the Seismic Collapse Performance of Cantilever Column and Moment Frame Retrofits using Los Angeles Soft-Story Basic Ordinance Guidelines

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Introduction

The 1994 Northridge Earthquake highlighted the dangers of multi-unit wood-frame structures with soft, weak, and open-front wall lines (SWOF). These buildings, which are constructed with adjacent stories having large differences in strength, can lead to the formation of a single-story mechanism during earthquake shaking. The Los Angeles Ordinance was enacted in 2015 with the aim of reducing the collapse risk for the estimated 13,500 SWOF Buildings in Los Angeles today (SEAOSC 2017).

Objective

This study conducts a performance-based assessment of the retrofitted SWOF woodframe building archetypes to compare the seismic collapse performance between steel special cantilever columns (SCCs) and OMF retrofits in accordance with Basic Ordinance design procedures.

The set of archetypes used in this study are identical to those used in Burton et al. 2019. Nonlinear structural models of the retrofitted (using moment frames and cantilever columns) archetypes are constructed in OpenSees (Mazzoni et al. 2013) and their collapse performance is assessed using incremental dynamic analyses (IDAs). The results from this study can be used to inform the selection of an appropriate lateral force system by owners and practicing engineers based on the implications to collapse risk reduction.

Archetype Description

A total of thirty-two archetype buildings were developed and used to represent the inventory of SWOF woodframe buildings in the City of Los Angeles (Burton et al. 2019). Among the 12000 buildings surveyed, approximately 17%, 2%, 61%, and 20% had layouts L1, L2, L3, and L4, respectively (**Figure 1**).

Archetype exterior walls were constructed with a combination of stucco on the outside and either gypsum wall board (GWB) or horizontal wood siding (HWS) on the inside. Each model is developed using a small and large building aspect ratio. *Details regarding each archetype can be found in Burton et al. 2019, Table 1.*

Archetype Layouts

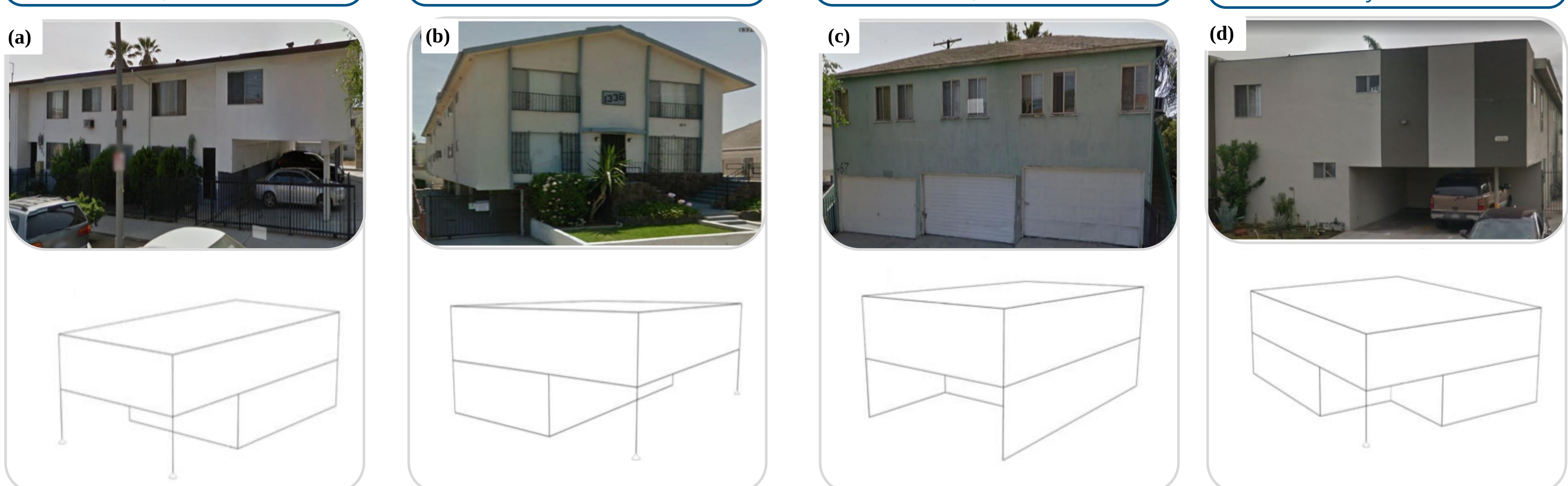


Figure 1: Schematic isometric views of typical SWOF woodframe building configurations (Burton et al. 2019) identified from survey (top), along with photos of typical SWOF woodframe building configurations (bottom): **a** Layout 1 (L1), **b** Layout 2 (L2), **c** Layout 3 (L3) and **d** Layout 4 (L4).

Retrofitted Archetypes

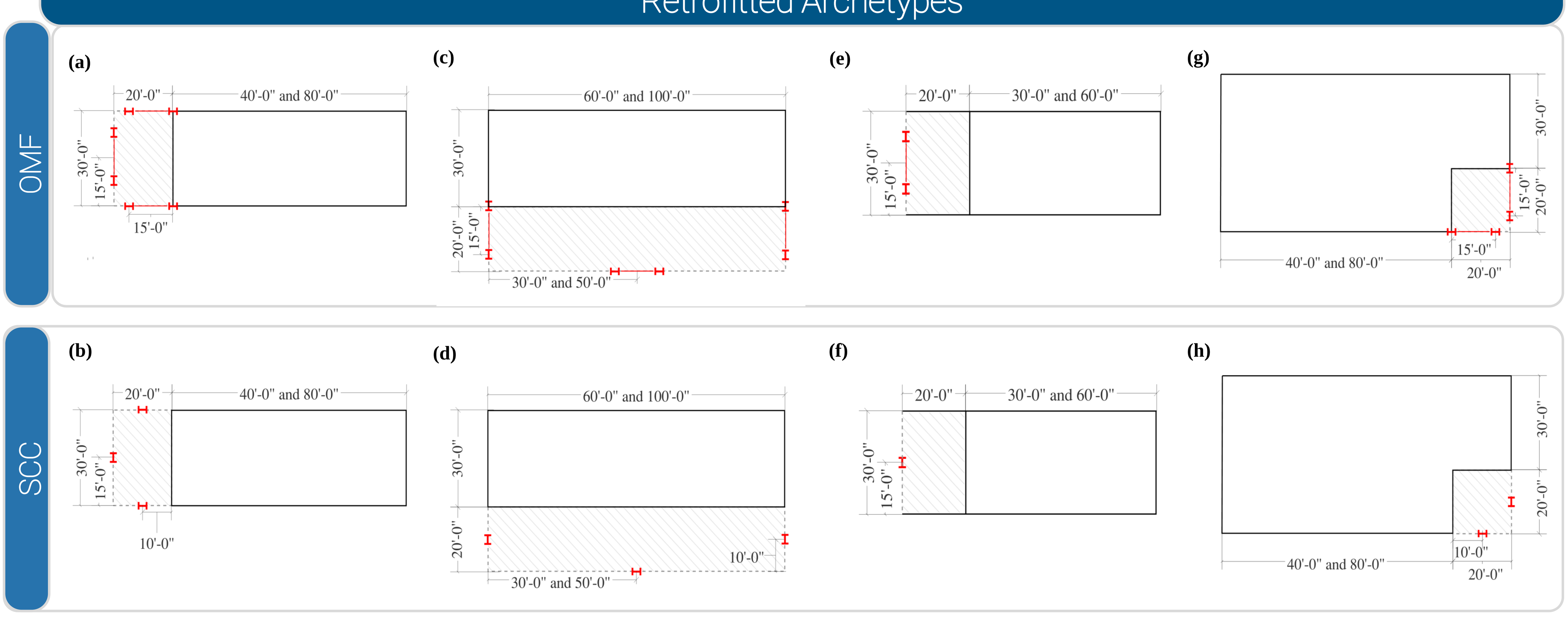


Figure 2: Archetype floor plans (not to scale) showing locations of retrofit elements for each configuration: **a** Layout 1, OMF, **b** Layout 1, SCC, **c** Layout 2, OMF **d** Layout 2, SCC **e** Layout 3, OMF, **f** Layout 3, SCC, **g** Layout 4, OMF, **h** Layout 4, SCC

Retrofit Design Parameters

Moment frame retrofits each utilize a 15'-0" one-bay steel OMF in the open wall line. While ordinary moment frames are generally not permitted in seismic design categories D, E, and F (ASCE 7-10 Table 12.2-1), an exception is made in cases where (a) the building height does not exceed 35 feet, (b) the roof and floor dead loads do not exceed 35 psf, and (c) the wall dead loads do not exceed 20 psf. Force demands used to design these elements are computed using a seismic response modification coefficient and deflection amplification factor of R=3.5 and CD = 3.0, respectively.

Since ordinary cantilever columns are only permitted in seismic design categories A and B, steel special cantilever columns (SCCs) were designed using values of R=2.5 and CD = 2.5 (ASCE 7-16, Table 12.2- 1), which are permitted in all categories. Each column is designed in accordance with AISC 341 (Seismic Provisions for Steel Buildings), and a single section is placed at the center of each open wall line. For each archetype, OMF and SCC retrofits are designed to achieve similar demand to capacity ratios (DCR) (Table 1).

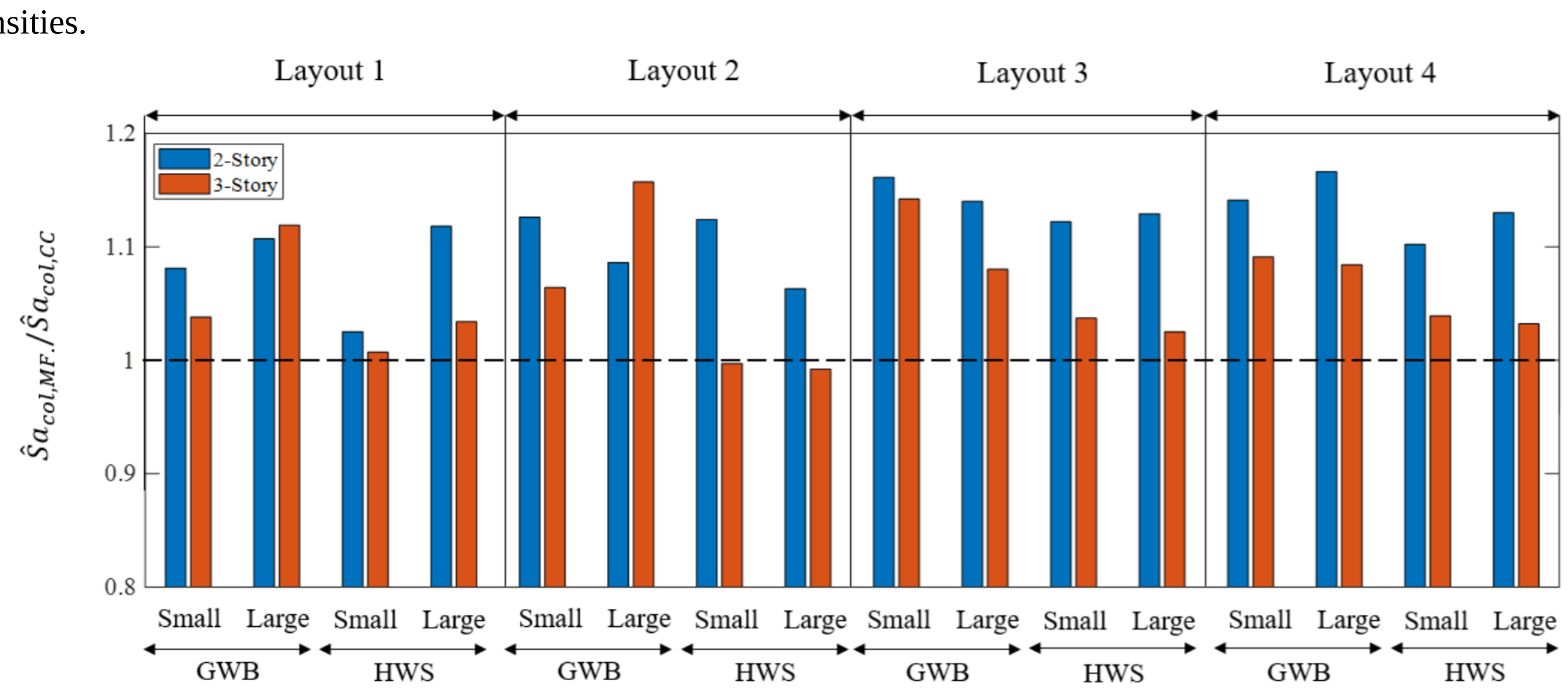
Table 1: Summary of retrofit DCRs for building archetypes L1 through L4.

Layout	No. of Stories	Aspect Ratio	X-Direction SWOF Line		Y-direction SWOF Line	
			SCC DCR	OMF DCR	SCC DCR	OMF DCR
L1	2	small and large	0.93	0.95	0.82	0.86
L1	3	small and large	0.97	0.92	0.96	0.95
L2	2	large	0.94	0.92	0.93	0.95
L2	3	small	0.94	0.92	0.93	0.95
L2	2	small	0.86	0.92	0.93	0.88
L2	3	large	0.94	0.92	0.92	0.90
L3	2	small and large	n/a	n/a	0.99	0.93
L3	3	small and large	n/a	n/a	0.89	0.95
L4	2	small and large	0.93	0.88	0.93	0.88
L4	3	small and large	0.98	0.95	0.98	0.95

Incremental Dynamic Analysis (IDA)

The collapse safety of the SCC and OMF retrofitted building cases is assessed using incremental dynamic analyses in OpenSees. The collapse analysis is performed using the far-field record set of 22 component pairs of the ground motions specified in the FEMA P695 (FEMA 2009) guidelines using bi-directional loading. The ground motions are scaled using a single factor such that the median spectra for the set matches the target intensity level at the period of interest. Two analyses are conducted for each record-pair, generating a total of 44 total collapse intensities.

Figure 4: Ratio of median collapse capacity between OMF and SCC-retrofitted SWOF buildings.



From Fig. 4, several conclusions can be drawn. The percentage increase in median collapse capacity by selecting the OMF retrofit is 8.69% higher than the SCC retrofit on average when considering all archetypes. Two-story structures see an average of 11.38% higher collapse capacity when retrofitted using an OMF compared to the SCC. However, this average decreases to 5.84% for the 3-story structures.

Nonlinear Static (Pushover) Analysis

Nonlinear Static (pushover) analyses are performed on the numerical models to investigate the effect of each retrofit on the strength and overall drift capacity of each SWOF building. Using the load pattern from ASCE 7-16, Section 12.8-3 (ASCE 7-16), the pushover analyses are performed on each OMF and SCC retrofitted archetype.

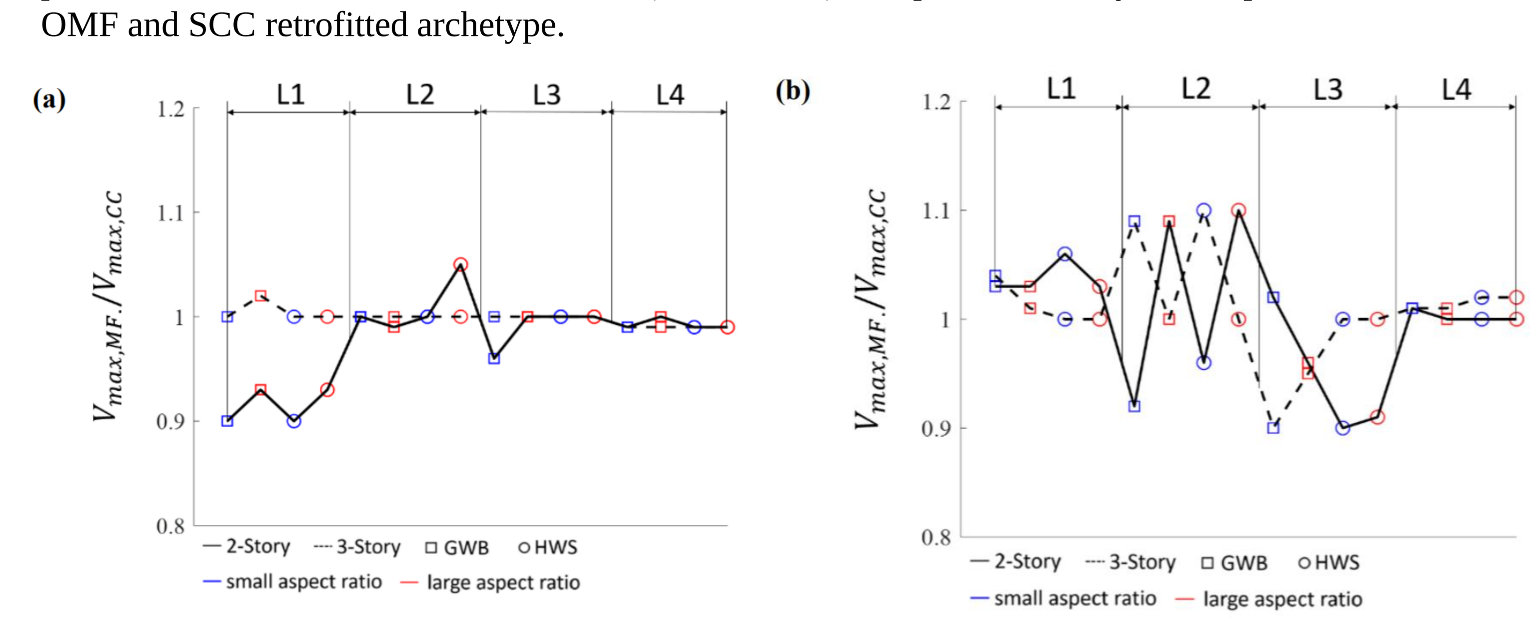


Figure 3 Ratio of maximum base shear from pushover response between OMF-retrofitted archetypes and SCC-retrofitted archetypes is presented for the X-direction (a) and Y-direction (b).

Summary & Conclusion

The Los Angeles Basic Ordinance is a prescriptive retrofit method developed by LADBS in accordance with the Los Angeles Soft Story Ordinance. A comparison of the seismic collapse performance of two permitted lateral systems, namely, ordinary moment frame (OMF) and special cantilevered column (SCC), was conducted using incremental dynamic analyses (IDAs). The pushover strength for each method varied between 2-10% but the average difference was only 1% across all models. The IDA results revealed that the 2-story archetypes derived the greatest benefit from selecting an OMF retrofit over an SCC retrofit, with an 11% average increase in median collapse capacity. The 3-story archetypes achieved average collapse capacity improvements equal to approximately 6%. Of the four archetype configurations, Layouts 3 and 4 experienced the greatest improvements using OMFs on 2-story and 3-story structures, respectively. These results demonstrate that on average, OMF retrofits under the Ordinance provide higher collapse capacities than SCC retrofits and that the number of stories and configuration determine the extent to which this is true.

References

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