

UC San Diego

UC San Diego Previously Published Works

Title

Shake Table Testing of Rooftop Mechanical Equipment with Different Attachment Strategies on A Full-Scale Ten-Story Building

Permalink

<https://escholarship.org/uc/item/1zz9x5d0>

Authors

Zhang, Xianzhao

Zhang, Jiachen

Hutchinson, Tara

Publication Date

2026-03-11

Copyright Information

This work is made available under the terms of a Creative Commons Attribution License, available at <https://creativecommons.org/licenses/by/4.0/>

Peer reviewed

Shake Table Testing of Rooftop Mechanical Equipment with Different Attachment Strategies on A Full-Scale Ten-Story Building

Xianzhao Zhang¹, Jiachen Zhang¹, and Tara C. Hutchinson¹

¹ Department of Structural Engineering, University of California San Diego
La Jolla, CA 92093, USA

e-mail: xiz217@ucsd.edu, j-charlie-zhang@ucsd.edu, tahutchinson@ucsd.edu

Abstract. The seismic performance of acceleration-sensitive mechanical equipment is a major area of interest within the field of nonstructural components and systems (NCSs). To save indoor space, conserve energy, or meet functional requirements, such equipment is often installed on building rooftops, where higher acceleration demands during earthquakes make rooftop-mounted units more susceptible to damage. Floor-mounted mechanical equipment is typically supported by vibration and noise isolation devices to reduce the transmission of unwanted motion to the supporting structure. However, limited attention has been given to understanding under what conditions, and to what extent, vibration and acoustical design strategies may enhance, or potentially compromise, the seismic performance of lightweight NCSs. To investigate this issue, five lightweight air-conditioning condenser units, each weighing no more than 1,500 N, including three with a slender aspect ratio of 3.7 and two with a squat aspect ratio of 1.1, were installed on the rooftop of a full-scale, ten-story cold-formed steel (CFS) building tested on a six-degree-of-freedom outdoor shake table. Different base attachment strategies were employed. All three slender units were screw-mounted at four manufacturer-provided feet to the CFS studs. Two of the units had a modified base boundary condition, with neoprene pads and spring isolators respectively added under the base feet. Both squat units were screw-mounted using four steel angles connected to the CFS studs, with one additionally supported by neoprene pads placed beneath the equipment. This paper presents the first release of preliminary results from the recently completed experimental program, focusing on rooftop mechanical equipment responses under service-level, design-level, and maximum-considered earthquake motions. Results presented include measured floor acceleration amplification factors, peak component accelerations, and component amplification factors. These findings are compared with code-based provisions to evaluate the adequacy of current design coefficients in capturing the acceleration demands on lightweight components.

Keywords: Attachment design, HVAC equipment, Nonstructural components, Seismic performance, Shake table test

1. INTRODUCTION

The safety and functionality of nonstructural components and systems (NCSs) during both frequent and rare earthquake events are essential for maintaining operational continuity of buildings and other infrastructure. Buildings that serve to provide emergency shelter, food, medical care, information, and other indispensable services must also remain functional as they serve as a cornerstone of community resilience.

For buildings engineered to withstand earthquakes, nonstructural damage often accounts for a substantial share of economic losses, particularly in acceleration-sensitive components such as mechanical and electrical equipment [Papadopoulos *et al.*, 2019]. For such equipment, the attachment condition significantly affects its performance during an earthquake. Feinstein and Moehle [2022] tested different attachments using yielding steel angles with varying stiffness and strength, demonstrating their influence on the dynamic response of floor-mounted NCSs connected to a reinforced concrete slab. Similarly, Elkady *et al.* [2025] studied the efficacy of sacrificial steel yielding elements as an attachment method to limit acceleration demands in sliding-motion-governed NCSs. In their work, a steel carriage supporting interchangeable mass plates was used to experimentally mimic the sliding components.

These and other experimental investigations of real mechanical or electrical equipment face two major challenges. First, the high capital cost of testing makes it difficult for academic institutions to pursue such research without direct collaboration with manufacturers. In practice, manufacturer-sponsored shake table tests conducted for seismic certification are primarily intended to qualify the equipment for use in earthquake-prone applications, using either synthetic earthquake motions or prescribed test protocols (e.g., AC156 [ICC 2012]). These tests have limited focus on comparing attachment methods or advancing fundamental understanding. Second, the inherent complexity of mechanical and electrical equipment, characterized by irregular geometries, uneven mass distribution, and designs developed outside the structural engineering domain without consideration of seismic performance, poses difficulties for deriving generalized rules of behaviour that hold scientific value.

Vibration-isolated heavy mechanical equipment has attracted particular research interest. Fathali and Filiatrault [2008] investigated a vibration-isolated centrifugal liquid chiller weighing 117,655 N, tested on a six-degree-of-freedom (6-DOF) shake table using synthetic ground motions derived from AC156 [ICC 2012]. Their study focused on evaluating the influence of snubber gap size on the dynamic response of the chiller. Astroza *et al.* [2015] conducted shake table tests on a rooftop-mounted cooling tower weighing 279,000 N (when filled with water), installed on a full-scale, five-story reinforced concrete building subjected to unidirectional shaking. Their findings showed that component amplification factors could substantially exceed those prescribed in standards, particularly when the equipment period was close to the predominant period of the supporting structure.

A shake table testing campaign of a full-scale, ten-story cold-formed steel (CFS) building was recently conducted at the Large High-Performance Outdoor Shake Table (LHPOST6) at University of California San Diego. This program provides a unique opportunity to investigate the seismic performance of both the structural system and a select suite of NCSs. On the building rooftop, three identical slender air-conditioning condenser units, each weighing 1,434 N with a resulting maximum aspect ratio of 3.7, and two identical squat condenser units, each weighing 1,339 N with a resulting aspect ratio of 1.1, were installed. Various attachment strategies were implemented, including direct anchorage, neoprene pads, and spring isolators, with the objective of comparing and understanding the influence of vibration and acoustical design practices on the seismic performance of lightweight mechanical equipment under real earthquake excitations. This paper first outlines the shake table test program and earthquake protocol, followed by a discussion of attachment designs implemented and equipment instrumentation. Subsequently, experimental findings related to the mechanical equipment are presented, including floor acceleration amplifications, peak component accelerations (PCAs), and component amplification factors.

2. EXPERIMENTAL PROGRAM

2.1 BUILDING SPECIMEN

The test specimen was a full-scale, 10-story CFS-framed building (Figure 1). The building measured 11.6 m by 6.9 m in plan, with a uniform story height of 3.05 m across all 10 stories, in addition to a CFS parapet at the roof level measuring 1.1 m in height. The lateral force-resisting system consisted of symmetric steel-sheet-sheathed shear walls along both the longitudinal (east–west) and transverse (north–south) directions. Further details about the structural system and its design considerations can be found in Hutchinson *et al.* [2026]. The building was of high fidelity, including nonstructural features such as prefabricated steel stairs, windows and doors, suspended ceilings, fire sprinkler systems, and rooftop mechanical equipment.

As shown in Figure 1(c–d), five roof curbs of two different geometries but with the same height of 172 mm were rigidly connected to either CFS floor joists or CFS blocking through the roof cementitious panel using CFS support clips. The roof curbs were constructed of CFS studs and cementitious floor panel material, similar to that used throughout the building floor diaphragm. The attachment of the roof curbs and roof diaphragm were designed to remain fixed, with no relative displacement assumed. Five supplemental weights, simulated by cementitious floor panels, were also anchored to the roof. In addition, a diaphragm opening of 1,219 mm by 1,219 mm was constructed to accommodate a roof access hatch near the southwest corner of the roof.

2.2 EARTHQUAKE TEST PROTOCOL

A total of 18 seismic tests, including 15 service-level earthquakes (SLE), one design earthquake (DE), and two risk-targeted maximum considered earthquakes (MCE_R), were conducted to cover a wide range of amplitudes, durations, and directionalities, with the three hazard levels progressively increasing the seismic demand on both the structure and the NCSs. Table 1 [Zhang *et al.*, 2026] summarizes the earthquake motions used in the CFS building tests, and Figure 2 presents the achieved peak input accelerations (PIA), recorded at the shake table platen using accelerometers located at its centre of mass (CoM).

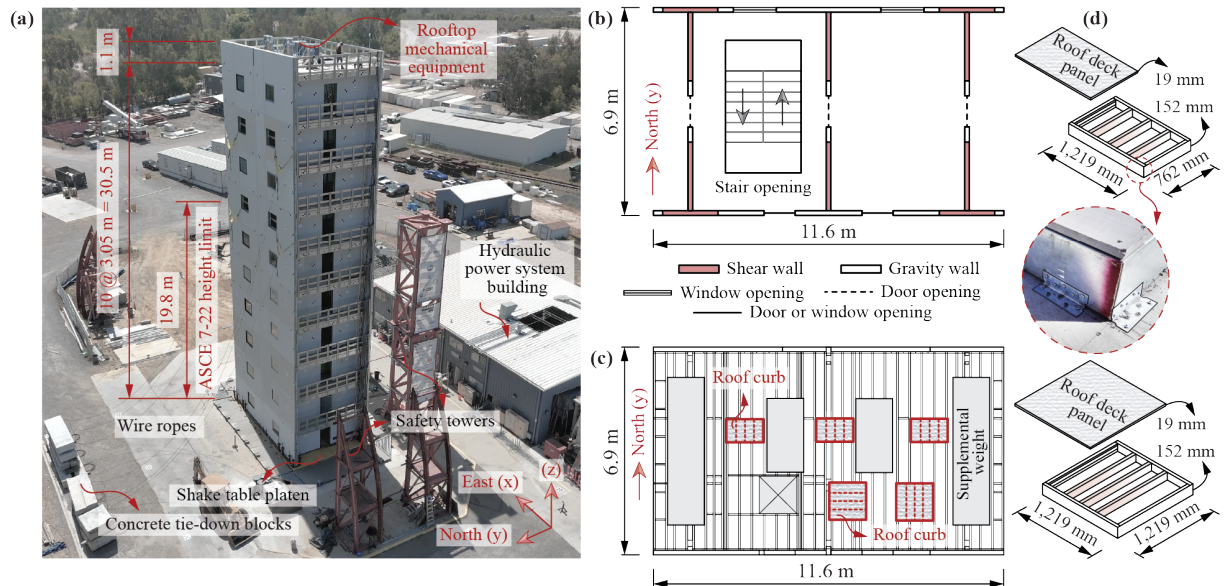


Figure 1. CFS building specimen: (a) aerial perspective view of the completed building from the northwest corner, (b) typical floor plan, (c) roof panel plan view, and (d) roof curb design

Table 1. Ground motion records and target hazard scales selected for shake table testing

Hazard level	MID	Earthquake event				Components		Input DOF	D ₅₋₉₅ [sec]
		Name	Year	M_w	Station	x	y		
SLE	1	Loma Prieta, California	1989	6.9	Gilroy Array #3	90°	0°	xyz	11.4
	2					90°	0°	xyz	11.4
	3					90°	—	x	11.4
	4					—	0°	y	6.4
	5	Northridge, California	1994	6.7	LA City Terrace	90°	180°	xyz	11.9
	6					180°	90°	xyz	11.9
	7					180°	—	x	11.9
	8					—	90°	y	11.6
	9	Cape Mendocino, California	1992	7.0	Rio Dell Overpass	270°	360°	xyz	15.3
	10					360°	270°	xyz	15.3
	11 ^a	Kahramanmaras, Türkiye	2023	7.8	4611	E	N	xyz	43.4
	12					E	N	xyz	43.4
	13	Elbistan, Türkiye	2023	7.5	4611	E	N	xyz	35.1
	14	Maule, Chile	2010	8.8	Curico Hospital	EW	NS	xy	45.2
	15	Kahramanmaras, Türkiye	2023	7.8	4611	E	N	xyz	43.4
DE	16	Loma Prieta, California	1989	6.9	Gilroy Array #3	90°	0°	xy	11.4
MCE _R	17	Loma Prieta, California	1989	6.9	Gilroy Array #3	90°	0°	xy	11.4
	18 ^b	Cape Mendocino, California	1992	7.0	Rio Dell Overpass	360°	270°	xy	11.4

^a MID11 target was 75% SLE.

^b MID18 target was 90% of MCE_R.

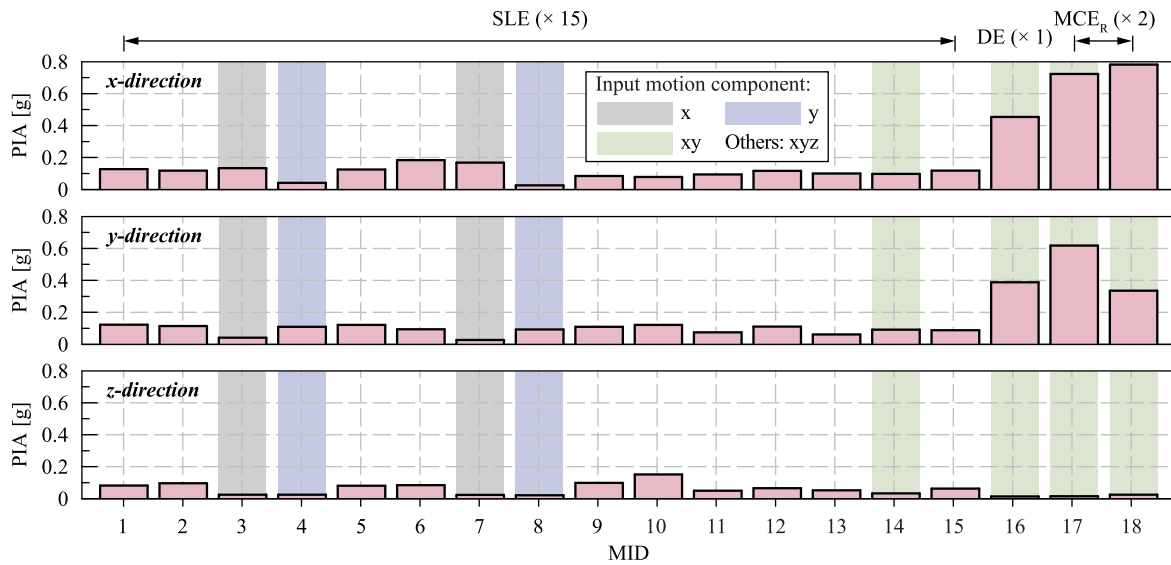


Figure 2. Achieved peak input acceleration at the shake table platen

2.3 ROOFTOP MECHANICAL EQUIPMENT

As shown in Figure 3(a), five lightweight air-conditioning condenser units, consisting of two different models, were installed on the roof curbs of the building. For brevity, SL-DA denotes the slender unit with direct attachment, SL-NP the slender unit with neoprene pads, SL-SI the slender unit with spring isolators, SQ-DA the squat unit with direct attachment, and SQ-NP the squat unit with neoprene pads. The slender unit measured 1,000 mm by 368 mm in plan and 1,365 mm in height, with a resulting maximum aspect ratio of 3.7 (Figure 3(b)), while the squat unit measured 902 mm by 902 mm in plan and 972 mm in height, resulting in an aspect ratio of 1.1 (Figure 3(c)). The slender unit was supported by two manufacturer-prefabricated steel tracks with four feet attached to its bottom face, whereas the squat units had no such installation aids. Because all five condenser units were pre-owned, the amount of refrigerant in each unit was uncertain. Loss of refrigerant charge reduces the unit weight, leading to small variations among the equipment. However, the contribution of refrigerant to the total weight was estimated to be less than 5%, so this variation was considered negligible. To obtain conservative seismic force estimates, the equipment weights were determined assuming each unit contained the full refrigerant charge, which corresponds to the maximum weight condition. The estimated weights of the slender and squat units were 1,434 N and 1,339 N, respectively.

Different base attachment strategies were employed for each rooftop mechanical equipment unit. As a benchmark configuration without vibration or acoustical mitigation measures (Figure 3(d)), a slender unit was directly screw-mounted at its four manufacturer-provided feet to the CFS studs of the roof curb. A 6.4 mm $\times$ 25.4 mm $\times$ 1.6 mm (inner diameter $\times$ outer diameter $\times$ thickness) fender washer was placed under the head of each self-drilling screw, which had a thread length of 76.2 mm and a nominal shank major diameter of 6.2 mm. To modify the base boundary conditions, two alternative attachment strategies were applied to slender units. In the first case (Figure 3(e)), four neoprene pads, each measuring 101.6 mm $\times$ 101.6 mm $\times$ 19 mm (length $\times$ width $\times$ thickness) were placed beneath shim plates. The shim plates distributed the load into the pads and directly supported the equipment feet. In the second case (Figure 3(f)), four spring isolators were used, each rated for a maximum vertical load of 500 N and a maximum horizontal load of 1,600 N. Both squat units were installed using four steel angle support clips (Figure 3(g–h)). One of the units was additionally supported by four neoprene pads placed beneath the equipment (Figure 3(i)). Each clip was fastened on the equipment housing side with three shorter self-drilling screws (thread length of 19 mm and nominal shank major diameter of 6.2 mm) and on the CFS stud side with two self-drilling screws identical to those used for the slender units. Although both squat units were oriented in the same direction, the placement of the CFS studs in the roof curb required different attachment layouts (Figure 1(c)). For the SQ-DA, the support clips were installed on the west and east sides of the equipment, while for the SQ-NP, they were installed on the north and south sides.

2.4 INSTRUMENTATION

For the seismic tests, more than 800 analogue sensors were strategically installed throughout the building to monitor the response of both the structure and the NCSs. Specifically for the rooftop mechanical equipment, a total of 36 analogue channels were used, consisting of 16 accelerometers and 20 linear potentiometers installed at selected locations. Figure 4 illustrates the instrumentation scheme of accelerometers and displacement transducers used for the rooftop equipment. Two uniaxial y-direction accelerometers were mounted at the northwest and southeast top corners of the slender unit to capture potential torsional response, since the mass of the slender condenser was offset toward the west side opposite the fan. In addition, one uniaxial x-direction accelerometer and one uniaxial z-direction accelerometer were installed at the centre of the top face of the slender unit. For the squat unit, one uniaxial accelerometer in each of the x- and y-directions was installed at the centre of the top face. Since the shake table test program for the DE and MCE_R ground motions did not include z-direction input and the squat unit was expected to generate negligible z-direction acceleration under these conditions, no z-direction accelerometers were installed on the squat units.

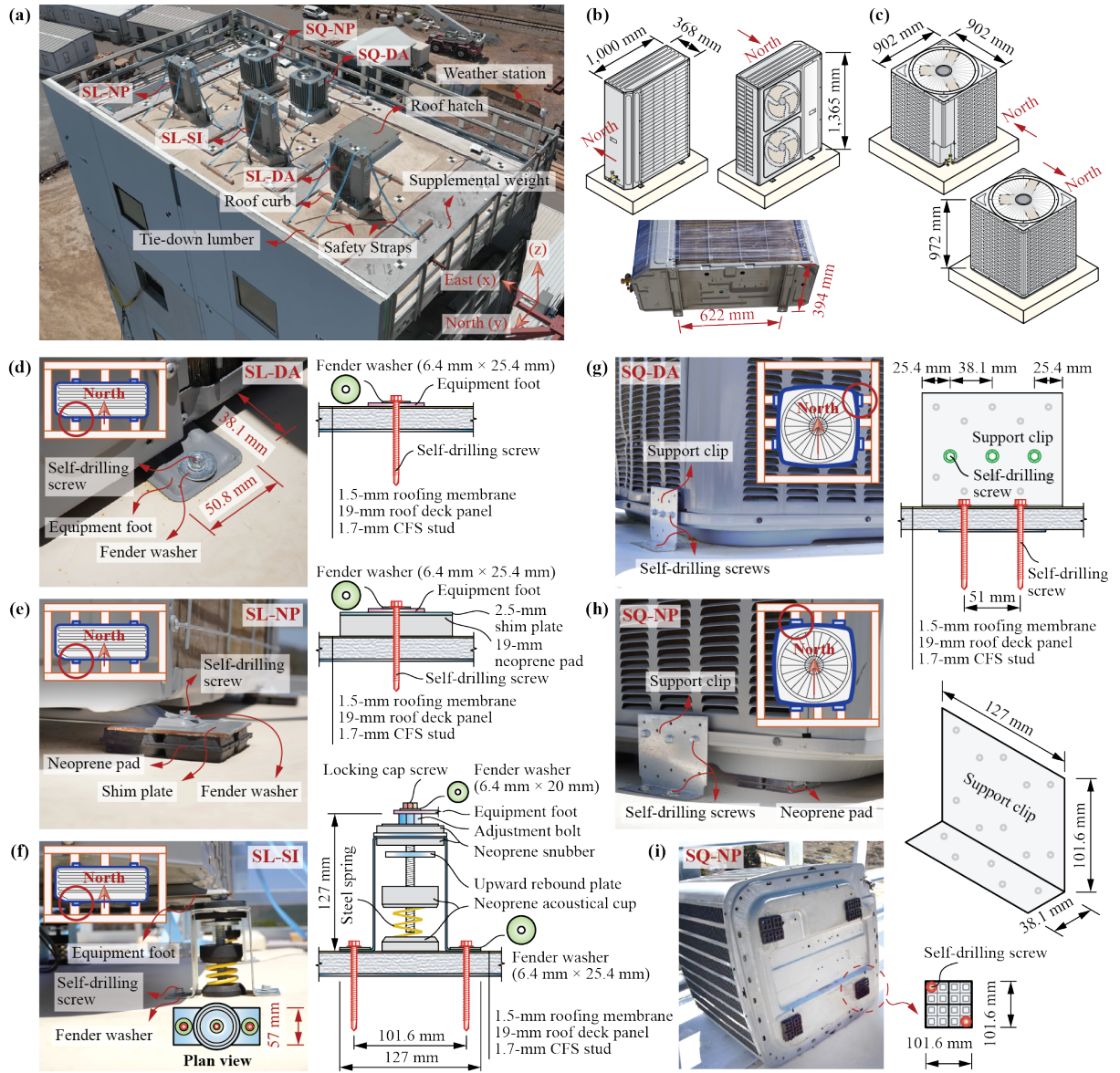


Figure 3. Overview of rooftop mechanical equipment: (a) aerial perspective view of the equipment layout from the northwest corner, (b) slender and (c) squat unit geometry, and attachment designs of (d) SL-DA, (e) SL-NP, (f) SL-SI, (g) SQ-DA, (h) SQ-NP, and (i) bottom view of SQ-NP

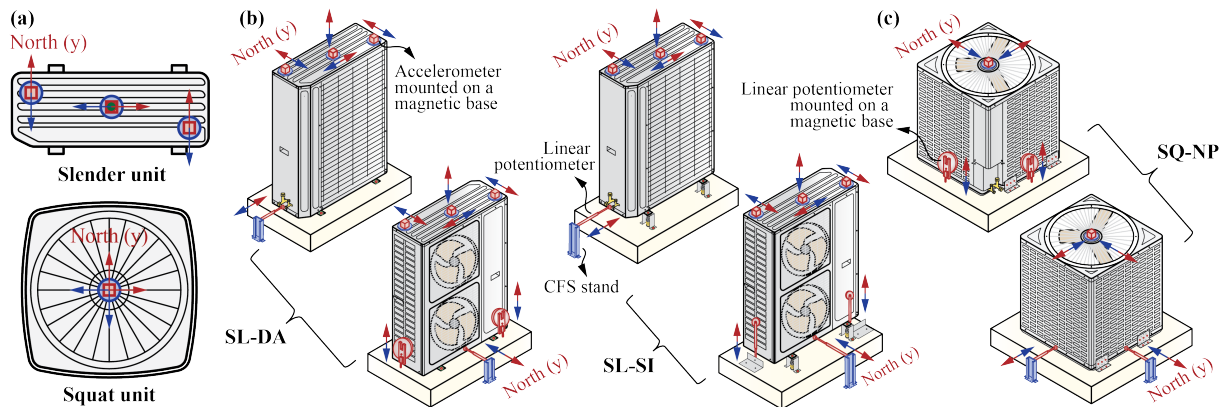


Figure 4. Instrumentation of rooftop mechanical equipment: (a) top view of accelerometer layout, representative configurations of accelerometers and displacement transducers for (b) slender and (c) squat units

The displacement transducer layout for the slender and squat units followed a similar approach (Figure 4(b-c)). One x-direction and one y-direction linear potentiometer were installed at the base of the equipment to measure displacements relative to the roof diaphragm, while two z-direction potentiometers were installed on adjacent sides near the base to record uplift. All recorded acceleration and displacement signals of the mechanical equipment were baseline-corrected and filtered using a fourth order bandpass Butterworth filter with cutoff frequencies of 0.2 Hz and 35 Hz, to remove signal noise while retaining the true response.

3.EXPERIMENTAL RESULTS

3.1 RESPONSE OF BUILDING SPECIMEN

Floor accelerations and the corresponding acceleration amplification factors are among the most critical structural response parameters affecting acceleration-sensitive NCSs. All accelerometers supplied by the LHPOST6 facility were used to generate the PFA/PIA profile. Note that only the motions actively exciting each orthogonal direction are considered. Figure 5 presents the peak floor acceleration (PFA), normalized by the achieved PIA, for both the x- and y-directions under 13 SLEs, one DE, and two MCE_R scaled tests. To capture the translational acceleration response of the building, one uniaxial accelerometer in the x-direction and one in the y-direction, provided by the LHPOST6 facility, were installed at the calculated CoM, as well as at the northwest and southeast corners of each floor. On the roof level, additional accelerometers were deployed on the eastern side of the CoM, at a distance of 2,185 mm, and at the northeast and southwest corners of the roof to provide a denser instrumentation array. In Figure 5, the variability of recorded accelerations among sensors on the same floor is depicted by a shaded light grey region, which spans the mean $\pm$ standard deviation, while the arithmetic mean response is highlighted by the red.

In the x-direction, the maximum average PFA/PIA ratios were 2.39 (SLE), 2.05 (DE), and 2.24 (MCE_R). In the y-direction, the corresponding averages were 2.67, 2.08, and 2.23. These maxima consistently occurred at the roof, where the building's whipping action led to greater acceleration amplification. Compared with the SLE and MCE_R cases, the DE case exhibited smaller roof-level amplification. However, this result may not be statistically robust, as it is based on only one DE ground motion. ASCE/SEI 7-22 [ASCE, 2022] Chapter 13 provides two alternative equations for calculating acceleration amplification factors along the height of a building. The fundamental-period-independent method, Equation (13.3-5), assumes a linear amplification profile ranging from 1.0 at the ground level to 3.5 at the roof level. The fundamental-period-dependent method, Equation (13.3-4), introduced in the latest edition, aims to improve prediction accuracy by incorporating the building's fundamental period. For the tested building specimen, the fundamental periods used in Equation (13.3-4), were determined from white-noise excitation data, prior to earthquake tests, as 0.77 sec in the x-direction and 0.73 sec in the y-direction.

As shown in Figure 5, the differences between the code-based acceleration amplification factors and the mean PFA/PIA ratios were calculated and compared at each floor. Under SLEs, both Equations (13.3-4) and (13.3-5) did not consistently yield conservative predictions of acceleration amplification, as shown in the shaded light red region, when the PFA/PIA ratios were computed from individual accelerometer recordings. Considering that the acceleration demand under SLE ground motions is relatively small, this lack of conservatism is unlikely to pose a safety concern. Overall, median box-plot values at each floor indicate that both code-based equations consistently provide reliable, conservative, acceleration amplification predictions, with the most conservative results consistently occurring at the ninth floor across both directions and all hazard levels.

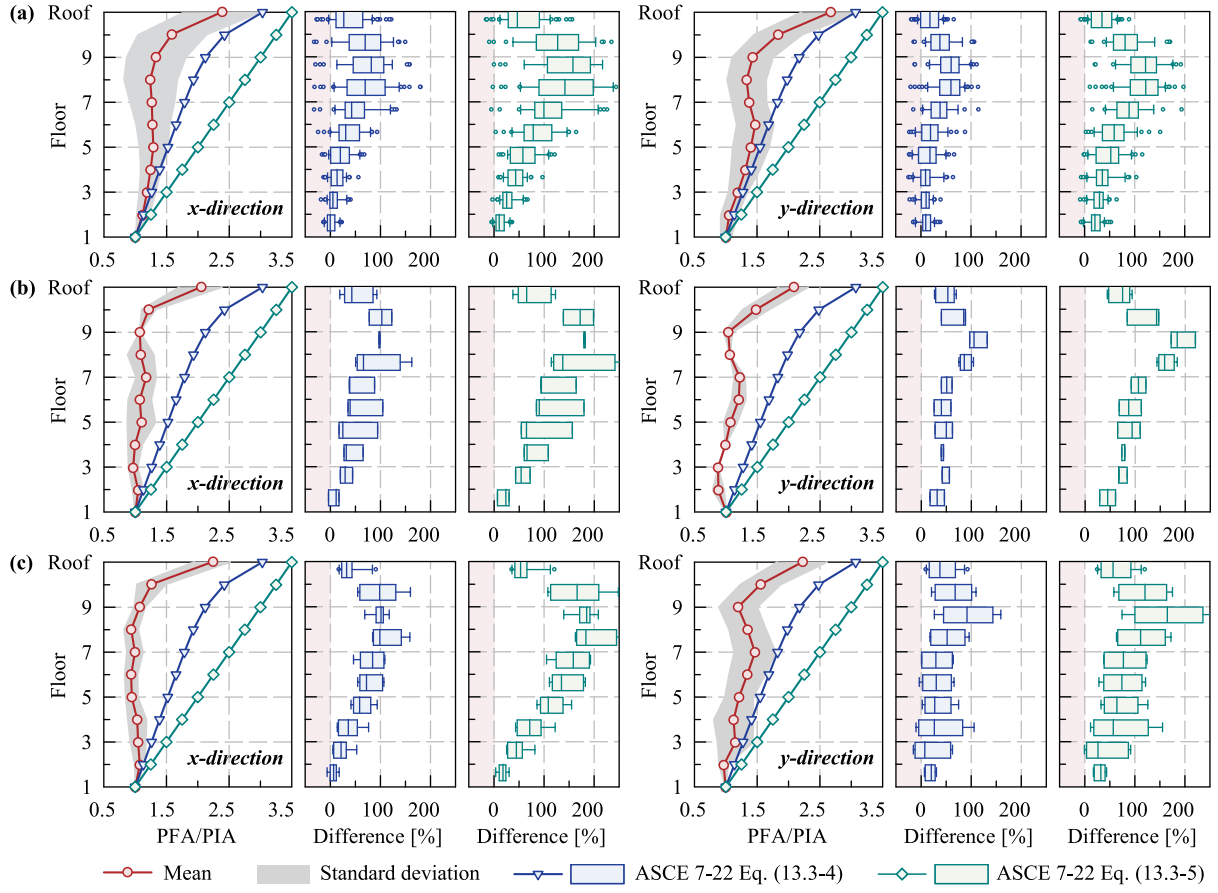


Figure 5. Acceleration amplification factors under: (a) SLE, (b) DE, and (c) MCE_R

3.2 RESPONSE OF ROOFTOP MECHANICAL EQUIPMENT

The peak component acceleration serves as a key parameter to compute the seismic design forces of acceleration-sensitive NCSs. In this study, PCA is defined as the maximum acceleration recorded by the accelerometers mounted at the top of each equipment unit. It should be noted that the actual CoM of the equipment is below the accelerometer locations, i.e., along the equipment's height. Therefore, the reported PCA values are expected to be larger than the accelerations corresponding to the true CoM. Figure 6 shows the PCAs induced by SLE, DE, and MCE_R ground motions. For DE and MCE_R cases, the z-direction PCAs are also included. In a qualitative sense, compared with SL-DA, the slender units with flexible base supports (SL-SI and SL-NP) tended to record larger PCAs under SLE tests in the y-direction, corresponding to the rocking-prone weak axis. Under DE and MCE_R tests, however, larger PCAs were recorded in the x-direction.

Due to the relatively large torsional mode of the building, the recorded accelerations varied across different roof locations. For the SLE cases, the coefficient of variation (CV) of peak roof accelerations (PRAs) ranged from 10.8% to 31.2% in the x-direction and 5.4% to 32.2% in the y-direction. For the DE case, the CVs were 16.7% and 11.3% in the x- and y-directions, respectively. For the MCE_R cases, the CV in the x-direction reached up to 15.2%. Figure 7(a-b) presents representative contour plots of PRAs in the x- and y-directions under four SLEs, one DE, and two MCE_R ground motions. These results indicate that locations sharing the same x-coordinate generally exhibited similar y-direction accelerations, while locations sharing the same y-coordinate exhibited similar x-direction accelerations. These observations are consistent with the findings of Ruggieri and Vukobratović [2024], who numerically evaluated floor acceleration demands of low-rise RC buildings considering in-plane torsional effects.

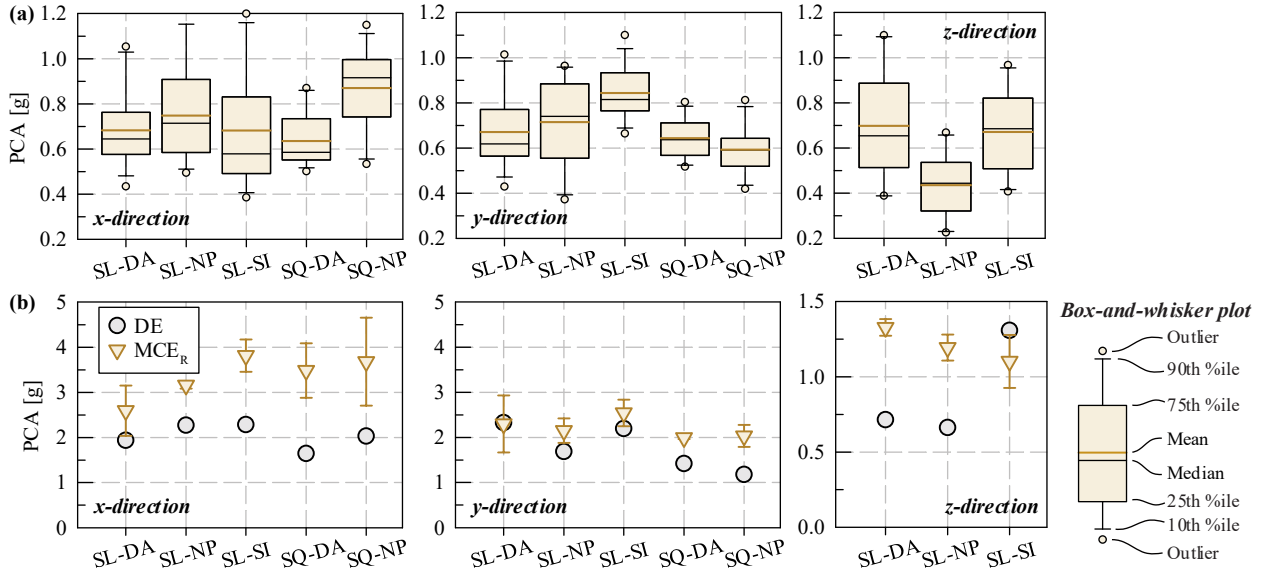


Figure 6. Peak component accelerations under: (a) SLE and (b) DE and MCE_R tests

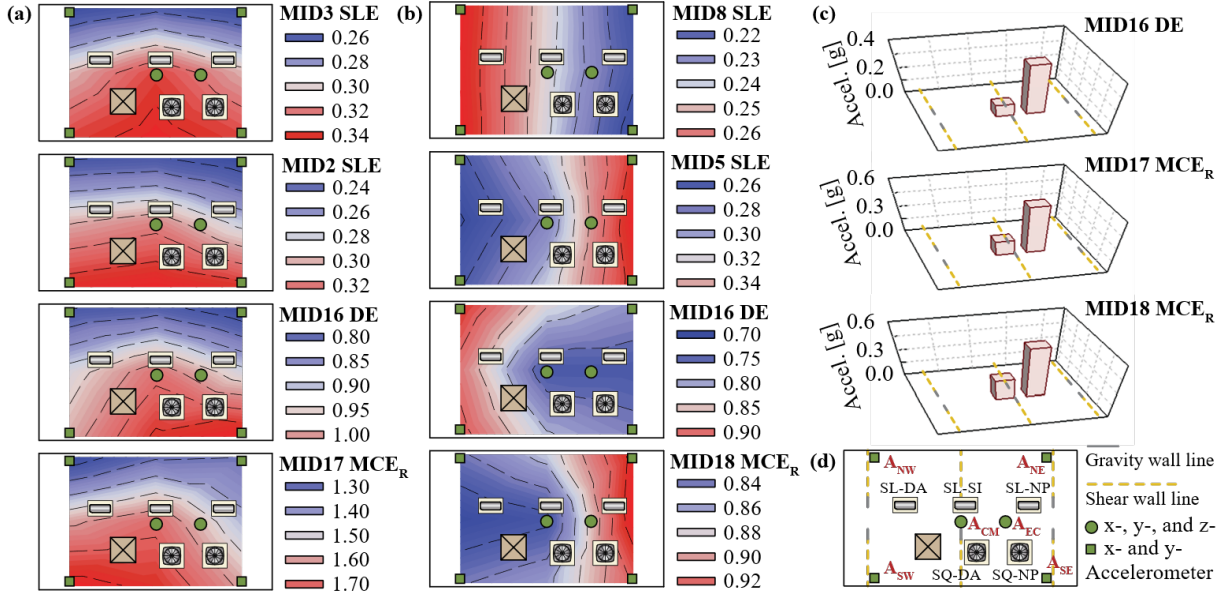


Figure 7. Peak roof acceleration distributions: contour plots of roof accelerations in the (a) x-direction and (b) y-direction, (c) bar graph representation of z-direction accelerations, and (d) layout of accelerometers on the roof diaphragm

In the z-direction, PRAs were governed by the vertical boundary conditions, as shown in Figure 7(c–d). Notably, the PRA recorded by the accelerometer at the calculated CoM (A_{CM}) was 63.7%, 67.7%, and 71.3% lower than that measured by the accelerometer (A_{EC}) positioned between the two shear wall lines, for MID16 (DE), MID17 (MCE_R), and MID18 (MCE_R), respectively. Component acceleration amplification factor, defined as PCA/PRA , was evaluated using the contour plots of PRAs (e.g., Figure 7). For the x- and y-directions, PRAs recorded at the geometric centre of the planar projection of each unit were directly used to calculate PCA/PRA . For the z-direction, PCA/PRA was evaluated using accelerometers located nearest to each unit. As illustrated in Figure 7(d), A_{CM} was used for SL-SI and A_{EC} was used for SL-NP. For the SL-DA, where no z-direction accelerometer was available in proximity, the sensor, A_{EC} adjacent to the calculated CoM was selected, based on the symmetry in the shear wall layout.

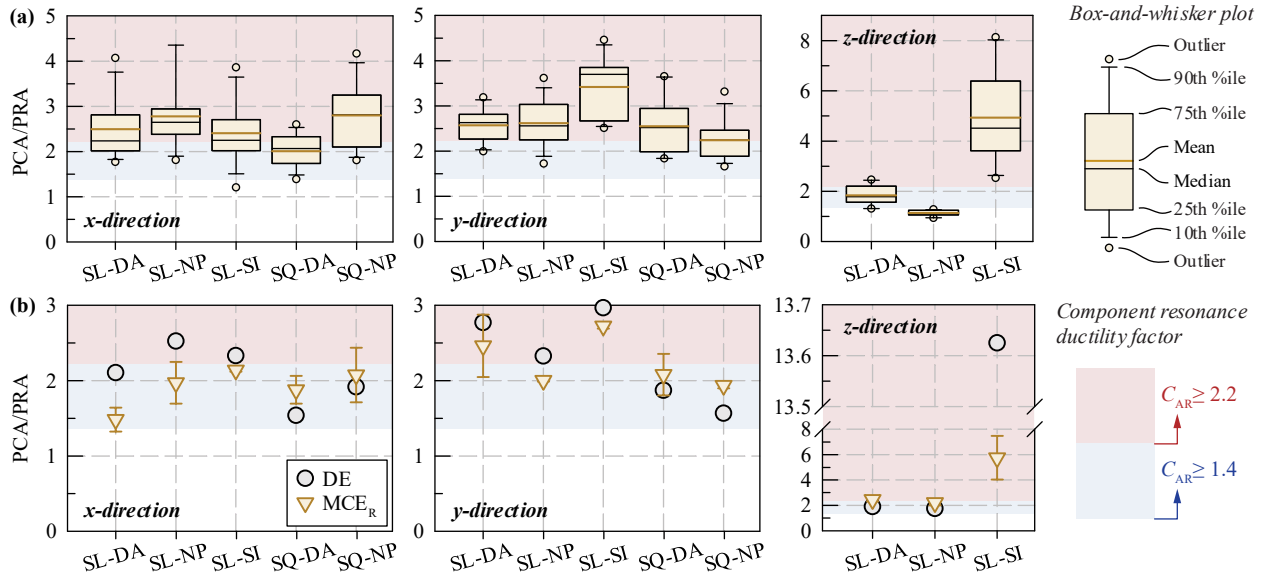


Figure 8. Component acceleration amplification factors under: (a) SLE and (b) DE and MCE_R tests

Figure 8 presents the component acceleration amplification factors for all five equipment units under SLE, DE, and MCE_R tests. For comparison, the code-based resonance ductility factor, C_{AR} specified in ASCE/SEI 7-22 [ASCE, 2022], 1.4 for non-vibration-isolated air-conditioning units and 2.2 for vibration-isolated components, are also plotted. Under SLE tests, comparison of the mean and median PCA/PRA values from the box plots indicates that the code-based coefficients generally underestimate the amplification demands for both non-isolated and vibration-isolated equipment. At higher hazard levels (DE and MCE_R), the code coefficients still do not consistently provide conservative envelope values above the calculated PCA/PRA scatter diagram. In particular, the spring-isolated slender unit (SL-SI) experienced significantly larger amplification in the z-direction than predicted by the code coefficient, owing to the inherent flexibility of its spring supports.

Two main factors likely explain these discrepancies. First, the PCAs reported in this study were measured at the top of each equipment unit, which are expected to be higher than CoM-associated PCAs. Second, the C_{AR} proposed in ASCE/SEI 7-22 [ASCE, 2022] may be more appropriate for heavier NCSs, whereas the mechanical equipment units evaluated here are exempt from seismic design calculations under the current code, since each unit weighs less than 1,779 N and has a CoM located no more than 1.22 m above the adjacent floor level.

4. CONCLUSIONS

This paper presents preliminary findings on the acceleration response of a full-scale, ten-story CFS building and its rooftop mechanical equipment from a shake table testing campaign. Five different equipment were installed, with varying attachment strategies implemented. It should be noted that piping connected to equipment that undergoes considerable movement must be sufficiently flexible to prevent damage at rigid interfaces. In this study, piping is not included. Its influence is isolated by assuming flexible connections, and only the equipment is evaluated experimentally. The results provide insight into the adequacy of current design provisions in capturing the acceleration demands on lightweight NCSs, while also offering an important benchmark dataset upon which numerical models can be evaluated. Modal properties and displacement responses of the equipment will be examined in future work.

ACKNOWLEDGEMENTS

This project was executed with support of the National Science Foundation under Grants CMMI-1663569 and CMMI-1663348, together with numerous other federal, state, and industry partners. Specific to the rooftop mechanical equipment discussed herein, additional support was provided by Mason West, Inc., Mason Industries, Inc., and Wells Plumbing and Heating Supplies, Inc. A complete list of sponsors and partners is available at: cfs10.ucsd.edu/sponsors-partners. The authors gratefully acknowledge all undergraduate and graduate students and visiting scholars (cfs10.ucsd.edu/people), as well as the LHPOST6 facility staff (esec.ucsd.edu/about/personnel), for their contributions to the project. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the sponsoring organizations.

REFERENCES

- ASCE [2022] *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, American Society of Civil Engineers, Reston, Virginia, USA.
- Astroza, R., Pantoli, E., Selva, F., Restrepo, J.I., Hutchinson, T.C., Conte, J.P. [2015] “Experimental evaluation of the seismic response of a rooftop-mounted cooling tower,” *Earthquake Spectra*, Vol. 31, No. 3, pp. 1567-1589.
- Elkady, A., Kazantzi, A.K., Dietz, M., Dihoru, L., De Risi, R., Vamvatsikos, D., Lignos, D.G., Miranda, E., Mylonakis, G. [2025] “Shake table tests on nonlinear steel fuses for the acceleration-control of nonstructural components,” *Earthquake Spectra*. (Online First)
- Fathali, S., Filiatrault, A. [2008] “Effect of elastomeric snubber properties on seismic response of vibration-isolated mechanical equipment: An experimental study,” *Earthquake spectra*, Vol. 24, No. 2, pp. 387-403.
- Feinstein, T., Moehle, J.P. [2022] “Seismic response of floor-anchored nonstructural components fastened with yielding elements,” *Earthquake Engineering & Structural Dynamics*, Vol. 51, No. 1, pp. 3-21.
- ICC [2004] *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems*, International Code Council, Whittier, California, USA.
- Papadopoulos, A.N., Vamvatsikos, D., Kazantzi, A.K. [2019] “Development and application of FEMA P-58 compatible story loss functions,” *Earthquake Spectra*, Vol. 35, No. 1, pp. 95-112.
- Ruggieri, S., Vukobratović, V. [2024] “The influence of torsion on acceleration demands in low-rise RC buildings,” *Bulletin of Earthquake Engineering*, Vol. 22, No. 5, pp. 2433-2468.
- Hutchinson, T.C., Eladly, M., Ji, R., Rivera, D., Rukundo, F.C., Singh, A., Sorosh, S., Zhang, J., Zhang, X., Padgett, L., Jones, H., Karns, J., Schafer, B.W. [2026] “Advancing use of cold-formed steel framing systems for mid-rise residential construction in seismic zones via full-scale shake table testing,” *Proceedings of the 8th Residential Building Design & Construction Conference*, State College, Pennsylvania.
- Zhang, J., Sorosh, S., Ji, R., Lotfizadeh, K.H., Schafer, B.W., Hutchinson, T.C. [2026] “Full-scale 10-story cold-formed steel building shake table test: Protocol development and shake table performance,” *Proceedings of the 13th National Conference on Earthquake Engineering*, Portland, Oregon, 2026. In review.