University of British Columbia

Guideline for Resilience-based Seismic Design of Nonstructural Systems

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1 Introduction

1.1 Scope and applicability of this guideline

Nonstructural components and systems (NCs) are known as components that are permanently attached to their parent structures and are not part of the gravity or lateral load carrying system of those structures. Also, the weight of these components should not exceed 25% of the effective mass of their supporting structure, otherwise they should be classified as nonbuilding structures. Nonbuilding structures and building contents are not covered in this guideline. Design guidance for building contents is provided in another guideline “Protection of Building Contents.

These guidelines can be applied to both new construction and renewals of existing buildings.

While not in the scope of this guideline, the vertical component of ground motion can be damaging to building NCs and, in some instances, has significantly exceeded the corresponding horizontal component of ground motion. For base-isolated buildings, horizontal building accelerations are lower due to isolation, whereas vertical accelerations do not experience the same reductions. Therefore, careful consideration should be given to the design of acceleration-sensitive NCs for vertical seismic shaking in base-isolated buildings in particular, since the horizontal component may not necessitate enhancements to NCs. To address the vertical ground motion component, the designer may identify component fragilities from literature that are based on vertical acceleration or use the default fragilities for horizontal shaking presented herein.

1.2 Purpose of the guideline and nonstructural performance objectives

Recent earthquakes have demonstrated that damage to nonstructural systems can be significant, even in buildings designed to modern codes, causing life-safety risks as well as downtime and financial losses. A seismic resilience study undertaken for UBC indicated that nonstructural losses on campus contributed most significantly to downtime and financial losses.

UBC has developed a resilience strategy that depends on limiting these losses. For new construction on campus and some renewal projects, UBC’s seismic real estate framework aims for REDi Platinum or Gold performance, which corresponds to limited downtime. This requires that buildings sustain only minor damage in large earthquakes. The building codes does not provide the guidance required to achieve this goal.

The main purpose of this guideline is to provide a design aid for engineers and designers to achieve the performance objectives set out in the seismic real estate framework for nonstructural systems. For REDi Platinum and Gold buildings, the performance objectives correspond to a 75% confidence level that the building would be capable of supporting operations (or functions) after 475 return period (RP) shaking intensity. For REDi Platinum buildings, the functionality of the building would be maintained because back-up systems would be installed to address municipal utility supply disruption. For REDi Gold buildings, the functionality of the building would be restored once municipal utility supply is restored. In either case, nonstructural systems and components should experience only light damage that would not impede functionality of the building.

Following these guidelines does not guarantee that the performance objective is met. This needs to be explicitly verified through a probabilistic risk analysis outlined in the REDi Guidelines. However, following these guidelines should provide a good chance that nonstructural systems and components will meet the performance objectives when the probabilistic risk assessment is completed. Some iteration may be required.

1.3 How to use this guideline

This guideline does not replace the building code requirements for nonstructural components and systems or any UBC-specific technical specifications. The building code, including the National Building Code of Canada (NBCC) and British Columbia Building Code (BCBC), sets the minimum design requirements. This guideline provides additional design guidance to achieve the higher performance targets outlined in UBC's seismic real estate framework.

This guideline focuses on addressing and mitigating three primary damage modes for nonstructural components, observed in past earthquakes:

1. **Damage to anchorage, restraints, and supports of nonstructural components and equipment**

   The intent of these guidelines is to keep anchorage, restraints, and supports of nonstructural components and equipment essentially elastic at 475 year RP shake intensity.

2. **Damage to nonstructural components themselves due to building movements**

   The intent of these guidelines is to design and detail nonstructural components to accommodate relative displacements and building accelerations with minimal damage at 475 year RP shaking intensity.

3. **Damage to mechanical and electrical equipment that may have internal parts susceptible to damage in shaking**

   The intent of these guidelines is that mechanical and electrical equipment are operable after 475 year RP shaking intensity.

4. **Damage to egress systems**

   The intent of these guidelines is that stairs and elevators can accommodate relative displacements and building accelerations with minimal damage at 475 year RP shaking intensity. In addition, stairs are intended to bear the full design loads under 2,475 year RP shaking.

In order to satisfy these objectives, this guideline outlines a multi-step process illustrated in Figure 1. Step 1 outlines the performance objectives for each damage mode. For each of the damage modes, the anchorage/restraints/supports, nonstructural components, and equipment must satisfy the design criteria outlined in Step 2. For NCs and equipment, a design aid is provided to check that typical components (compliant with minimum code requirements *and* baseline design actions presented in Table 1 in this document) can accommodate building movements with little damage. If the building demands exceed these thresholds for any component or equipment, several design and analysis options are provided to address the noncompliance. In the next section, further guidance on Step 2 is provided for the designer. Details for each component, including standard design practices and enhanced solutions, is provided in the appendices.

Once the design of anchorage/restraints/supports, NCs, and equipment satisfies the guidance herein, the performance must be verified explicitly through a probabilistic risk assessment (Step 3) according to the REDi guideline. New sets of fragility values and consequence functions should be defined for bespoke units and those with enhanced designs.

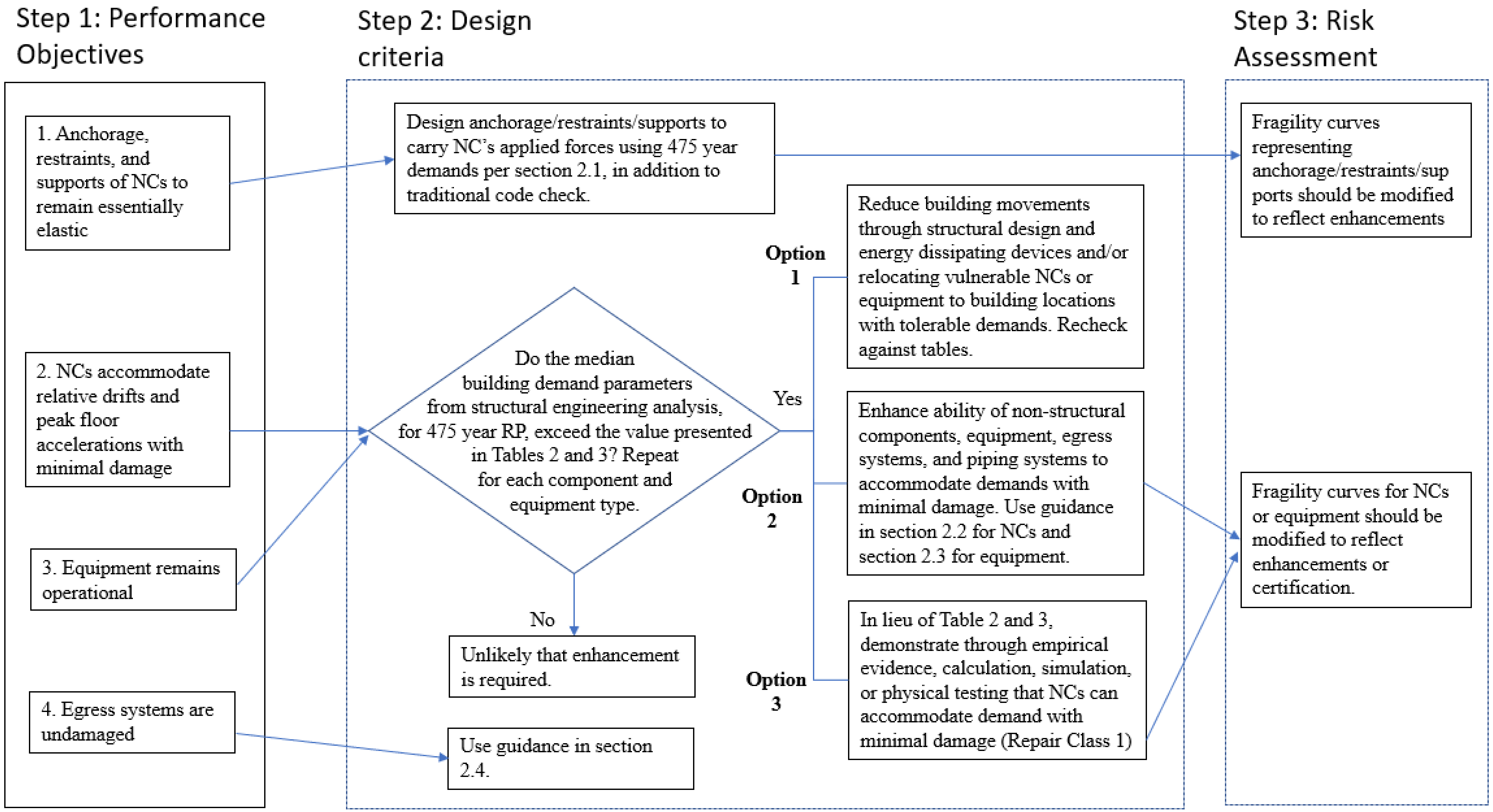

Figure 1. Outline of design procedure.

2 Design Criteria

The following sections provide guidance on how the performance objectives outlined above can be achieved.

2.1 Design of anchorage, restraints, and supports

The support, bracing and connection points of nonstructural components or equipment with their parent structure are one of the critical elements to address. Generally, anchorage and restraint failures are associated with sudden and widespread damage in NCs and equipment. According to design codes, anchorage and supports of nonstructural systems shall carry applied force at the component's center of gravity. The code-based design per NBCC should be completed. In addition, the design criteria outlined below are to minimize damage and support functionality-level performance of NCs and equipment at 475 year RP shaking. The design of all NC supports, bracing and anchorage shall be governed by the higher of the code-based check and the forces herein:

$$V_p = a_i A_r C_p / R_p$$

Where:

- a_i is the peak floor acceleration at level i, in the maximum direction observed, obtained from structural analysis. If response history analysis is used, a_i is the mean + 1 standard deviation (84^{th} percentile) peak floor acceleration in the maximum direction observed from the suite of ground motions. If modal analysis is used, a_i shall be the geomean of both orthogonal components, multiplied by 1.2 (from Shahi and Baker) to account for maximum direction effects, then multiplied by 1.5 to account for variability in the response.
- C_p is the element or component factor taken from Table 4.1.8.18 in the NBCC.
- R_p, the element or component response modification factor, should be set to 1.
- A_r is the element or component response amplification factor from Table 4.1.8.18 in the NBCC.
- W_p is the component weight.
- Material overstrength factors should be applied for design of anchorage to concrete.

2.2 Design of nonstructural components and systems

In general, NCs designed to minimum building code requirements are very likely to satisfy life-safety requirements but may suffer significant damage that would hinder re-occupancy and continuity of operations. This guideline aims to minimize damage in NCs at 475 RP shaking intensity to Repair Class I (aesthetic or minimal damage that does not impede functionality – see the REDi Guidelines).

The following steps outline the process:

1. As a minimum design for NCs, the code requirements as well as the baseline design best practices presented in Table 1 should be followed. The baseline design details for various NCs are explained in more detail in appendices A through F. Guidance for egress systems is contained in section 2.4 and Appendix E for further stair details.

2. Median engineering demand parameters (EDPs) such as interstory drift (IDR), peak floor accelerations (PFAs), residual interstory drifts (RIDRs), and other relevant EDPs should be extracted from structural analysis of the building under earthquake demands representative of 475 year RP shaking, for each floor of the building. PFA's should be multiplied by 1.2 if modal analysis was used to derive the medians. Guidance on acceptable structural analysis methods as well as further definition of the EDPs is contained in the REDi guideline.

3. For each NC, use the *median* EDPs from the structural analysis at the corresponding floor and compare against the thresholds provided in Table 2. The thresholds in the table correspond to the 10% probability of damage for a given component, derived from fragility functions primarily developed for the FEMA P-58 probabilistic seismic risk assessment framework. By corollary, components that are subject to the demands listed in the table should have a 90% probability that they will not sustain damage capable of hindering functionality. The purpose of comparing the *median* EDPs to the 10th percentile thresholds is to provide a reasonable level of assurance, prior to explicit risk analysis, that the building as a whole will have a 75% confidence level of achieving functionality in 475 year shaking. If a particular component is not listed, then the designer should derive the 10% threshold from published studies of similar components in the academic literature, simulation, calculation, or results from physical studies. The interstory drift capacity related to the no damage state of cladding and glazing on the building envelope should be calculated based on the actual details. Otherwise, proceed to the next step.

4. If the EDPs do not exceed the thresholds provided, no further action is necessary for that particular NC. For any NCs where the *median* EDPs exceed their corresponding threshold capacity, or where the thresholds have not and/or cannot be derived, further design or assessment is required. Three options are presented in Figure 1.

    a. **Option 1:** NCs can be relocated until the *median* EDPs are lower than the thresholds in Table 2 and 3.

    b. **Option 2:** Enhance the design of NCs using the guidance in Appendix A through F. The EDPs used for design should be the mean + 1 standard deviation (84th percentile) demands from a suite of ground motions if using response history analysis, or 1.5x the mean demands if the EDPs are derived from modal analysis. For PFA's, the demands should relate to the maximum direction (see a_i in section 2.1). Drift-sensitive components should be designed to accommodate these demands with minimal (aesthetic only) damage which would not impede functions.

c. **Option 3:** Justify through obtained empirical evidence, calculation, simulation, or physical testing (including certification) that either 1) the capacity of standard components in Table 2 can be augmented to accommodate the EDPs, or 2) the capacity of any nonstandard components or improved detailing to enhance the design of NCs (not contained in the Appendices) can be augmented to accommodate the EDPs. For any critical components that employ nonstandard detailing, physical testing to international standards (e.g. AC156) is recommended. Option 3 also applies to any NC's that are not listed in Table 2.

Table 1. Baseline and enhanced design actions for nonstructural components

Nonstructural Component	Baseline Design Requirements	Enhanced Design Solutions
Cladding/Glazing	**Refer to Appendix F2**	**Refer to Appendix F3**
Interior Partitions	Refer to Appendix D2	Refer to Appendix D3
Stairs	Refer to Section 2.4 and Appendix E2	Refer to Section 2.4
Elevator	Refer to Section 2.4	Refer to Section 2.4
Suspended Ceiling	Refer to Appendix C2	Refer to Appendix C3
Pipes	Refer to Appendix A2	Refer to Appendix A3
Mechanical Equipment	Refer to Appendix B2	Refer to Appendix B3
Electrical Equipment	Refer to Appendix B2	Refer to Appendix B3

Table 2. 90 percent confidence level capacity of nonstructural capacities

Nonstructural Component	Capacity Type	Capacity Threshold	Nonstructural Component	Capacity Type	Capacity Threshold
Cladding/Glazing			**Interior Partitions**		
All cladding/glazing	IDR (%)	NA[3]	Typical applications	IDR (%)	1.23
Exterior Partitions			Sterile environments (e.g., operating rooms)	IDR (%)	0.22
Steel framing with wood sheathing	IDR (%)	0.24	Smoke barriers	IDR (%)	0.70
Steel framing with flat strap X bracing	IDR (%)	1.01	**Suspended Ceiling**		
Steel framing with steel sheathing	IDR (%)	1.38	Lighting fixtures	PFA (g)	0.90
Wood framing with wood sheathing	IDR (%)	0.14	Acoustic tiles	PFA (g)	1.15
Stairs			**Pipes**		
All stairs	IDR (%)	NA[1]	Threaded steel piping	PFA (g)	0.33
Elevators			Welded steel piping	PFA (g)	1.19
Traction	PGA (g)	0.22[2]	Sanitary waste piping (cast iron with bell and spigot coupling)	PFA (g)	1.58
	RIDR (%)	0.14[2]	**HVAC Distribution**		
Hydraulic	PGA (g)	0.34[2]	HVAC ducts (cross section < 6 sq ft)	PFA (g)	0.90
	RIDR (%)	0.14[2]	HVAC ducts (cross section ≥ 6 sq ft)	PFA (g)	2.25
			HVAC drops/diffusers	PFA (g)	0.78

1. See Section 2.4 for design requirements for stairs
2. See Section 2.4 for design requirements for elevators; RIDR expected to be negligible for REDi Gold and Platinum buildings.
3. See Appendix F for design requirements for cladding and glazing.

2.3 Protection of equipment

It is well understood that buildings cannot remain functional if equipment is damaged and unable to operate. Therefore, keeping equipment operable is a crucial goal of this guideline.

The following steps outline the process:

1. As a minimum design for equipment, the code requirements as well as the baseline design best practices presented in Table 1 should be followed. The baseline design details for various equipment are explained in more detail in Appendix B.

2. Engineering demand parameters (EDPs) for equipment are peak floor accelerations (PFAs). These should be extracted from structural analysis of the building under earthquake demands representative of 475 year RP shaking, for each floor of the building. For PFA's, the demands should relate to the maximum direction (see a_i in section 2.1). Guidance on acceptable structural analysis methods as well as further definition of the EDPs is contained in the REDi guideline.

3. For each piece of equipment, the *median* PFA's from the structural analysis at the corresponding floor should be extracted and compared against the thresholds provided in Table 3. The thresholds in the table correspond to the 10% probability of damage for a given piece of equipment, derived from fragility functions primarily developed for the FEMA P-58 probabilistic seismic risk assessment framework. By corollary, pieces of equipment that are subject to the demands listed in the table should have a 90% probability that they will not sustain damage that will render them inoperable. The purpose of comparing the *median* EDPs to the 10^{th} percentile thresholds is to provide a reasonable level of assurance, prior to explicit risk analysis, that the building as a whole will have a 75% confidence level of achieving functionality in 475 year shaking. If a particular piece of equipment is not listed, then the designer should derive the 10% threshold from published studies of similar components in the academic literature, simulation, calculation, or results from physical studies. Otherwise, proceed to the next step.

4. If the PFA's do not exceed the thresholds provided, no further action is necessary for that particular piece of equipment. For any equipment where the *median* EDPs exceed their corresponding threshold capacity, further design or assessment is required. Three options are presented in Figure 1.

    a. **Option 1:** Equipment can be relocated until the *median* EDPs are lower than the thresholds in Table 3.

    b. **Option 2:** Equipment should be seismically certified (to an internationally recognized standard such as the ICC-ES AC156) to the PFAs corresponding to the mean + 1 standard deviation (84^{th} percentile) demands from a suite of ground motions if using response history analysis, or 1.5x the mean demands if the PFAs are derived from modal analysis. The demands should relate to the maximum direction (see a_i in section 2.1). If a piece of equipment from a particular vendor is not seismically certified, "experience data" from similar equipment that has been previously seismically certified is allowed.

    c. **Option 3:** Justify through obtained empirical evidence, calculation, simulation, or physical testing that the capacity of standard equipment in Table 3 can be augmented to accommodate the EDPs. This option also applies to any equipment not listed in Table 3.

Table 3. 90 percent confidence level capacity of equipment

Equipment	Capacity Type	Capacity Threshold
Mechanical Equipment		
Chiller	PFA (g)	0.56
Cooling tower	PFA (g)	0.91
Compressor	PFA (g)	0.85
Air handling unit	PFA (g)	0.71
HVAC fan	PFA (g)	2.22
HVAC fan (inline)	PFA (g)	1.35
Variable air volume box	PFA (g)	1.14
Electrical Systems		
Switchgear	PFA (g)	1.44
Motor control center	PFA (g)	1.50
Transformer	PFA (g)	1.61
Distribution panel	PFA (g)	1.83
Emergency Backup Power		
Battery rack	PFA (g)	1.80
Battery charger	PFA (g)	1.25
Diesel generator	PFA (g)	1.55

2.4 Egress systems

Egress systems consist of the nonstructural components that allow for occupants' evacuation from the building. As a minimum, egress systems shall meet the minimum requirements of the code. This section provides additional guidance to ensure that egress systems can achieve the performance objectives set out in the seismic real estate framework.

Stairs

All stair framing elements and their connections must be designed to resist the forces and drifts that the stair will experience in an earthquake. Stairs typically serve as the primary evacuation path in the event of required evacuation, such as a fire or earthquake. As such, it is imperative that the integrity of the egress stairs is maintained during a seismic event.

Stairs should be designed to achieve the following performance criteria:

1. Stair framing elements and their connections should be designed and detailed to remain undamaged when subject to the expected inter-story drifts of the primary structure in 475 RP seismic shaking.

2. Stair framing elements and their connections should be designed and detailed to maintain structural integrity and stability during the expected inter-story drifts of the primary structure in 2,475 RP seismic shaking.

These objectives may be achieved through the following design practices:

- Design the stair framing to remain elastic when subjected to the design forces in a 475 year event (see section 2.1).
- Design and detail the stairs to accommodate the interstory drifts (mean + 1 standard deviation) in a 475 year event with minimal damage (i.e. minor hairline cracking allowed). Slip connections may be used; examples of slip connections include bolts in slotted holes or sliding bearings.
- Design and detail the stairs to accommodate the interstory drifts (mean + 1 standard deviation) in the 2,475 year event, or a displacement of 25mm (1.0 in), whichever is larger, while maintaining support of full dead and stair live loads. Ductile connections or slip connections may be used. If slip connections are used, ensure that bearing length is adequate and that displacements will not exceed the length of the slots.

Elevators

The two main elevator components susceptible to damage in an earthquake are the elevator cab and the elevator guide rails. To minimize damage to elevator systems, the design of the guiderails should adhere to the following guidelines.

Design loads

- At a minimum, elevators, their components and anchorage should meet the minimum design criteria of ASME A17.1, the NBCC, the BCBC, and the guidelines presented in Section 2.1.
- Design loads should be derived from NBCC Section 4.1.8.18 with the following modifications or clarifications:
  - Elevator guiderails should be designed to remain elastic when subjected to the design forces in a 475 year event (R_p=1.0), assuming roof level accelerations.
  - Elevator guiderail supports should be designed to remain elastic when subjected to the design forces in a 475 year event (R_p=1.0).
  - The seismic weight of the elevator, W_p, should be taken as the larger of the weight of the counterweight or the total weight of the car plus 40% of the rated load.
  - The minimum design horizontal acceleration is 0.5g.

- For the guardrail forces, the design seismic forces are assumed to be distributed one-third to the top guiding members and two-thirds to the bottom guiding members, unless other data is provided by the elevator manufacturer.
- For the design of the guiderail support, the design seismic forces should be assumed to act at the worst possible location along the height of the guiderail support. The worst-case loading location is dependent on several factors, including floor-to-floor heights, maximum unsupported rail lengths, and building height. For the anchorage design, the design seismic forces should be assumed to act at the worst possible location, which may differ from the worst location for the guiderail support.

Deflection criteria

- Deflections are limited to avoid damage of the guiderails and disengagement of the elevator retainer plates from the guiderails during a seismic event.
- Guiderails and guiderail supports should be designed such that the maximum deflection of the rail between fixed supports is limited to 6mm (0.25in) for the expected accelerations in a 475 year seismic event (assuming $R_p = 1.0$).

Elevator controls

- Elevators operating with a speed of 46m/min (150 ft/min) or greater should have seismic switches per ASME A17.1 Section 8.4.10.1.2.

Doors

There has been evidence from previous earthquakes that jamming of egress doors may occur at very low seismic drifts <0.5%. Ideally, egress doors would be designed to accommodate drifts from major earthquakes. However, the technology to allow seismic movements in doors to avoid jamming, while maintaining acoustic integrity, fire life safety, and energy efficiency in normal operating conditions, may not be developed. The guidance herein is for the designer to inquire with contractors and vendors to understand whether connection details can be improved to avoid door jamming. Other operational mitigation measures, such as providing means to break down jammed doors with sledgehammers, may be explored and discussed with UBC project managers.

3 Implementation

The designer should incorporate the enhanced design criteria, including design forces/capacities, specification of performance including certification, and design details in applicable drawings and technical specifications. These may include:

- General Notes on Structural, Architectural, and Mechanical Drawings
- Structural, architectural, mechanical, and other relevant detail sheets
- Technical specifications

4 Risk Analysis

The enhanced design and specification of nonstructural components and equipment should be reflected in the probabilistic risk analysis (see REDi Guidelines). by augmenting the fragility curves of each affected component or deriving a unique fragility if one does not already exist for standard components. The procedures for doing this may involve:

- Revising the anchorage design capacities corresponding to enhanced demands outlined in Section 2.1
- Revising mechanical and electrical equipment capacities based on certification results
- Revising any component based on empirical evidence, virtual simulation, calculation/analysis, and physical testing. Academic studies can be used as the basis to derive or augment fragility curves.

Appendix A | Piping Systems

A1 Background Information

Piping systems carry and transfer a wide variety of fluids and gases in and around the buildings. These piping systems are generally categorized as non-pressurized or pressurized piping with a minimum pressure of 15 psi. Piping systems are also grouped based on their attachment types such as suspended, roof-mounted, floor-mounted, wall-mounted etc.

Damage to piping systems can compromise the functionality of a building, while damage of fire protection services may pose a life-safety risk. The seismic performance of piping systems widely varies based on several characteristics that are unique to each building, such as the type of piping system, size, configuration and layout of the distribution system, piping sizes, piping and pipe fitting material, bracing type and configuration, etc. To minimize damage, the design and detailing of the piping systems should adhere to the following guidelines.

A1.1 Associated risks

- **Life Safety:** The life-safety risk associated with seismic damage to general piping systems is relatively low, with the exception of damaged fire sprinkler systems which may pose a life-safety risk in a fire following an earthquake. Similarly, high life-safety risks may be associated with piping systems carrying hazardous materials. Past earthquakes have also caused pipe leaking and standing water could cause electrical shorts, which may be dangerous. Finally, mold caused by water from leaking pipes can cause health issues if not remediated.
- **Downtime:** Seismic damage of piping poses a medium to high risk to the continuation of building operations. Since these components carry fluids, damage is not constrained to the pipes themselves but anything that may be water damaged. Even relatively minor leaking can cause issues such as mold if the damage and leaking is hidden from view.
- **Repair Costs:** The cost of piping damage is relatively high due to the spray of fluid on building contents. In case of major damage, they may cause flooding inside the building, which can cause significant damage to the finishes.

A2 Baseline Design Requirements

A2.1 Design loads

At a minimum, piping systems should meet the minimum design criteria of ASME, NBCC and the BCBC. The design of the anchorage, pipe connections, bracing and supports should adhere to the requirements of ASME, the NBCC, and the guidelines presented in Section 2.1.

A2.2 Detailing considerations

- All piping systems should be provided with vertical, lateral and longitudinal bracing and supports to resist the required design loads. Solid sway bracing is recommended in lieu of cable bracing. Examples of solid bracing are depicted in Figure 2.

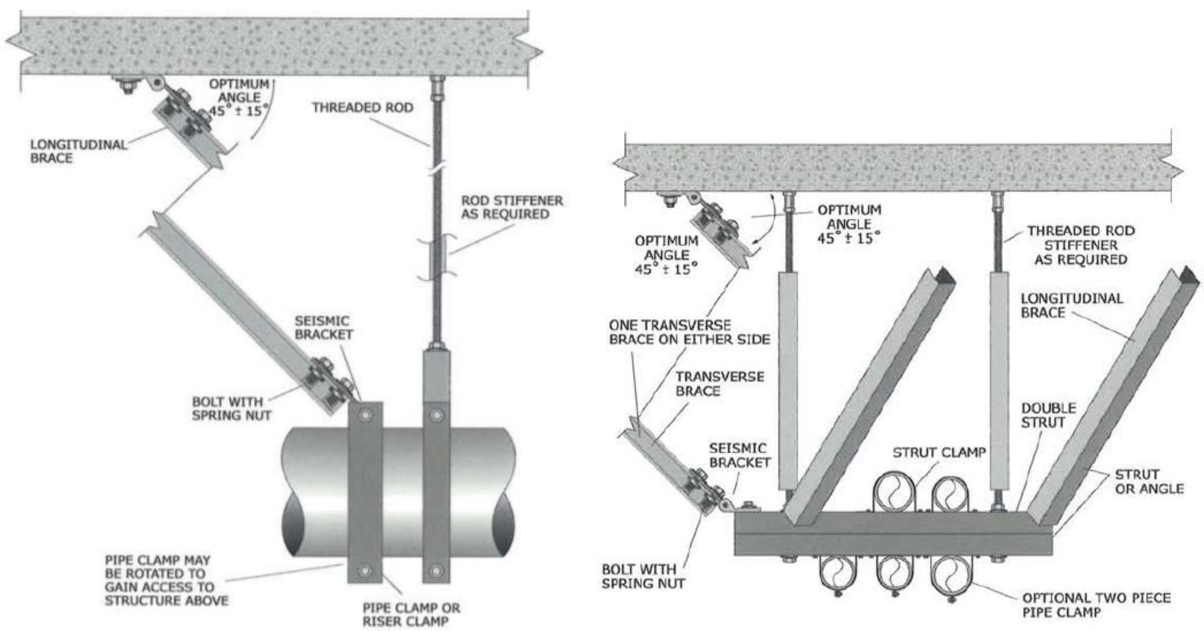

Figure 2. Examples of Single and Grouped Piping Brace Assemblies (Photo from FEMA P-414).

- For fire sprinkler piping systems, additional wire restrainers (two at each location) should be provided at the end of all branch lines, including systems with frequent short armovers. Rigid sprinkler head hose drops should be avoided and replaced with flexible drops designed to remain intact when subjected to the interstory drifts (mean + 1 standard deviation) in the 2,475 year event. See Figure 3 for an example of a flexible hose drop.

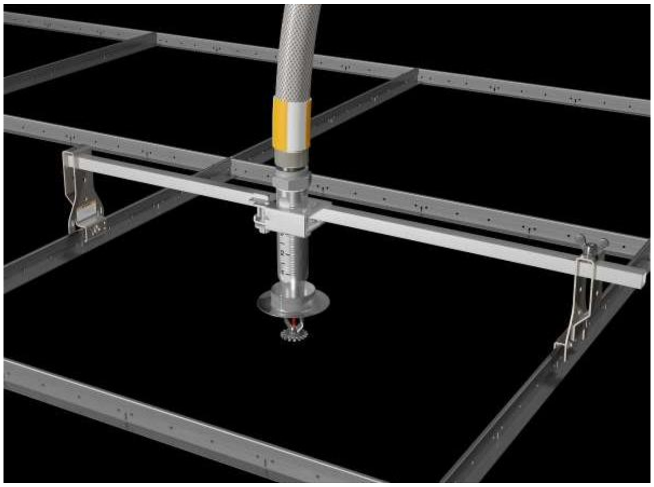

Figure 3. Sample of Flexible Hose Sprinkler Pipe Drop (Photo from victaulic.com).

A3 Enhanced Design Solutions

A3.1 Detailing considerations

- Threaded and grooved pipe fittings are often damaged and cause leakages in earthquakes and thus should be avoided. Welded pipe connections, or flexible connections if deemed feasible, should be provided in lieu of traditional threaded pipe fittings and should be designed per the guidelines presented in Section 2.1.
- Flexible pipes and pipe connections should be provided and designed to accommodate the interstory drifts (mean + 1 standard deviation) in the 2,475 year event with minimal damage. As a minimum, flexible connections should be provided as follows:
  - Vertical pipe risers should be provided with flexible connections at the supporting floors.
  - Flexible connections, such as those depicted in Figure 4, should be provided at the interfaces of piping and any system that is likely to experience differential displacement, such as at the connections to any MEP equipment, runs through walls, between floors, between buildings.

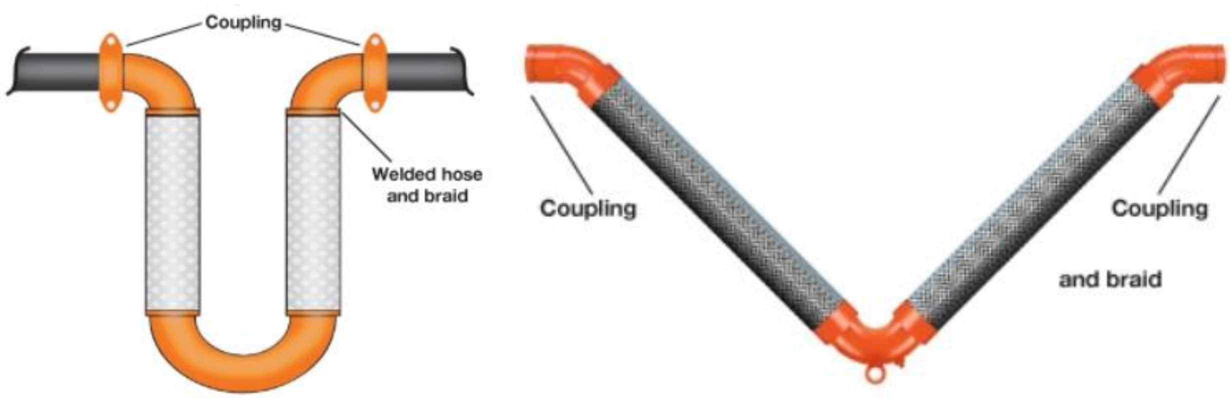

Figure 4. Examples of Flexible Pipe Connections (Photo from metaflex.com).

- Where flexible piping and connections are not feasible, penetrations around the piping required by code and standard practice may be provided. Penetrations must be sized to accommodate interstory drifts (mean + 1 standard deviation) in the 475 year event at a minimum. If possible given project constraints, penetrations should ideally accommodate interstory drifts in the 2475 year event. Penetrations for piping systems carrying hazardous materials must be sized for the 2475 year event.
- Piping systems carrying hazardous materials should be provided with leak detection and emergency shut offs. These piping systems should be designed based on NFPA49, NFPA491 and IFC. Double-walled piping systems are one of the most common construction details that have been widely used for hazardous materials (see
- Figure 5).

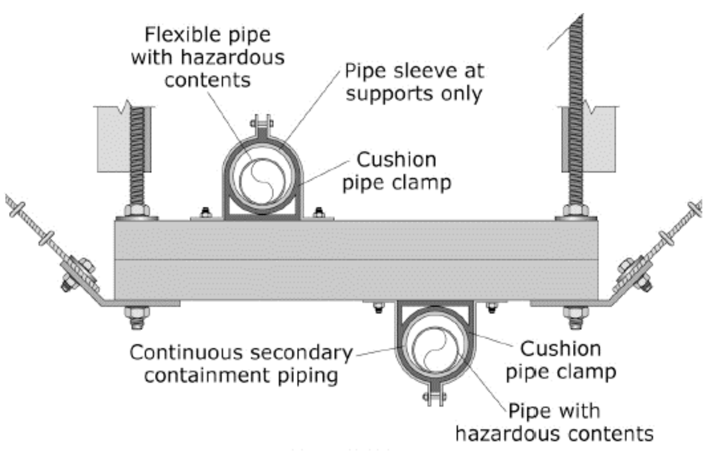

Figure 5. Sample Detail for Double Walled Braced Piping System (Photo from FEMA E-74).

- Using more advanced support and bracing systems, such as viscous dampers, can significantly enhance the seismic performance of piping systems (see Figure 6). Such devices can be designed and used in critical facilities.

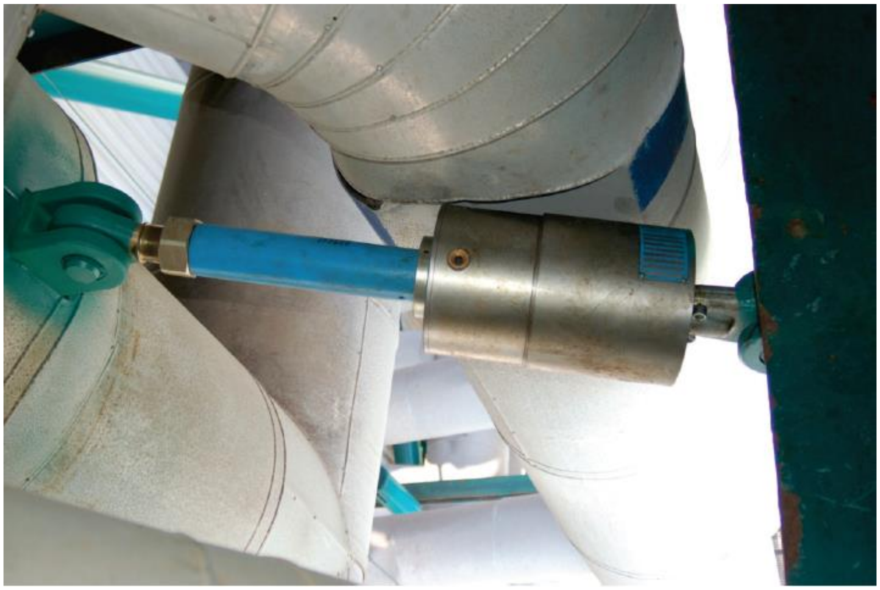

Figure 6. Sample Use of a Viscous Damper as a Pipe Restrainer (Photo from FEMA E-74).

Appendix B | Mechanical & Electrical Equipment

B1 Background Information

Mechanical equipment includes chillers, cooling towers, air handling units, fans, tanks, heat pumps, water pumps, boilers, etc. Figure 7 shows examples of the larger mechanical equipment including chillers and cooling towers. Electrical equipment consists of switchgears, transformers, battery racks, distribution panels, etc. Figure 8 shows examples of battery racks and distribution panels.

Figure 7. Examples of a chiller (left, photo from Sander Mechanical Service) and cooling towers (right, photo from Tower Tech, Inc.).

Figure 8. Examples of battery racks (left, photo from Data Center Frontier, LLC) and power distribution systems (right, photo from Primary Engineering, Inc.)

B1.1 Associated Risks

- **Life Safety:** The life-safety risks associated with seismic damage to mechanical and electrical equipment are generally negligible, with the exception of components that may be overhead and pose a falling hazard, such as rooftop equipment located near the edge of the building or heavy suspended light fixtures.
- **Downtime:** Seismic damage to mechanical and electrical equipment poses a high risk to the continuation of building operations, depending on the extent of damage. Since these components comprise the main source of building services, their damage can significantly impede functionality, and the long lead times associated with procurement of replacement equipment may cause significant downtime.
- **Repair Costs:** The cost of damage to mechanical and electrical equipment is relatively high, as equipment repair or total replacement is generally costly. In case of major damage, the equipment may leak or spray on other mechanical, electrical, or architectural components, which can cause significant secondary damage to those components.

B2 Baseline Design Requirements

B2.1 Design loads

All mechanical and electrical components, supports, and connections should conform to the minimum requirements of the code and should adhere to guidelines presented in section 2.12. The design of the anchorage, connections, bracing and supports should adhere to the requirements of the guidelines presented in Section 2.1. Refer to section 2.3 for acceptable seismic certification requirements for equipment.

B2.2 Detailing considerations

- All equipment should be provided with a positive connection to the supporting structure. Some exceptions, which should be verified through analysis, could include anchorage of large water tanks where overturning is an unlikely
- Flexible connections should be provided between all pieces of equipment and the associated ductwork, piping, conduits, and raceways; Flexible connections should be designed to remain intact when subject to the interstory drifts (mean + 1 standard deviation) in the 475 year event at a minimum. If possible given project constraints, flexible connections should ideally accommodate interstory drifts in the 2475 year event. Flexible connections for systems carrying hazardous materials must be sized for the 2475 year event.
- All equipment should be planned and located in such a way to eliminate the risk of seismic impact between components.

- Anchorage and support structures of all outdoor equipment should be properly corrosion-protected to prevent deterioration and ensure that seismic capacities are maintained.
- Most equipment, either with or without vibration isolators, requires anchorage or supports that are capable to resist vertical and lateral forces. Equipment supported on vibration isolators should be provided with lateral restraints, or "snubbers." To limit the amplification of seismic shaking effects on vibration-isolated equipment, the gap between the snubber and equipment should be limited to 0.25in, and snubbers should have an elastomeric or robust surface to lessen impact effects. Examples of common types of equipment attachments are presented in Figure 9 and Figure 10.

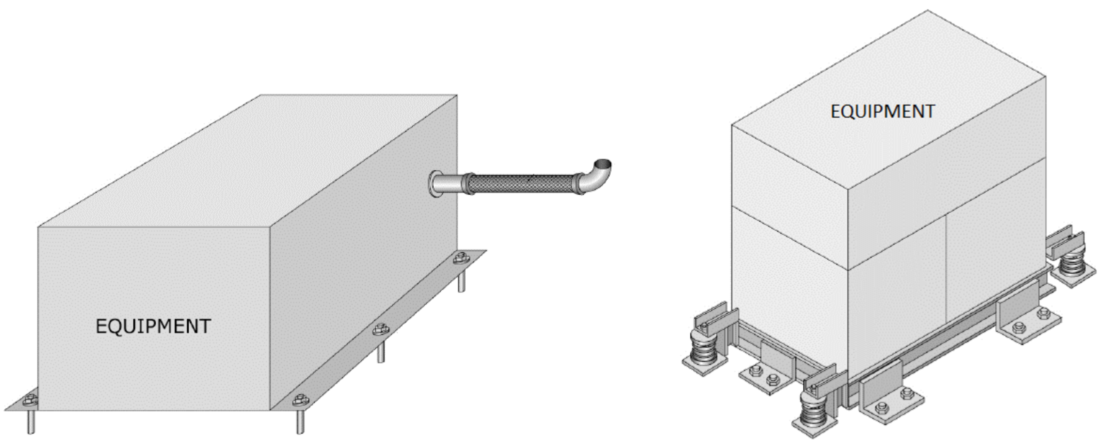

Figure 9. Examples of mechanical equipment attachments: direct rigid connections (left) and connections with vibration isolators and snubbers (right) (Photos from FEMA 412).

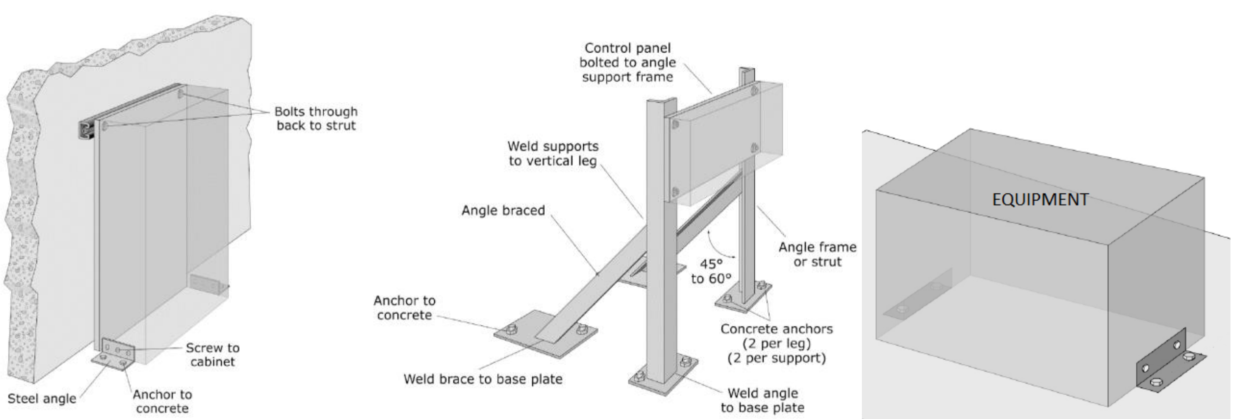

Figure 10. Examples of electrical equipment support conditions: wall mounted equipment (left), free-standing panels (middle), and floor-mounted equipment (right) (Photos from FEMA E-74).

- Similar to piping systems, suspended mechanical equipment and electrical components (i.e. raceways, conduit, cable trays, etc.), should be seismically braced with either rigid or cable bracing. Schematic details of suspended components with either rigid or cable bracing are illustrated in Figure 11 and Figure 12. See Section 2.1 for design forces.

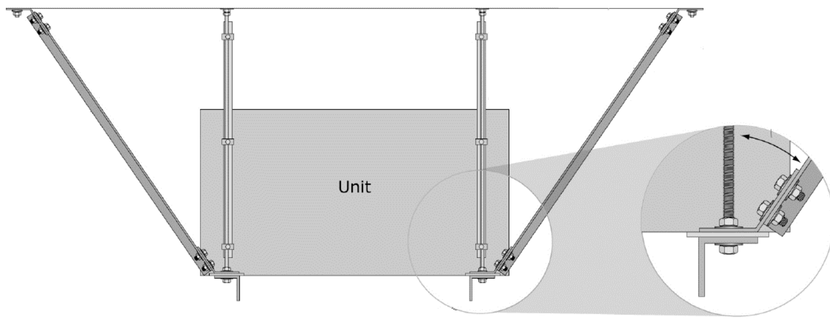

Figure 11. Suspended equipment with rigid bracing (Photo from FEMA E-74).

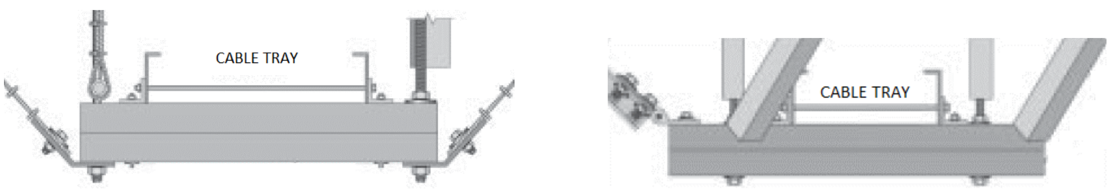

Figure 12. Examples of cable bracing (left) and solid bracing (right) of cable trays (Photos from FEMA 413).

- For mechanical equipment (e.g. water heaters) supported on the floor adjacent to structural walls, metal straps with flexible connections can be used as seismic restrains. A diagrammatic example of this installation is presented in Figure 13.

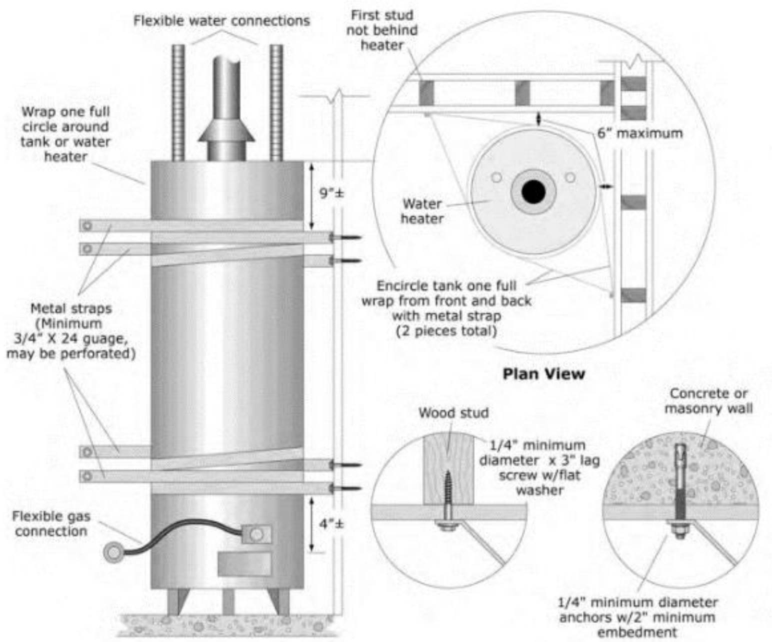

Figure 13. Example of water heater restraint installation (Photo from FEMA E-74).

- Batteries should be adequately restrained through the use of seismic racks to ensure that the batteries do not fall from the racks. Spacers should also be provided between battery cases to avoid damage from seismic impact. Numerous vendors manufacture seismic rack systems that are typically anchored to floor and/or walls. Two examples of seismic battery racks are illustrated in Figure 14.

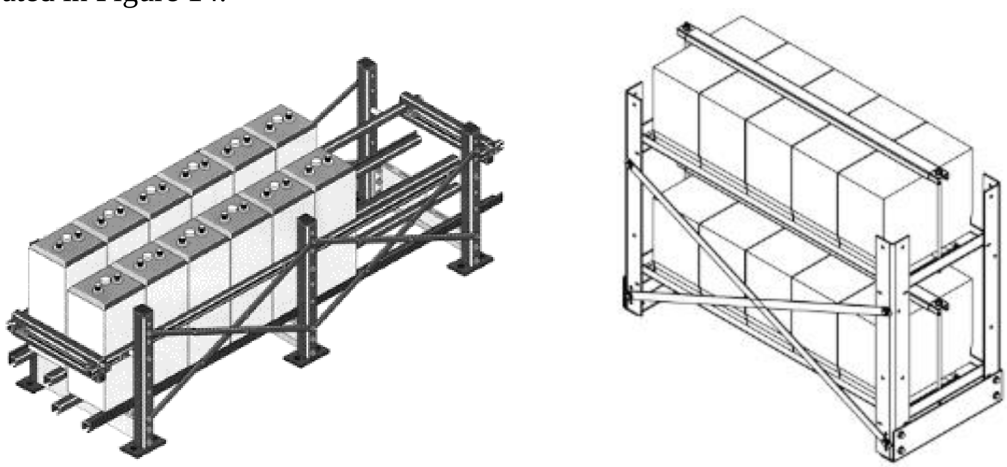

Figure 14. Examples of seismic battery racks (Photo from Storage Battery Systems, LLC).

- Photovoltaic (PV) panels supported on aluminum or galvanized steel tracks are typically either flush or tilted. New products are generally integrated with the roofing materials and may not require additional seismic considerations. However, any structural elements supporting PV panels should be designed to resist the imposed seismic forces, and positive connections should be provided between all the system components. Friction fittings should not be used.
- All equipment with slide-out components, such as electrical control panels, computer equipment, etc., should be provided with a latching mechanism to restrain the components during seismic shaking.

B3 Enhanced Design Solutions

B3.1 Testing

B3.2 Detailing considerations

- Using more advanced resisting systems, such as viscous dampers (shown in Figure 6, Appendix A3.1) can significantly enhance the seismic behavior of mechanical and electrical equipment.
- The use of seismic isolators under critical mechanical and electrical equipment are effective in reducing the acceleration demands on equipment by shifting the equipment natural frequency and increasing the system damping ratio. Examples of common isolation systems used for mechanical and electrical equipment are presented in Figure 15, Figure 16, and Figure 17.

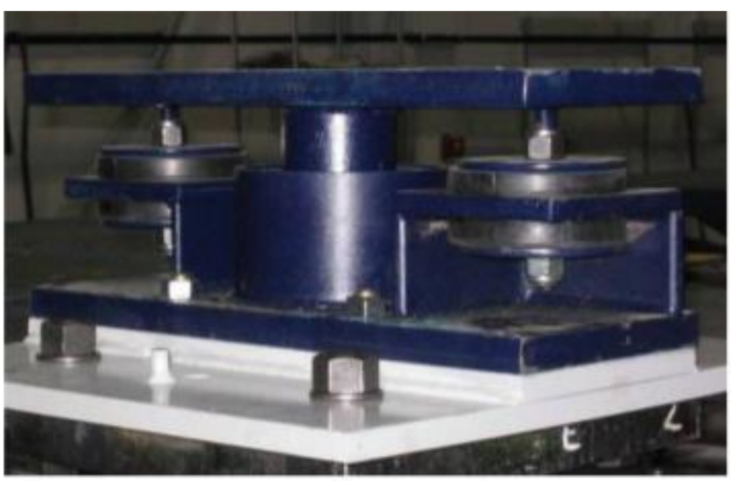

Figure 15. Restraint component of ASHRAE-type isolation/restraint systems for mechanical equipment (Fathali & Filiatrault, 2007).

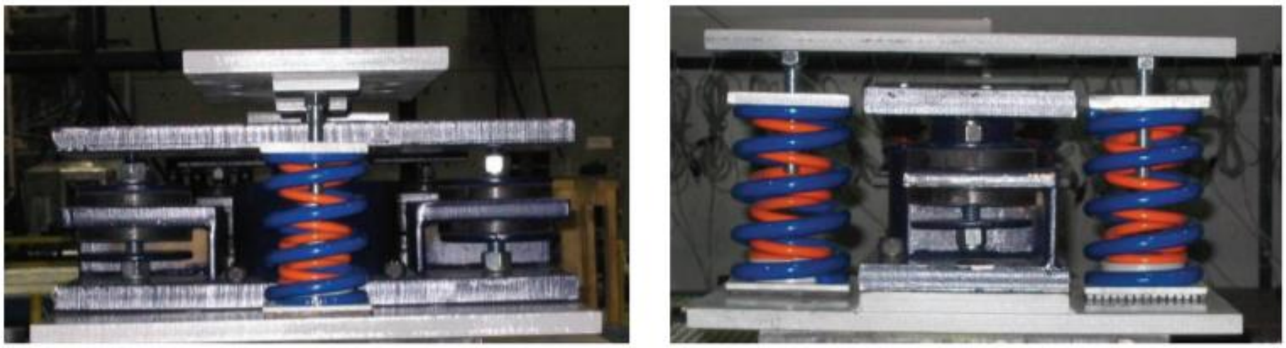

Figure 16. Assembled ASHRAE-type isolation/restraint system for mechanical equipment (Fathali & Filiatrault, 2007).

Figure 17. Example of electrical equipment seismic isolation: ISO-Base^{TM} Base Isolation Platform (left) and Ball-N-Cone^{TM} Seismic Isolation Bearing (right) (Photos from Strand Earthquake Consultants).

Appendix C | Suspended Ceiling Systems

C1 Background Information

Suspended ceiling systems are installed within buildings to serve as an aesthetic or acoustic barrier between electrical, mechanical, and piping systems and the occupied spaces below. The entire ceiling grid is hung from the structural floor above. The two most common suspended ceiling types are: acoustical lay-in ceiling panels and drywall or plasterboard ceilings, both shown in Figure 18. Lay-in panel ceilings have smaller panel sizes (e.g. 2ft to 4ft square) and their panels rest between the grid framing without a positive connection, while drywall ceilings consist of larger panels (e.g. 4ft to 8ft) that are screwed to the underside of the ceiling grid framing. Additionally, lay-in panel ceilings are typically constructed from high-density fiber material which is lighter than drywall.

Figure 18. Common suspended ceiling types: lay-in acoustical panel ceilings (left, photo from Armstrong Ceiling Solutions) and drywall ceilings (right, photo from USG Corporation).

C1.1 Associated Risks

- **Life-Safety:** The life-safety risks associated with seismic damage to suspended lay-in acoustical panel ceilings are generally low even though they may create a falling hazard, since they are often manufactured from light materials. The life-safety risks are slightly higher for a drywall or plasterboard ceiling system which are generally heavier, may have metal or wood panel materials, or may support heavier equipment such as lights, fans, etc.
- **Downtime:** Seismic damage to suspended ceilings poses a low to high risk to the continuation of building operations, depending on the level of damage. If only a few panels fall, then only minimal clean-up is required. More significant damage can lead to damage of other components and require up to multiple weeks for repair or replacement, including of the ceiling grid system. Since these components are located above all the building contents, they can cause significant disruption to operations if they were to fall. Additionally, damaged ceilings can also impact the

functionality of other building systems, as ceilings are often integrated with lighting, HVAC distribution, electrical distribution and other equipment.

- **Repair Costs:** While the direct cost of ceiling damage may be low relative to the building's assets, the consequences of ceiling damage are often costly and significant, such as secondary damage to other contents, components or services.

C2 Baseline Design Requirements

C2.1 Design Loads

All ceiling systems should conform to the minimum requirements of the code and should adhere to guidelines presented in section 2.12. The design of the anchorage, connections, bracing and supports should adhere to the requirements of the guidelines presented in Section 2.1.

C2.2 Detailing Considerations

- All ceiling systems should be provided with adequate seismic bracing, as unbraced ceiling systems are easily damaged with low levels of floor acceleration. See Section 2.1 for design forces.
- Drywall ceiling systems are typically heavier than lay-in panel systems. Key-lock drywall ceiling systems, illustrated in Figure 19, should be avoided unless sufficient engineering calculations and/or experimental performance data is provided and meets the target requirements. In past earthquakes, common types of damage to key-lock systems have included a brittle failure of the supports which has led to extensive ceiling damage over large areas.

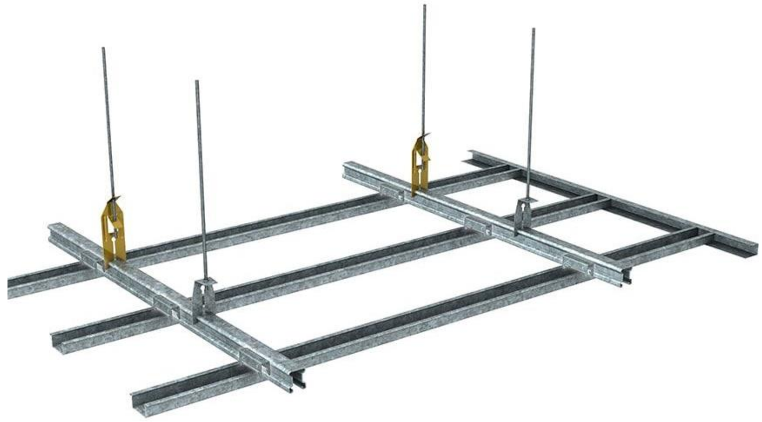

Figure 19. Example of a key-lock suspended drywall ceiling system (photo from USG BORAL).

- Typical ceiling framing and bracing for lay-in panel ceilings and drywall ceilings is illustrated in Figure 20. The lateral bracing assembly of ceiling systems should be composed of a compression post and splay wire bracing installed at 12ft spacing, with the first post located 4 -6ft from the nearest wall. Rigid bracing can be provided in lieu of splay wire bracing. Intermittent vertical hanger wires should also be provided in a regular grid for vertical support of the ceiling system. The hanger and splay wires should be constructed of 12-gauge wire that is looped through holes in main ceiling framing members, or “main runners”, and supported from the structure above.

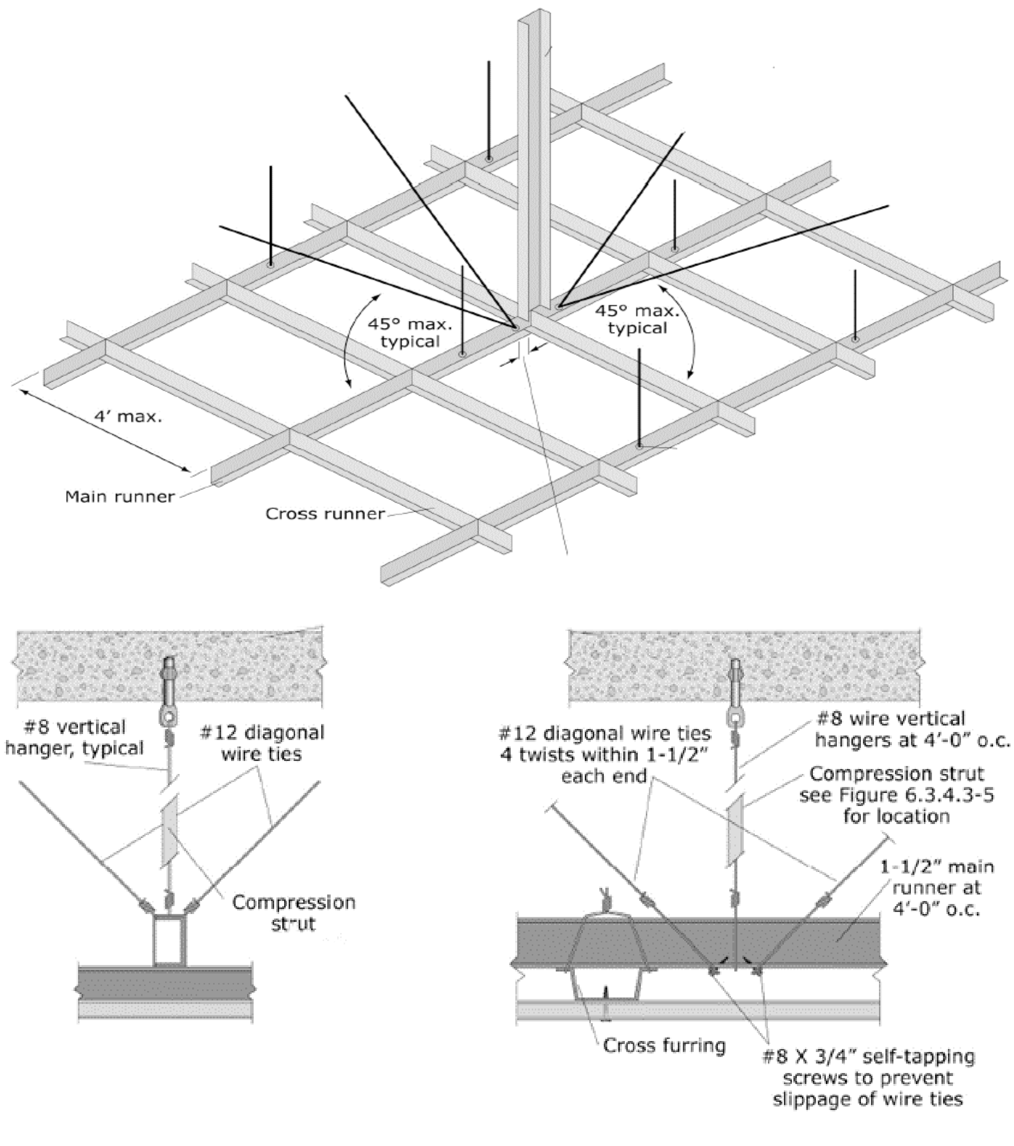

Figure 20. Ceiling bracing layout for a lay-in panel ceiling (top), and bracing assembly details for drywall ceilings (bottom) (photos from FEMA E-74).

- At ceiling perimeters, the ceiling framing should be fixed to the supporting walls at only two adjacent boundaries. At the other two adjacent wall boundaries, a minimum clearance of 3/4in should be provided between the supporting wall angle and the grid framing connection to allow for lateral movement. Seismic clips should be used at all ceiling boundaries. The seismic clips are attached to the supporting closure angle or channel with a minimum of two screws per clip and are installed around the entire ceiling perimeter. At the remaining two adjacent boundaries, the seismic clips are provided with a 3/4in clearance and screws in long-slotted holes, which allow for lateral movement. These connections are shown in Figure 21. Where seismic clips are provided, wall angles with a 7/8in minimum width are typically used. However, various experimental studies have shown that 7/8in wide angles do not provide a deep enough seat for the grid framing members and result in severe damage. Seismic fragility analysis has shown that angles with a 1.5in width provide the optimal seat length for ceiling grids with seismic clips (Soroushian, et al., 2016).

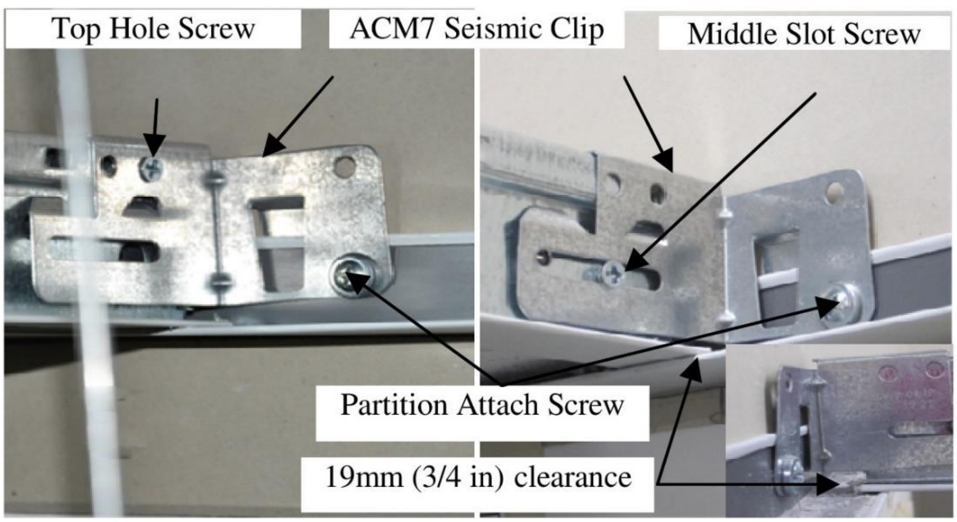

Figure 21. Example of a perimeter seismic clip installation: restrained connection (left) and slip connections (right) (Soroushian, et al., 2016).

- For ceiling systems integrated with lights, diffusers and other services, independent hangers and safety wires should be provided for each component and an intermediate duty or heavy-duty grid must be provided. Hanger wires should be provided at the four corners of suspended light fixtures where possible (see Figure 22). Independent seismic bracing should be provided for heavy light fixtures or light fixtures integrated in a ceiling system without seismic bracing.

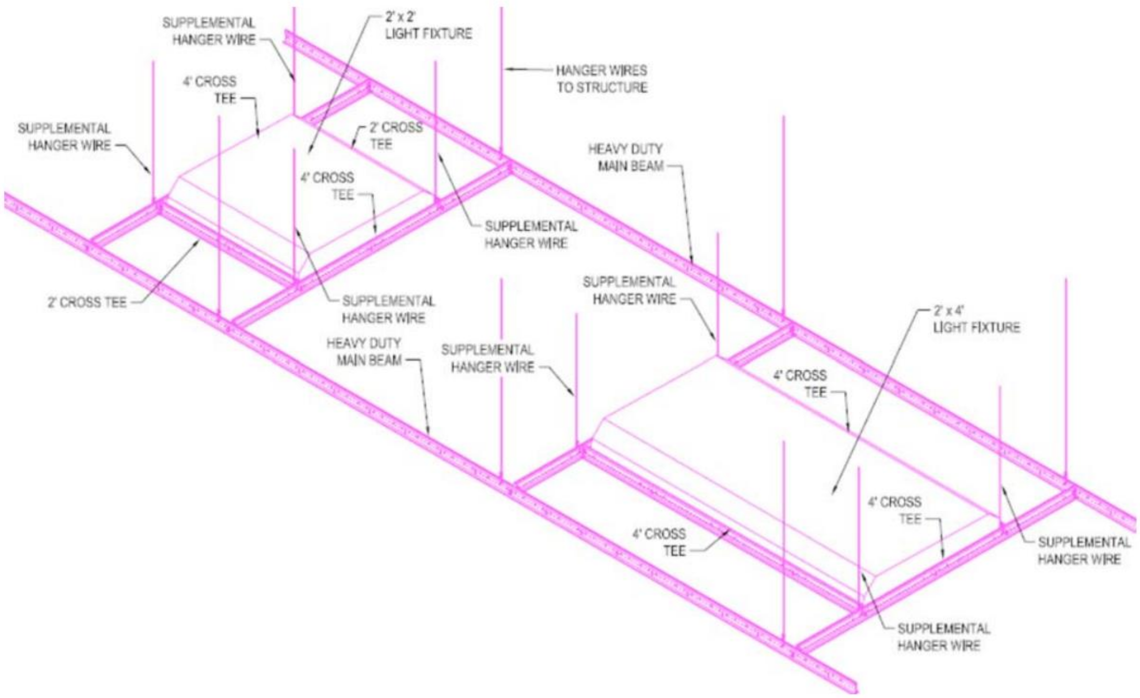

Figure 22. Suspended light fixtures with independent hanger wires (Photo from ASTM E-580).

C3 Enhanced Design Solutions

Suspended acoustic lay-in ceiling systems generally have three failure mechanisms: dislodging of ceiling tiles, damage of ceiling support framing, and loss of seating and support at ceiling system boundaries. The solutions presented herein aim to mitigate some of these failure modes, but there is a lack of quantitative validation and testing on the system-level performance of each of these enhancements. Therefore, the designer should undertake their own due diligence when selecting enhanced solutions.

C3.1 Detailing Considerations

- When high floor accelerations are expected, suspended ceiling systems should be avoided if possible. This is especially crucial in critical facilities.
- With standard ceiling bracing configurations, shown on the left of Figure 23, the rigid connection of the compression posts causes the ceiling system to move with the floor structure above, which causes the loose ceiling tiles to displace (Ryan, Pei, & Hutchinson, 2020). A new proposed ceiling system, shown on the right of Figure 23, uses shallow angle bracing between the ceiling framing grid and the compression posts in order to improve the seismic behavior of the lay-in panel ceiling system.
- Another potential enhancement would be to secure the ceiling tiles within the framing grid with magnets or positive connections, although there may not be an off-the-shelf solution available. Past experimental studies have shown that compression posts attached to the ceiling grids increase the chance of fallen panels due to the deck vibrations under large vertical component of ground motions. Therefore, the use of magnet panels or new shallow angle bracing system can significantly improve the seismic behavior of lay-in panel ceiling system in this regard.

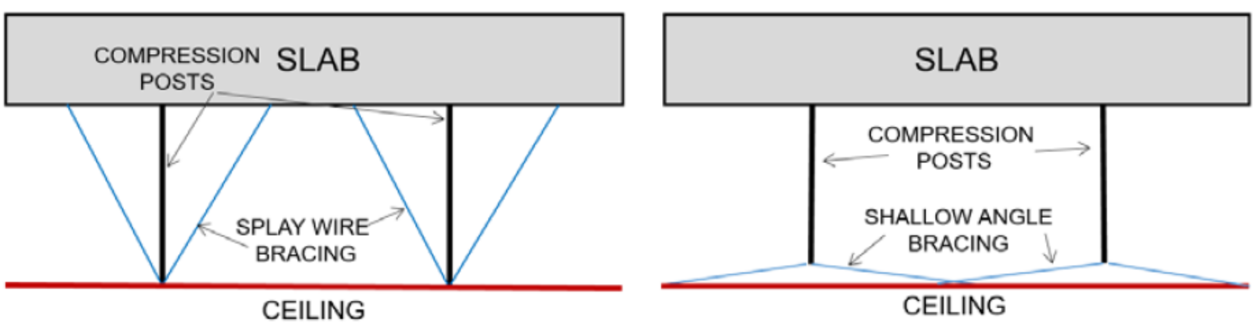

Figure 23. Schematic of Left: Current Bracing, and Right: New Shallow Angle Bracing System (Ryan, Pei, & Hutchinson, 2020)

Appendix D | Interior Partitions

D1 Background Information

Interior partition walls are generally non-load-bearing and are categorized as either heavy or light walls. Heavy partition walls are typically reinforced. Light partition walls are comprised of wood or metal studs with either a gypsum board or a lath and plaster finish. Figure 24 shows images of heavy and light partition wall systems.

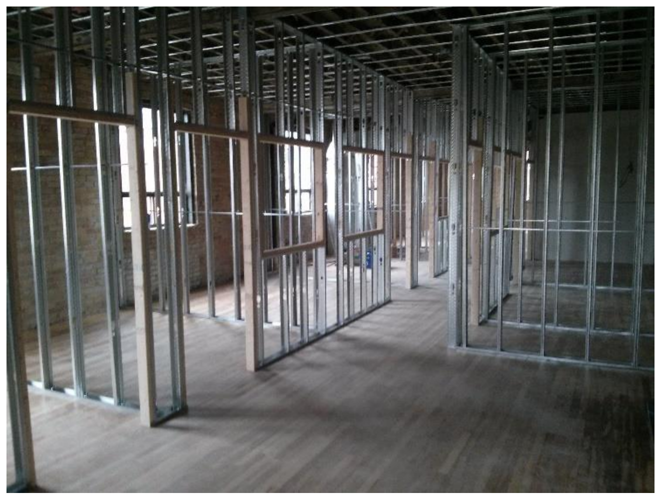

Figure 24. Examples of non-load-bearing interior partition wall systems: heavy partitions (left, photo from Bond Masonry Ltd.) and light partitions (right, photo from Centennial Drywall, Inc.).

D1.1 Associated Risks

- **Life-Safety:** The life-safety risk associated with seismic damage to partition walls is generally low, as damaged partitions typically do not pose a falling hazard. However, it is possible that out-of-plane wall failure may result in a falling hazard and blocked corridors and exits which would increase life-safety risks but this type of damage is unlikely.

- **Downtime:** Seismic damage to partition walls poses a low to medium risk to the continuation of building operations, depending on the type of partition and occupancy type. The associated risks may be higher if the walls enclose essential equipment or services (such as operating room). Damage to stair or shaft walls can similarly hinder the continued operations of a building. In facilities where partitions provide a barrier for sterilization, insulation, acoustics, security, or fire safety, damage to partitions may pose a high risk to the building functionality, especially where large gaps may form at partition corners. Typically, visible cracking of partitions does not cause downtime but may be repaired during building occupancy.

- **Repair Costs:** Costs associated with damage to partition walls and their respective contents range from low to high, depending on the type of partition, type of failure, and extent of damage.

D2 Baseline Design Requirements

D2.1 Design Loads

All interior partition wall systems should conform to the minimum requirements of the code and should adhere to guidelines presented in Section 2. The design of the anchorage, connections, bracing and supports should adhere to the requirements of the guidelines presented in Section 2.1.

For determination of the seismic demands on the partition wall system, the system weight should include an allowance for any items that will be supported on the partitions, such as shelving, equipment, etc.

D2.2 Detailing considerations

- Heavy partition walls are both acceleration-sensitive components (in the out-of-plane direction) and drift-sensitive components (in the in-plane direction). To reduce the demands on the walls due to the interstory drifts, an in-plane slip joint should be provided. This detail can be used with continuous or intermittent steel angles as shown in Figure 25.

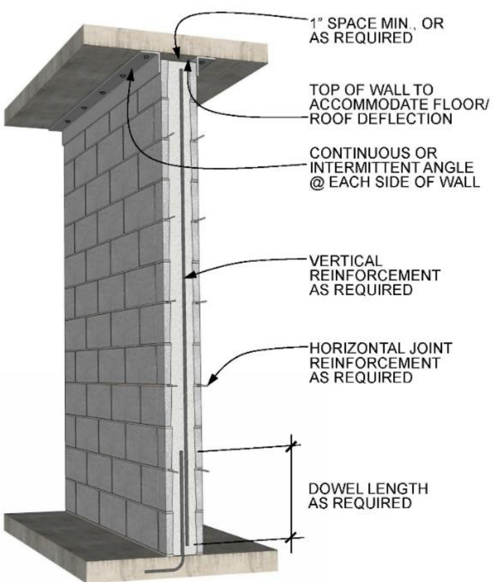

Figure 25. Examples of slip-joint details for heavy partition walls with continuous angles (left, photo from International Masonry Institute) and intermittent angles (right, photo from FEMA E-74).

- All partitions taller than 6 feet must be laterally braced to the structure, independent of any non-structural ceiling lateral bracing. In general bracing of partitions from the non-structural ceiling should be avoided, as it may increase the likelihood of damage to both the partitions and ceilings.
- For full-height light partition walls, the detailing of the partition top track connection is crucial to the nature and severity of the expected seismic damage. The differential movement of the top and base of the wall results in significant cracking in the plane of the wall when conventional top track detailing, also known as full-connection detailing (see Figure 26), is provided. Where possible, all partitions should be provided with in-plane slip-track detailing instead of full-connection detailing in order to reduce damage. In-plane slip-track details use a double-track or sliding connection to isolate the partition wall from movement of the floor above in the in-plane direction (see Figure 27). Careful consideration should be given to the intersection of perpendicular walls, as the perpendicular wall may still restrict movement, and damage may occur.

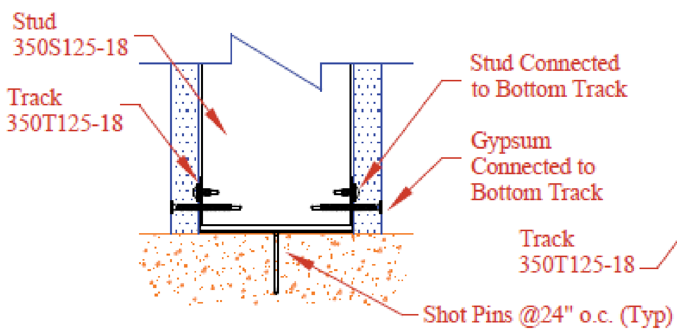

Figure 26. Full connection detailing for full-height light partition walls (Photo from FEMA P-58/BD-3.9.32).

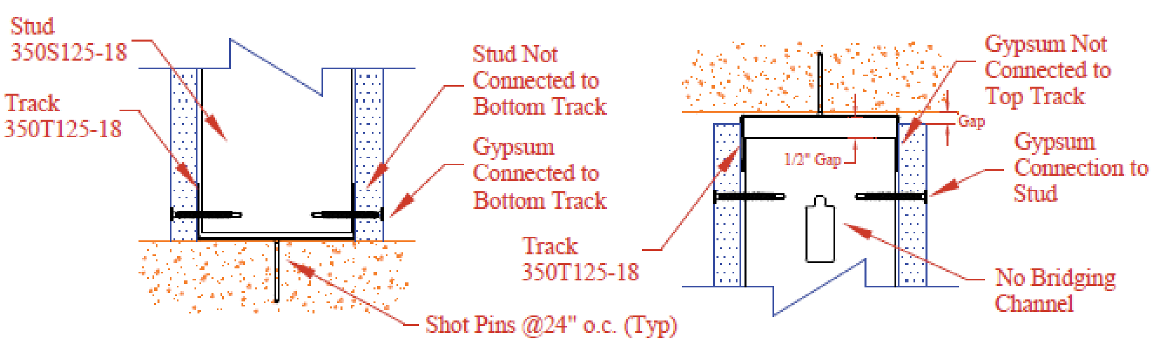

Figure 27. In-plane slip-track connection detailing for full-height light partition walls ((photo from FEMA P-58/BD-3.9.32).

- Heavy partial-height partitions are generally used as non-structural infill walls, exterior walls or guardrails. These walls should be self-supporting and isolated from the structural framing to avoid impact with or unintended restraint of the structural frame. An example is provided in Figure 28.

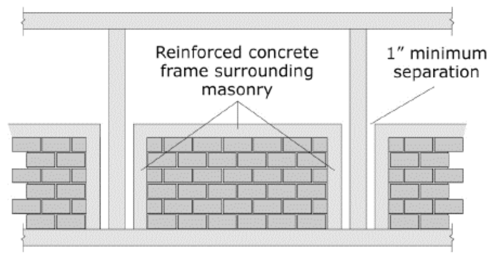

Figure 28. Schematic detailing for heavy partial-height partitions (Photos from FEMA E-74).

- In light partial-height partitions, rigid diagonal bracing is required in both orthogonal directions and should be independent of any suspended ceiling system bracing. An example is provided in Figure 29.

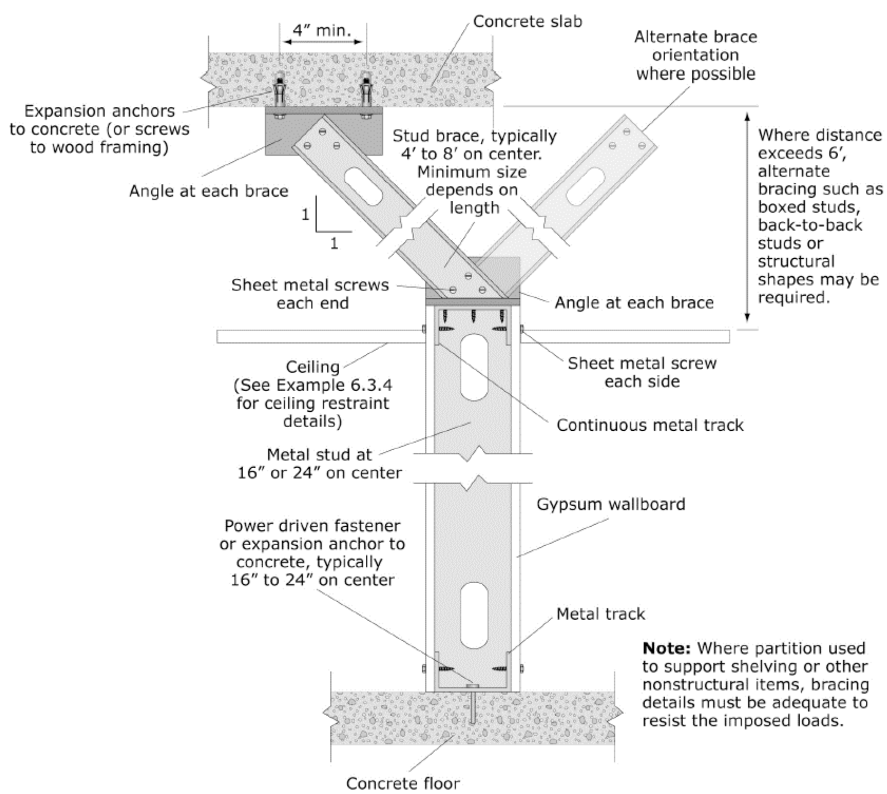

Figure 29. Schematic detailing for light partial-height partitions (Photos from FEMA E-74).

- Glazed partitions should be provided with "safety glazing" where provided in areas of egress, as this will reduce the life-safety and human injury risks in an earthquake. Special detailing may be required for glazing.

D3 Enhanced Design Solutions

D3.1 Detailing Considerations

Partition walls typically observe cracking, corner damage and joint separation at low interstory drift ratios. Low damage solutions continue to be the focus of many academic research studies. To date, there has been a lack of testing and validation of practical and constructible solutions proven to delay damage at wall corners when subject to bi-directional motion. The solutions presented herein aim to mitigate damage, but there is a lack of validation on the performance of these enhancements.

- One potential solution, aimed at mitigating corner damage, consists of corner gaps at wall corners and wall intersections. The studs and tracks are terminated at the face of the intersections, and the intersecting space is filled with mineral wool to help achieve acoustic and fire insulation. The corner gap detail is shown in Figure 30. The corner gap has been tested in conjunction with conventional in-plane slip track detailing in a study by Davies et. al. (2011), where the only damage observed was detachment of the corner beads at 0.2-0.4% drift levels. Corner bead damage is generally inconsequential to continued operations.

  This detailing was the subject of a recent test program, where similar behavior was observed for corner bead damage. Furthermore, the corner gap detail delayed substantial wall damage for up to 2% drift levels (Hasani & Ryan, n.d.). This study is still in review and has not yet been published.

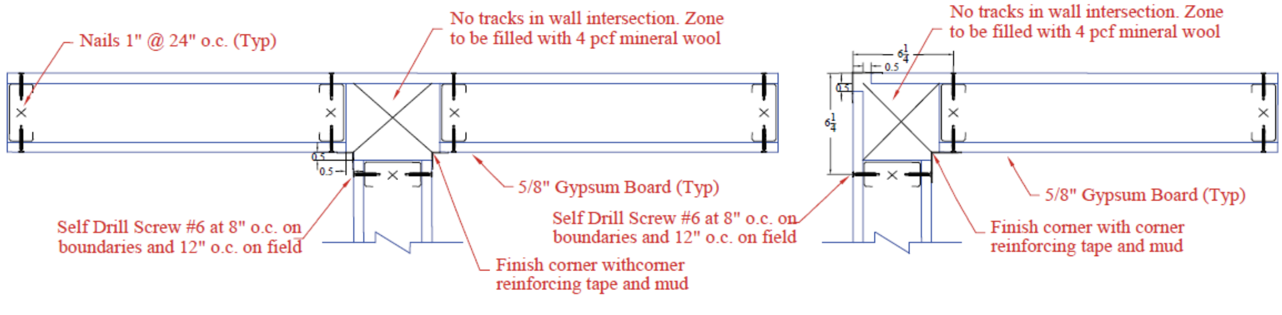

Figure 30. Corner gap detailing at wall intersections (left) and wall corners (right) (Davies, Retamales, Mosqueda, & Filiatrault, 2011)

- Another solution that is more challenging to achieve is sliding track connection detailing, which effectively isolates the partition wall from movement of the floor above in both the in-plane and out-of-plane directions. This may increase the drift compatibility of the partition walls for drift ratios of up to 1.5% (see Figure 31). The implementation of this detail may be challenging, as the track is a bespoke element that is not currently in production.

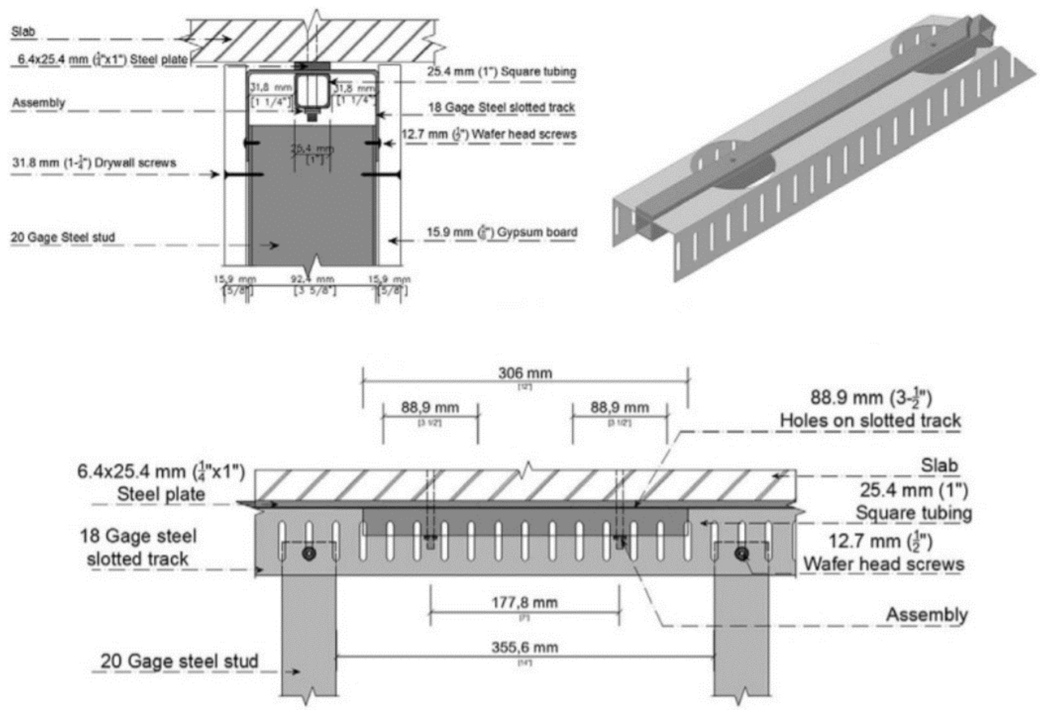

Figure 31. Sliding Connection Detail for Light Partition Walls (Araya-Letelier, Miranda, & Deierlein, 2019)

Appendix E | Egress Stairs

E1 Background Information

Stairs are the primary means of evacuation in a multistory building, and thus it is imperative that the integrity of the egress stairs is maintained during a seismic event.

E1.1 Associated Risks

- **Life-Safety:** The life-safety risk associated with seismic damage to stairs is high. Damaged stairs or blocked stairways can prevent occupants from safely exiting the building in the event of an earthquake.
- **Downtime:** Seismic damage to stairs pose a high risk to the continuation of building operations, depending on the extent of damage. In the event of complete collapse of the stairs, occupants will likely not able to safely enter or exit the building until the stairs are repaired, as elevators are also likely to be shutdown, which would preclude continued operations.
- **Repair Costs:** Costs associated with damage to stairs range from low to high, depending on the type of stair, type of failure, and extent of damage.

E2 Baseline Design Requirements

E2.1 Design Loads

All stairs should conform to the minimum requirements of the code and should adhere to guidelines presented in Section 2. The design of the anchorage and connections should adhere to the requirements of the guidelines presented in Sections 2.1 and 2.4.

E2.2 Detailing Considerations

The stair detailing should conform to the guidelines outlined in Section 2.4. Acceptable connections to accommodate the required seismic movement of the stairs consist of slip connections with bolts in slotted holes, sliding bearing connections, or ductile connections. When slip connections are provided, careful consideration should be given to the direction of the allowed slip movement. Examples of various slip connections with bolts in slotted holes are presented in Figure 32, Figure 33, and Figure 34.

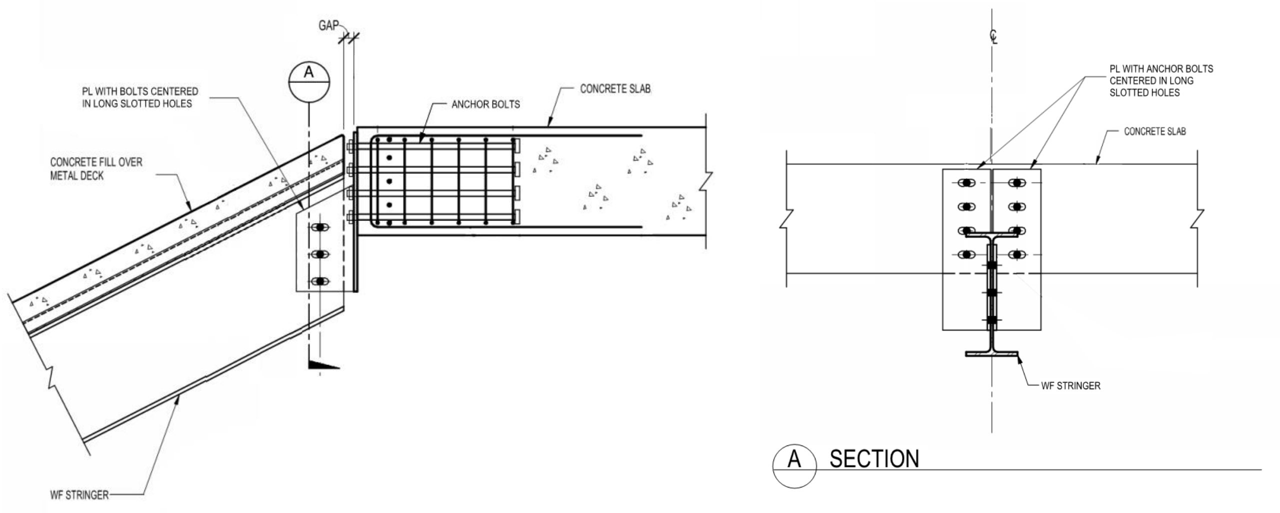

Figure 32. Example of a top slip connection that allows for movement in two directions (SEAOC Seismology Committee, 2018).

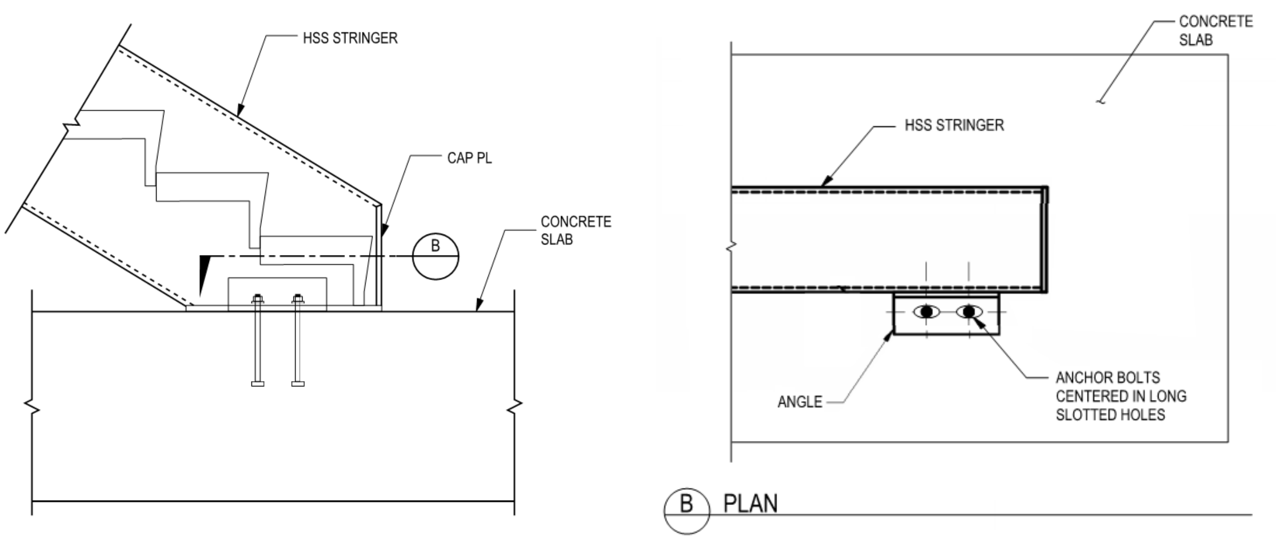

Figure 33. Example of a base slip connection that allows for movement only in the longitudinal direction of the stair (SEAOC Seismology Committee, 2018).

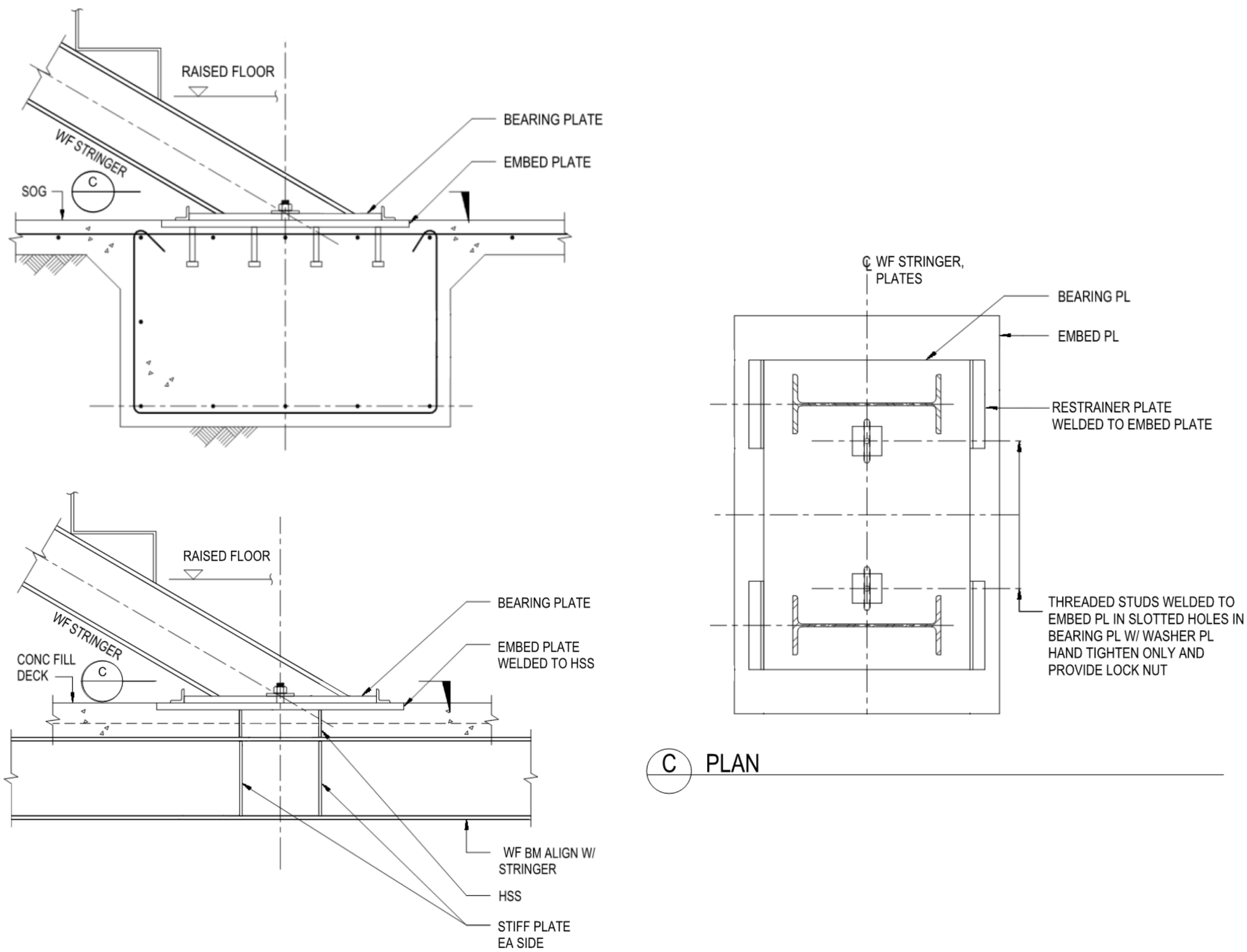

Figure 34. Examples of a base slip connection that allows for movement only in the direction transverse to the stair axis (SEAOC Seismology Committee, 2018).

Appendix F | Facades

F1 Background Information

Facades consist of a variety of systems, including curtain walls, large storefront windows, operable wood-framed windows, glass blocks, etc. Figure 35 shows curtain and glass block façade systems. Glass used in façade systems may be annealed, heat-strengthened, tempered, laminated or in-sealed, insulating glass units. The structural systems of facades are classified as fully-unitized (swaying behavior), hybrid-unitized (rocking behavior), and stick framing systems (racking behavior).


Figure 35. Examples of curtain walls (left, photo from Glasscon GmbH) and glass block facades (right, photo from Exterior Technologies, Inc.)

F1.1 Associated Risks

- **Life-Safety:** The life-safety risks associated with seismic damage to facades are medium to high. Failure of or detachment of facades create a falling hazard and could result in serious injury or death to both people standing outside and inside the building and to occupants evacuating the building. Code design provisions should preclude this type of failure.
- **Downtime:** Seismic damage to facades poses a medium to high risk to the continuation of building operations, as façade damage breaches the building envelope and exposes the interior building contents to the elements and leaves the interior building susceptible to wind and water damage during rain or storms, compromises the environmental conditions, and could lead to mold and/or condensation on electrical equipment and computers.
- **Repair Costs:** The cost associated with façade repair and replacement, and repair of the consequential damage to interior building contents, can range between medium and high.

F2 Baseline Design Requirements

F2.1 Design Loads

Façade systems and their respective components should conform to the minimum requirements of the code and should adhere to guidelines presented in section 2. The design of the anchorage, connections, bracing and supports should adhere to the requirements of the guidelines presented in Section 2.1.

F2.2 Performance Requirements

- The façade shall accommodate interstory drifts associated with 475 year shaking with no damage. Connections should remain elastic and the building envelope should remain effective in preventing air and water intrusion. Some damage at discontinuities such as corners and transitions may be allowed provided it is easily reparable and does not compromise the internal environment. As stated in Section 2.2, the EDPs used for design should be the mean + 1 standard deviation (84^{th} percentile) demands from a suite of ground motions if using response history analysis, or 1.5x the mean demands if the EDPs are derived from modal analysis.
- The façade shall be designed to achieve life safety performance objectives and experience no glass fallout when subject to 2475 year interstory drifts (mean + 1 standard deviation).
- The façade suppliers typically have prior analysis and/or test data to ensure the performance objectives stated above are achieved with their respective systems. Analysis is an acceptable method of confirmation for most sealed façade systems. However, testing will be required for all proposed interlocking gasket and for any bespoke systems and details.
- Where testing is required, the façade consultant and/or engineer should provide a testing specification. At a minimum, the façade conditions provided in the test should include the following:
    - All typical framing conditions
    - A corner condition
    - Bespoke details

F2.3 Detailing Considerations

- There are several proprietary products built that allow for the translation and rotation of glass panels to accommodate the expected building deformations. The anticipated behavior of the glass in an earthquake, along with an indicative connection is presented in Figure 36.

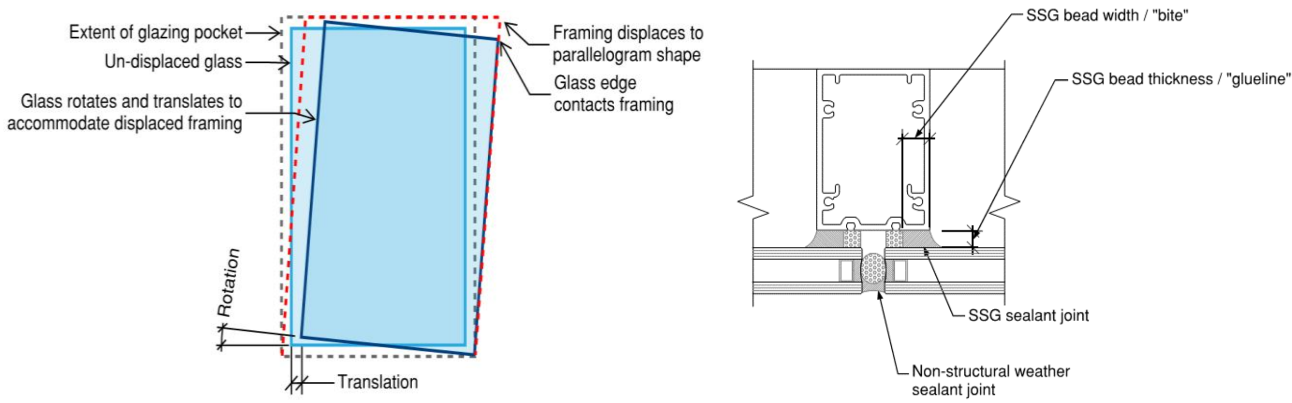

Figure 36. Glass translation and rotation mechanisms (left), and a sample connection (right) that allows for this type of movement.

- Where glass blocks are used, the glass block panel should be isolated from the structure for interstory drifts. Panels should be supported for both in-plane and out-of-plane forces but should be isolated from the movement of the surrounding structure. To decouple the blocks from the surrounding structure while still maintaining in-plane and out-of-plane support of the block panels, these blocks should be attached with mortar to the sill at the panel base, and slip joints should be provided along the top and sides of the panel as shown in Figure 37. Additionally, horizontal steel reinforcement should be provided in alternate mortar joints.

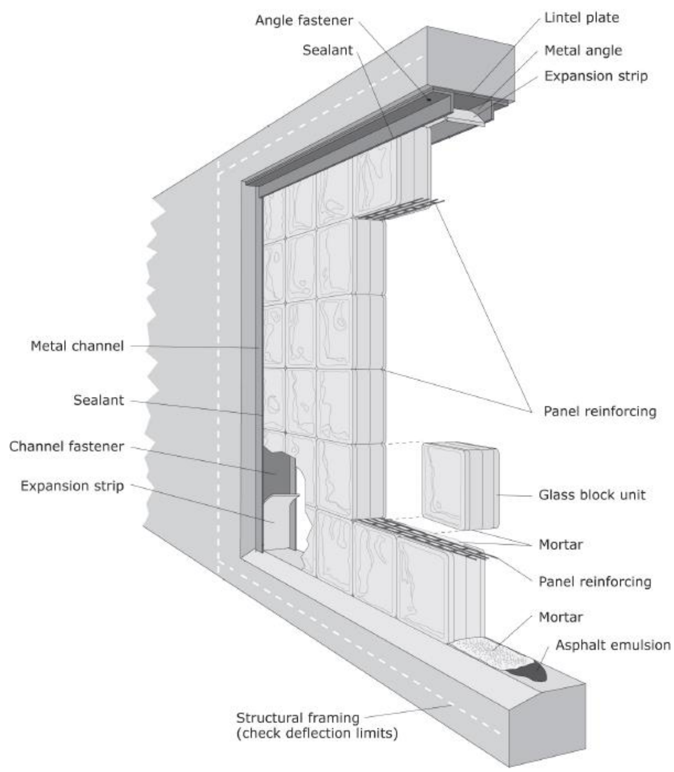

Figure 37. Typical glass block panel support details (photo from FEMA E-74).

F3 Enhanced Design Solutions

- Well-engineered façade systems can typically tolerate high inter-story drift ratios. In many cases, façade vendors and consultants provide special engineering and design services to ensure an enhanced system. This approach is recommended where drifts are high due to flexible systems such as moment frames.

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