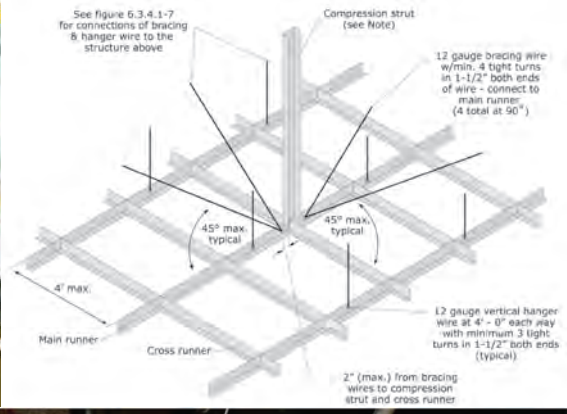






Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide

FEMA E-74 / December 2012

FEMA

nehrp

PREFACE

Under its ongoing "Seismic and Multi-Hazard Technical Guidance Development and Support" contract (HSFEHQ-04-D-0621) with the Federal Emergency Management Agency (FEMA), the Applied Technology Council (ATC) was awarded a task to update the third edition of the FEMA 74 report, *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide*, issued by FEMA in 1994. This project was designated the ATC-69 project and completed in 2012.

This fourth edition of the FEMA 74 document (renamed FEMA E-74) explains the sources of earthquake damage that can occur in nonstructural components and provides information on effective methods for reducing risk associated with nonstructural earthquake damage. It is intended for use by a nontechnical audience that includes building owners, facility managers, maintenance personnel, store or office managers, corporate or agency department heads, and homeowners. FEMA E-74 updates both the content and the format of the report. A considerable amount of new information now exists as a result of ongoing National Earthquake Hazard Reduction Program (NEHRP) activities, local and state government programs, private sector initiatives, and academic work focused on reducing the potential for nonstructural earthquake damage. In addition, the document has been redesigned for use on the internet. The new format makes it simple to browse, review focused information, print selected details and download spreadsheets, checklists and other useful tools.

TABLE OF CONTENTS

Preface i

Chapter 1. Introduction 1-1
1.1 Purpose 1-1
1.2 Intended Audience 1-1
1.3 Regional Applicability 1-5
1.4 Limitations 1-6
1.5 Acknowledgements 1-7

Chapter 2. Behavior of Nonstructural Components 2-1
2.1 Definitions 2-2
2.1.1 Structural Components 2-2
2.1.2 Nonstructural Components 2-2
2.1.3 Relative Costs 2-5
2.2 Causes of Nonstructural Damage 2-6
2.2.1 Inertial Forces 2-6
2.2.2 Building Deformations 2-7
2.2.3 Building Separations 2-8
2.2.4 Nonstructural Interaction 2-10
2.3 Extent of Nonstructural Damage 2-10
2.4 Importance of Nonstructural Damage 2-12
2.4.1 Life Safety (LS) 2-13
2.4.2 Property Loss (PL) 2-18
2.4.3 Functional Loss (FL) 2-19
2.5 Common Types of Nonstructural Earthquake Damage 2-22
2.5.1 Life Safety 2-22
2.5.2 Property Loss 2-26
2.5.3 Functional Loss 2-28

Chapter 3. Survey and Assessment Procedures for Existing Buildings 3-1
3.1 Survey of Nonstructural Components 3-1
3.1.1 Survey Forms 3-3
3.2 Estimating Seismic Risk 3-6
3.2.1 Estimating Seismic Shaking Intensity 3-6
3.2.2 Estimating Seismic Risk Ratings 3-9
3.2.3 Assigning Priority Ratings 3-10
3.2.4 Application of Nonstructural Guidelines 3-10

Chapter 4. Nonstructural Risk Reduction for Existing Buildings 4-1
4.1 Program Objectives and Scope 4-1
4.1.1 Voluntary vs. Mandatory Risk Reduction 4-2
4.1.2 Performance-Based Design Concepts 4-3
4.1.3 Legal Considerations 4-10
4.2 Design Considerations 4-11
4.3 Project Planning and Implementation Strategies 4-13
4.3.1 Integration with Maintenance Programs 4-15
4.3.2 Integration with Remodeling 4-15
4.3.3 Phased or Incremental Upgrading 4-16
4.3.4 Integration with Purchasing 4-16
4.4 Responsibility and Program Management 4-16
4.4.1 Responsibility 4-16

4.4.2 Sustaining Protection 4-20
4.4.3 Program Evaluation 4-20
4.5 Cost Benchmarks—Examples 4-21
4.5.1 Example 1 – Manufacturing Facility 4-21
4.5.2 Example 2 – School District 4-22
4.5.3 Example 3 – California Hospital 4-23

Chapter 5. Nonstructural Risk Reduction for New Buildings 5-1
5.1 Program Objectives and Scope 5-1
5.1.1 Voluntary vs. Mandatory Risk Reduction 5-3
5.1.2 Performance-Based Design Concepts 5-4
5.2 Design Considerations 5-6
5.3 Building Code Requirements 5-7
5.3.1 2012 Edition of the International Building Code (IBC 2012) 5-7
5.3.2 Enforcement of Code Requirements 5-11
5.3.3 Requirements for Contents 5-13
5.3.4 Other Standards and Protocols 5-13
5.3.5 Validation and Refinement of Code Requirements 5-14
5.4 Responsibility and Project Management 5-14
5.4.1 Example: Responsibility Matrix 5-16
5.4.2 Example: Seismic Code Block, Saint Louis County, Missouri 5-17

Chapter 6. Seismic Protection of Nonstructural Components 6-1
6.1 Protective Measures 6-1
6.1.1 Common Sense Measures 6-1
6.1.2 Nonstructural Component Protection Measures 6-2
6.1.3 Building Protection Measures 6-4
6.2 Nonstructural Component Examples 6-5
6.2.1 Typical Mitigation Details 6-6
6.3 Architectural Components 6-11
6.3.1 Exterior Wall Components 6-11
6.3.2 Interior Partitions 6-58
6.3.3 Interior Veneers 6-89
6.3.4 Ceilings 6-94
6.3.5 Parapets and Appendages 6-130
6.3.6 Canopies, Marquees, and Signs 6-136
6.3.7 Chimneys and Stacks 6-139
6.3.8 Stairways 6-144
6.3.9 Freestanding Walls or Fences 6-154
6.4 Mechanical, Electrical, and Plumbing (MEP) Components 6-162
6.4.1 Mechanical Equipment 6-163
6.4.2 Storage Tanks and Water Heaters 6-203
6.4.3 Pressure Piping 6-237
6.4.4 Fire Protection Piping 6-314
6.4.5 Fluid Piping, Not Fire Protection 6-325
6.4.6 Ductwork 6-346
6.4.7 Electrical and Communications Equipment 6-360
6.4.8 Electrical and Communications Distribution Equipment 6-406
6.4.9 Light Fixtures 6-416
6.4.10 Elevators and Escalators 6-448
6.4.11 Conveyors 6-476
6.5 Furniture, Fixtures, and Equipment (FF&E) and Contents 6-482
6.5.1 Storage Racks 6-482
6.5.2 Bookcases, Shelving 6-501

6.5.3 Computer and Communication Equipment....6-518
6.5.4 Hazardous Materials Storage....6-544
6.5.5 Miscellaneous Furniture, Fixtures, and Equipment....6-550
6.5.6 Miscellaneous Contents....6-566
6.6 Installation Notes, Safety Warnings, and Additional Guidelines....6-587
6.6.1 Positive Connections....6-587
6.6.2 Typical Wall Attachment Details....6-588
6.6.3 Typical Floor and Ceiling Attachment Details....6-592
6.6.4 Typical Shelf or Countertop Attachment Details....6-594
6.6.5 Purchasing....6-595
6.6.6 Patching, Painting, and Corrosion Protection....6-595
6.6.7 Safety Precautions....6-596
6.6.8 Electrical Danger Warnings and Guidelines....6-596

Chapter 7. Post-Earthquake Data Collection....7-1

Appendix A. Specification....A-1

Appendix B. Responsibility Matrix....B-1

Appendix C. Nonstructural Inventory Form....C-1

Appendix D. Checklist of Nonstructural Seismic Hazards....D-1

Appendix E. Nonstructural Seismic Risk Ratings....E-1

Appendix F. Post-Earthquake Data Collection Forms....F-1

Appendix G. List of Resources Related to Nonstructural Components....G-1

Appendix H. Glossary....H-1

Appendix I. References....I-1

Appendix J. Project Participants....J-1

1. INTRODUCTION

This chapter of the document describes the purposes of this e-document and describes the intended audience for the e-document.

1.1 Purpose

Nonstructural failures have accounted for the majority of earthquake damage in several recent U.S. earthquakes. Thus, it is critical to raise awareness of potential nonstructural risks, the costly consequences of nonstructural failures, and the opportunities that exist to limit future losses. Nonstructural components of a building include all of those components that are not part of the structural system; that is, all of the architectural, mechanical, electrical, and plumbing systems, as well as furniture, fixtures, equipment, and contents. Windows, partitions, granite veneer, piping, ceilings, air conditioning ducts and equipment, elevators, computer and hospital equipment, file cabinets, and retail merchandise are all examples of nonstructural components that are vulnerable to earthquake damage. The primary purpose of this guide is to explain the sources of nonstructural earthquake damage and to describe methods for reducing the potential risks in simple terms.

1.2 Intended Audience

This guide is intended for use by a non-engineer audience located within the United States; this audience includes building owners, facility managers, maintenance personnel, store or office managers, corporate or agency department heads, business proprietors, risk managers, and safety personnel. The guide is also designed to be useful for design professionals, especially those who are not experienced with seismic protection of nonstructural components. It addresses nonstructural issues typically found in schools, office buildings, retail stores, hotels, data centers, hospitals, museums, and light manufacturing facilities. It is not intended as a guide for homeowners. How to make homes safer from earthquakes is covered in FEMA 232 *Homebuilders' Guide to Earthquake-Resistant Design and Construction* (2006). This document is also not intended to address nonstructural issues relevant to heavy manufacturing, specialized industrial manufacturing, or power generation facilities.

The guide is aimed at a wide audience with varying needs. Some readers may be small business owners with a limited number of potential problems, which could be addressed in a few days by hiring someone to install some of the non-engineered or prescriptive details that are presented in Chapter 6 of this guide. Other readers may be responsible for hundreds of facilities and may

need a survey methodology like the one described in Chapter 3, to help them understand the magnitude of their potential risk. For those who need to implement nonstructural details, the specification and responsibility matrices in Appendices A and B can be used to clarify the scope of work and assign parties responsible for implementation. The prospective audience can be subdivided into the following four general categories:

- General Interest—the non-engineer reader who wants an illustrated overview of the subject of nonstructural earthquake damage.
- Small Business Owner—the reader who wants a general overview of the subject, along with help in identifying potential risks and specific guidance on suggested protective measures that the reader can implement on his or her own. This may be all that is required for a small business or simple facility, if the items can be addressed using the non-engineered or prescriptive details shown in Chapter 6.
- Facilities and Planning Personnel—the reader who needs an overview of the subject, as well as a survey methodology that is applicable to an organizational setting. This guide contains forms and checklists that can be used to survey a facility, in order to identify potential risks and to estimate seismic vulnerability and potential earthquake losses. The guide includes suggestions for both existing and new construction and differentiates between methods that can be readily implemented by a handy worker following the non-engineered and prescriptive details in Chapter 6 and methods that require professional design assistance and additional engineered details.
- Architect or Engineer—the architect or engineer who has limited knowledge of nonstructural earthquake damage and who needs an introduction to the subject, along with a list of resources that will provide more detailed technical information. For this audience, the examples provided in Chapter 6 may serve as a starting point or conceptual design for common conditions; calculations may be required to size members and connection hardware for each particular situation. Each example contains brief summaries of the nonstructural bracing requirements in the codes that govern the design of new buildings and the

General Interest Sidebar

This style of sidebar is used in this guide to provide additional clarification or examples for the general interest reader.

Technical Sidebar

This style of sidebar is used in this guide to provide additional technical details for architects and engineers.

seismic strengthening of existing buildings. The specification and responsibility matrices in Appendices A and B are also targeted for this audience; these are tools intended to help clarify the scope of work and assign responsibility for the various tasks involved.

Table 1.2-1 below is intended to help readers identify those portions of the guide that may apply to their particular situation and interests. The chapters and their respective audiences are intended to be helpful, not restrictive. Readers are encouraged to use this guide and to adapt the forms and checklists herein in any way that is helpful to their particular circumstances. The flowchart on the following page provides some additional guidance on how to use this document. While earlier editions of FEMA 74 were aimed at a more general audience, the 4th edition has been greatly expanded to assist owners, facility managers, and design professionals implement nonstructural mitigation programs. A flowchart is also provided in Figure 1.2-1 to help readers identify portions of the guide that may apply to their situation.

Table 1.2-1 How to use this guide

Chapter Title	General Interest	Small Business Owner	Facilities and Planning Personnel	Architect or Engineer
Chapter 1. Introduction	X	X	X	X
Chapter 2. Behavior of Nonstructural Components	X	X	X	X
Chapter 3. Survey and Assessment Procedures for Existing Buildings		X	X	X
Chapter 4. Nonstructural Risk Reduction for Existing Buildings			X	X
Chapter 5. Nonstructural Risk Reduction for New Buildings			X	X
Chapter 6. Seismic Protection of Nonstructural Components	X	X	X	X
Chapter 7. Post-Earthquake Data Collection	X		X	X
Appendix A. Specification				X
Appendix B. Responsibility Matrices				X
Appendix C. Survey Form		X	X	X
Appendix D. Checklist		X	X	X
Appendix E. Risk Ratings		X	X	X
Appendix F. Post-Earthquake Data Collection Forms	X		X	X
Appendix G. Resources				
Appendix H. Glossary				

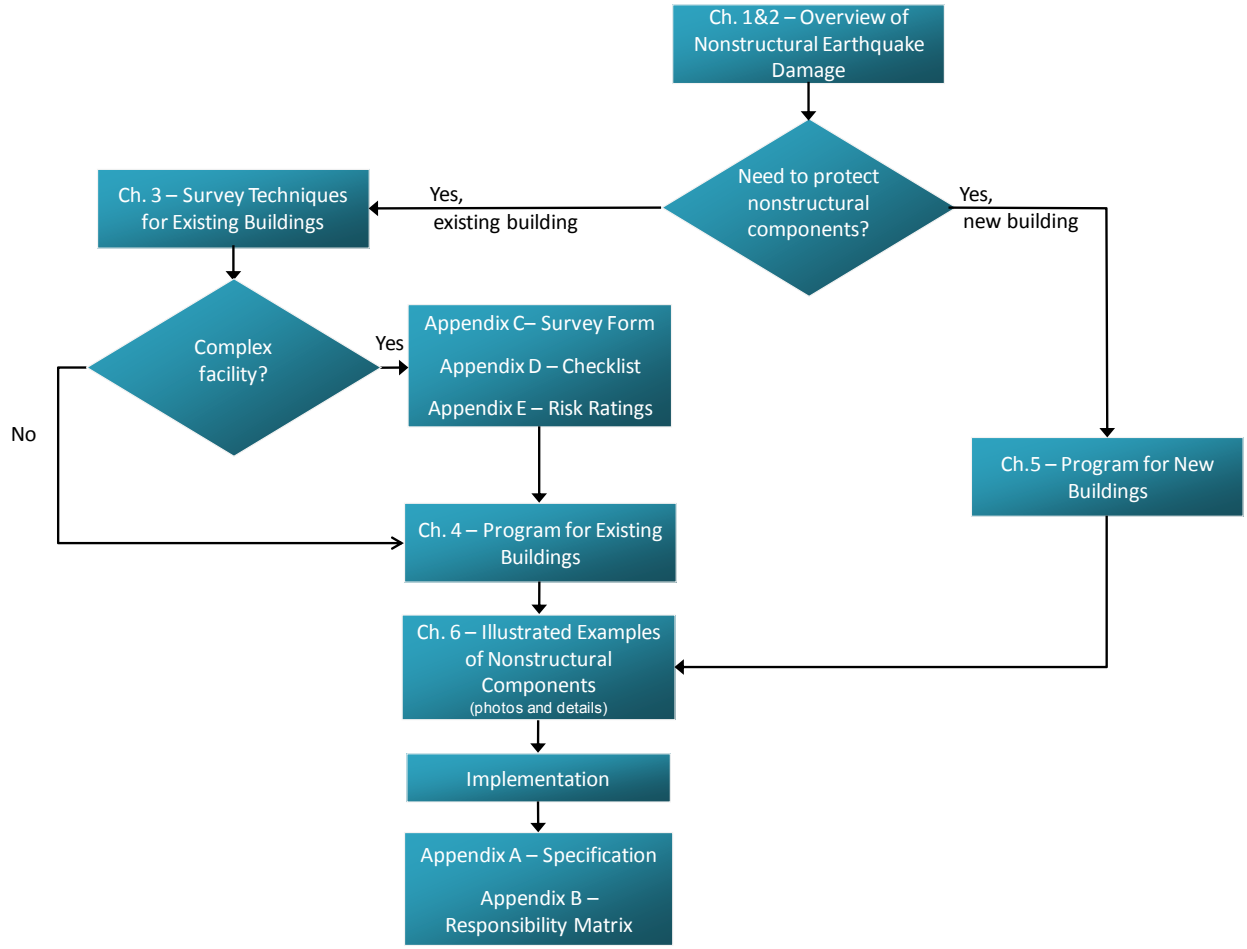


Figure 1.2-1 Flowchart describing the relationship of document chapters and appendices. The forms discussed in Chapter 7 and provided in Appendix F can be used

1.3 Regional Applicability

Different geographic areas of the U.S. are likely to experience different levels of seismic shaking in future earthquakes. In conjunction with the Probable Shaking Intensity Map shown in Figure 3.2.1-1, the following considerations will help to determine if these guidelines are applicable to your facility:

- If the Shaking Intensity Map indicates that the building site is located in an area with minimal level of shaking, then the seismic hazard risk is extremely low and thus seismic anchorage and bracing of nonstructural components is not considered necessary.
- If the Shaking Intensity Map indicates that the building site

Essential Facilities

Hospitals, fire, rescue, and police stations, emergency vehicle garages, and designated emergency shelters are examples of essential facilities that require special design considerations.

is located in an area with low level of shaking and if the facility is not an essential type facility, then only parapets and exterior unreinforced masonry walls should be considered for seismic retrofit.

- If the Shaking Intensity Map indicates that the building site is located in an area denoted with moderate level of shaking, and if the facility is not an essential type facility, then only architectural components should be considered for seismic retrofit; anchorage and bracing for other nonstructural components may not be necessary.
- If the Shaking Intensity Map indicates that the building site is located in an area denoted with high level of shaking, then adequate retrofitting of all nonstructural component items should be considered.

If in doubt about the applicability of these guidelines to a particular case, then it may be useful to check the requirements in ASCE/SEI 7-10 *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2009) for new construction. If the nonstructural component does not require bracing for new construction at the site, then it may not be necessary to brace this component in existing construction, pending consideration of the specific risks posed by potential damage.

1.4 Limitations

This guide advises users on how to identify nonstructural hazards and how to implement earthquake protection measures. Earthquake engineering expertise is often desirable when identifying and reducing earthquake risks, and in some situations, it is required. This guide attempts to provide advice regarding earthquake protection measures and presumes that the advice will be applied wisely, and that expert assistance will be obtained whenever necessary.

When in doubt about the seismic vulnerability of a facility, one should consult a civil or structural engineer or an

Limitations of the Non-engineered Approach

If this guide explained how a person could administer his or her own health exam, diagnose any health problems, and prescribe and administer appropriate treatment, then an obvious question would arise: How far can an untrained person proceed before requiring the services of a physician? While doctors commonly recommend many self-help measures, such as taking one's own temperature and treating minor colds with home remedies, it is important to recognize when one has exceeded the limits of commonsense measures and needs to seek the advice of a medical professional.

When in doubt about a health problem, consult a medical professional.

When in doubt about the "seismic health" of a facility, consult a civil or structural engineer or architect.

architect with specific training and expertise related to the evaluation and mitigation of nonstructural earthquake hazards.

1.5 Acknowledgements

This document was originally completed in 2011 under the ATC-69-1 project. ATC gratefully acknowledges the ATC-69-1 Project Management Committee, including Maryann Phipps, Cynthia Perry, Robert Bachman, James Carlson, Eduardo Fierro, and Richard Kirchner for their efforts in researching and developing the material contained in this report. The Project Review Panel, consisting of Tim Brown, Mary Comerio, David Conover, Doug Fitts, Michael Griffin, John Henry, Robert Reitherman, and Jeffrey Soulages, provided technical review, advice and consultation at key stages of the work. In addition, Dawn Anderson, Jon Gregg, and Eric Peabody provided review comments for Appendices A and B.

While the ATC-69-1 Project aimed to include as many photographs of damage to nonstructural components during earthquakes that occurred in 2010 (Chile, New Zealand) and 2011 (New Zealand and Japan), the development timeframe did not allow for a thorough study of all lessons learned and data collected from these earthquakes to be incorporated in the FEMA E-74 document. Thus, the ATC-69-2 project developed an update to FEMA E-74 in 2012. ATC gratefully acknowledges the ATC-69-2 Project Management Committee, including Maryann Phipps, Robert Bachman, John Gillengerten, William Holmes, and Eduardo Miranda. In addition, Philip Caldwell provided technical review comments. Ayse Hortacsu and Thomas McLane served as ATC project managers for this work. The affiliations of these individuals are provided in the list of project participants.

ATC also gratefully acknowledges Mike Mahoney and Cathleen Carlisle (FEMA Project Monitors) and Barry Welliver (Subject Matter Expert) for their input and guidance in the preparation of this report, Peter N. Mork for ATC report production services, Scott Hiner for the expert graphics, and Steven Kuan as ATC Board Contact on this project.

2. Behavior of Nonstructural Components

Effective seismic risk reduction strategies for nonstructural component damage begins by clearly understanding the scope and nature of nonstructural components in buildings, their behavior in earthquakes, and the consequences of damage. The next section will address the following key questions:

- What are nonstructural components?
- What are the primary causes of damage to nonstructural components during earthquakes?
- What is the significance of nonstructural component damage?
- Which nonstructural components are most vulnerable in an earthquake?
- What are the consequences of damage to nonstructural components?

A picture is worth a thousand words.

The Hyogo Earthquake Engineering Research Center in Japan has posted video footage of shake table testing of nonstructural components during a simulated earthquake. Two of these video clips speak volumes about the hazards of nonstructural components during an earthquake. The video clips focus on the behavior of furniture, contents, and some architectural components.



Figure 2-1 Result of shaking table test on room contents (from 01, 2008 test)

Click on the link below and select one of the following video clips:

-Shaking table tests on room safety issue of a high-rise building (01, 2008)

-Shaking table tests on non-structure furniture in a high-rise building (03, 2007)

http://www.bosai.go.jp/hyogo/movie.html - click on English and then click on Movies. Scroll down to Office Space in High Rise Jan 2008 - Click on Video

2.1 Definitions

Buildings consist of both "structural" and "nonstructural" components. The distinction between the two types of building components is described below.

2.1.1 Structural Components

The structural components of a building resist gravity, earthquake, wind, and other types of loads and typically include the following elements:

- vertical supports such as columns, posts, pillars, and pilasters
- horizontal supports such as trusses, girders, beams, joists, and purlins
- load-bearing walls that provide vertical support or lateral resistance
- diagonal elements such as braces
- floor and roof slabs, sheathing or decking
- foundation systems such as slabs on grade, mats, spread footings, or piles

The structural system of buildings is typically analyzed and designed by a civil or structural engineer and is presented on construction drawings or plans, except in the case of houses. The structural components of a typical building can be seen on Figure 2.1.2-1 by clicking on the "structural components only" button.

2.1.2 Nonstructural Components

The nonstructural components of a building include all building parts and contents except for those previously described as structural. These components are generally specified by architects, mechanical engineers, electrical engineers, and interior designers. However, they may also be purchased and installed directly by owners or tenants after construction of a building has been completed. In commercial real estate, the architectural and mechanical, electrical, and plumbing systems may be considered a permanent part of the building and belong to the building owner; the furniture, fixtures, equipment and contents, by contrast, typically belong to the building occupants.

In this guide, nonstructural components are divided into three broad categories:

Architectural COMPONENTS such as partitions, ceilings, storefronts, glazing, cladding, veneers, chimney, fences, and architectural ornamentation.

Mechanical, electrical, AND PLUMBING (MEP) COMPONENTS such as pumps, chillers, fans, air handling units, motor control centers, distribution panels, transformers, and distribution systems including piping, ductwork and conduit.

Furniture, Fixtures & Equipment (FF&E), And contents such as shelving and book cases, industrial storage racks, retail merchandise, books, medical records, computers and desktop equipment, wall and ceiling mounted TVs and monitors, file cabinets, kitchen, machine shop or other specialty equipment, industrial chemicals or hazardous materials, museum artifacts, and collectibles.

The list of nonstructural components is nearly endless and constantly evolving, as new technologies alter our built environment. Figure 2.1.2-1 displays a typical building with nonstructural components discussed in this document, along with typical structural components. Clicking the "structural components only" button strips away the layer of nonstructural components to emphasize the ubiquity of architectural, MEP, and FF&E components in the built environment.

Note that most structural components are typically concealed from view by nonstructural materials, such as architectural finishes. For example, in steel construction, fireproofing is typically applied directly to steel members and then covered with finish materials such as gypsum board. In wood construction, there is usually no way to visually distinguish between a non-load-bearing partition and a structural or shear wall. Steel diagonal braces are often hidden inside walls. Similarly, mechanical, electrical, and plumbing components are also typically concealed by architectural components.

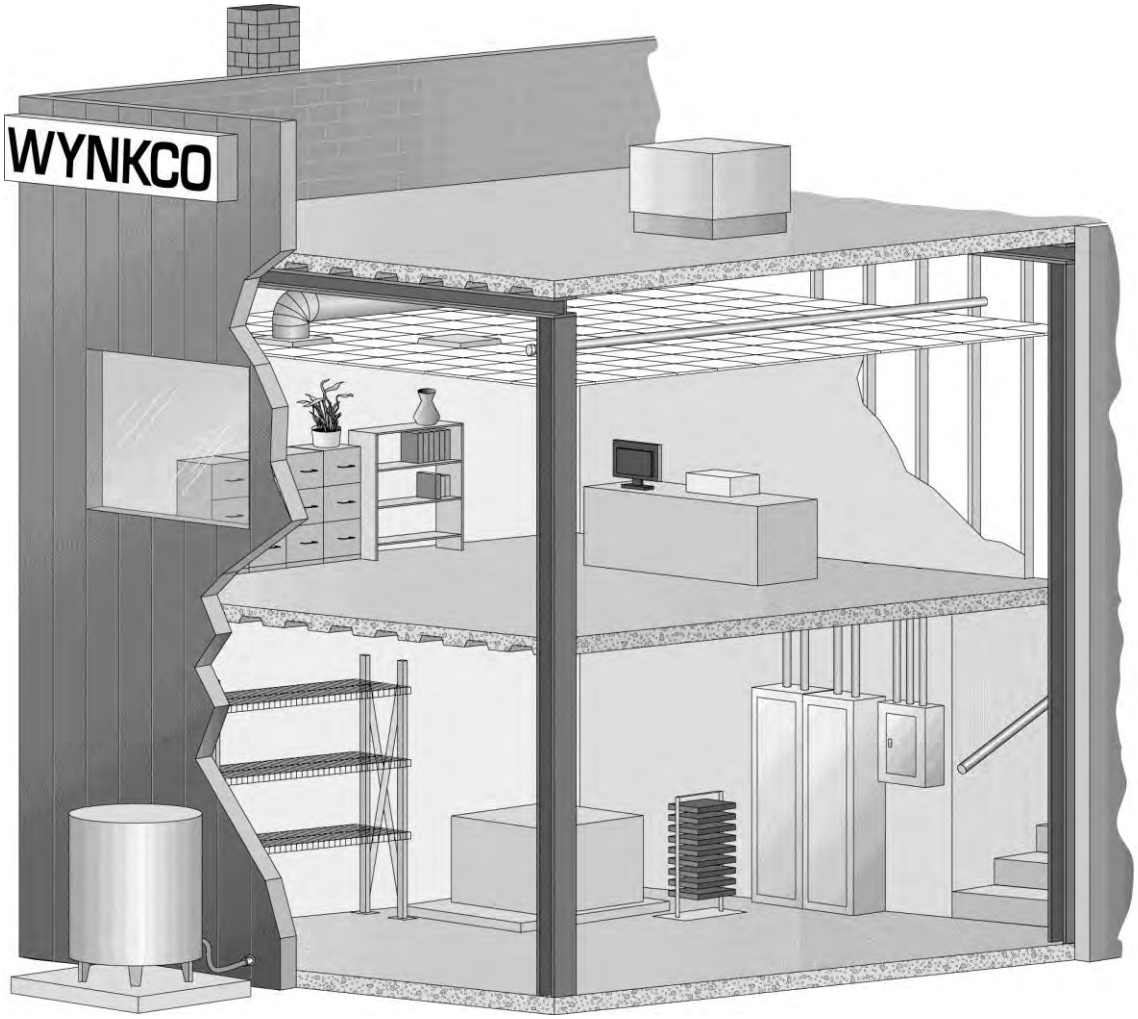


Figure 2.1.2-1 A three-dimensional view of a portion of a building. This figure shows both structural and nonstructural components.

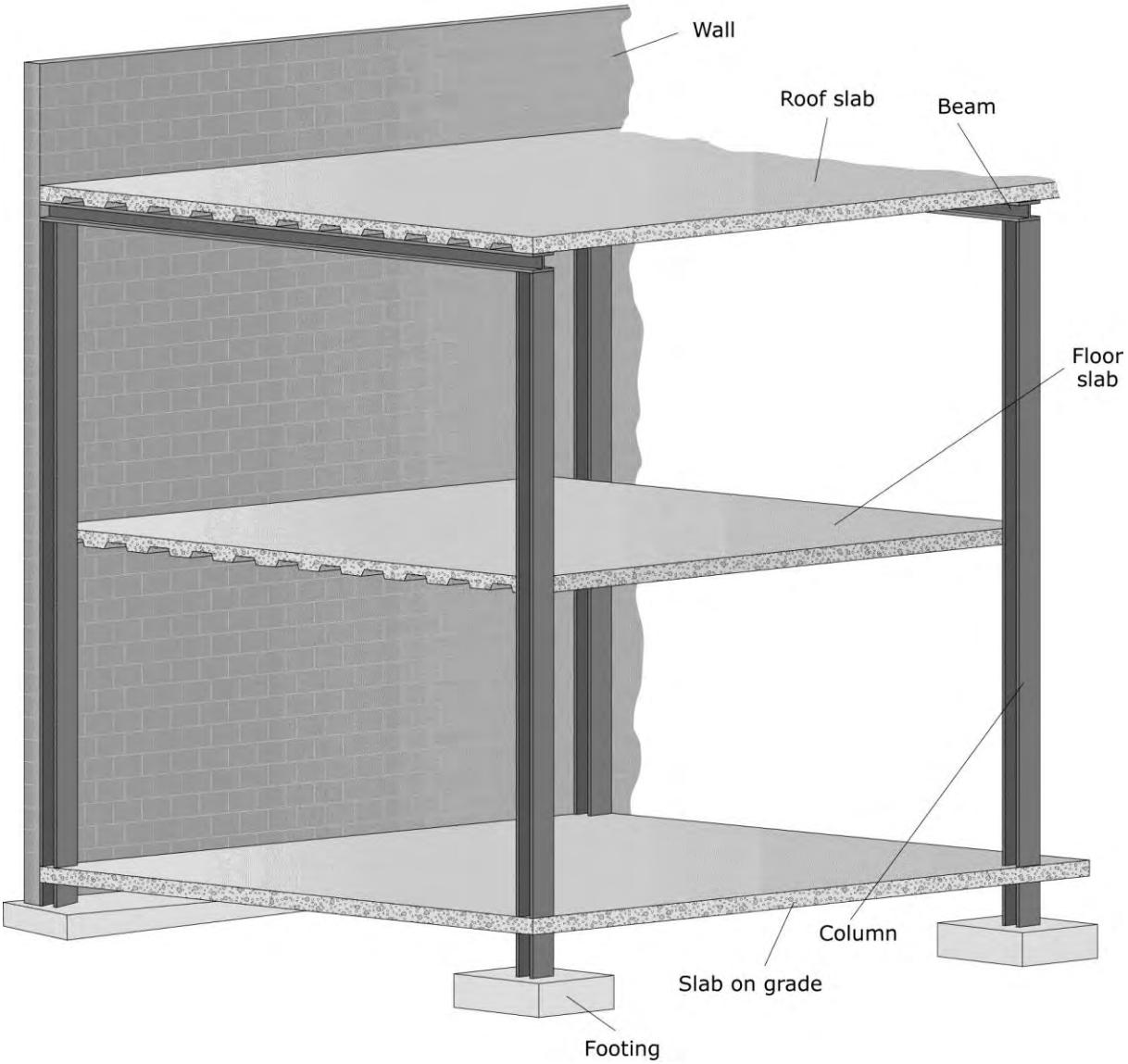


Figure 2.1.2-2 A three-dimensional view of a portion of a building showing structural components only.

2.1.3 Relative Costs

In general, the structural components of a commercial building account for approximately 15–25% of the original construction cost, while the nonstructural (mechanical, electrical, plumbing, and architectural) components account for the remaining 75–85% of the cost. Contents belonging to the building occupants, such as movable partitions, furniture, and office or medical equipment, represent a significant additional value at risk. When these costs are compared, it becomes clear that the largest capital investment in most commercial buildings is in the nonstructural systems and contents. This is illustrated in Figure 2.1.3-1 below for three common types of commercial construction (Whittaker and Soong, 2003).

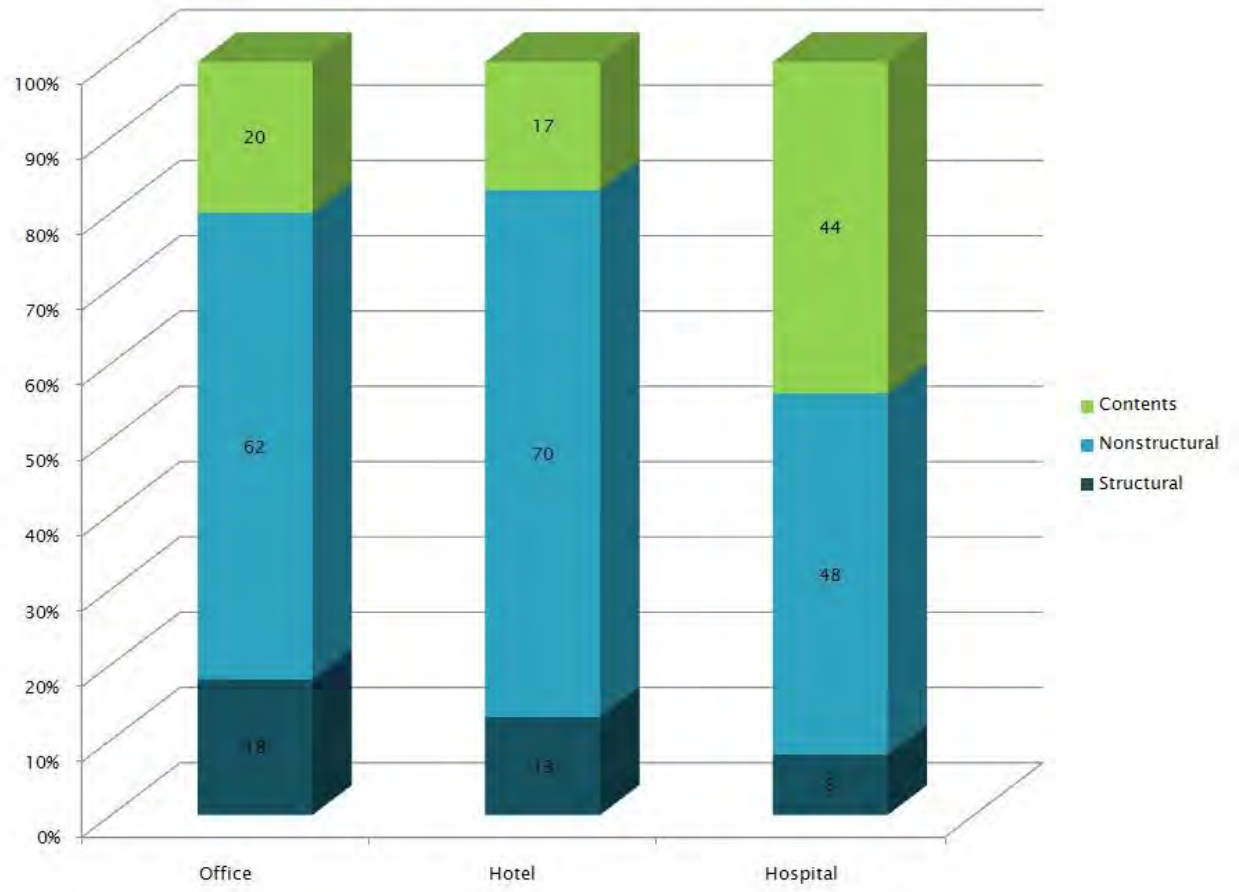


Figure 2.1.3-1 Typical investments in building construction.

2.2 Causes of Nonstructural Damage

Earthquake ground shaking causes damage to nonstructural components in four principal ways:

- Inertial or shaking effects cause sliding, rocking or overturning (Section 2.2.1).
- Building deformations damage interconnected nonstructural components (Section 2.2.2).
- Separation or pounding between separate structures damage nonstructural components crossing between them (Section 2.2.3).
- Interaction between adjacent nonstructural components (Section 2.2.4) cause damage.

2.2.1 Inertial Forces

When a building shakes during an earthquake, the base of the building typically moves in unison with the ground. The entire building and its contents above the base experience inertial

forces that push them back and forth in a direction opposite to the base excitation. In general, the earthquake inertial forces are greater if the mass of the building is greater, if the acceleration or severity of the shaking is greater, or if the location is higher than the base, where excitations are amplified. Thus, the earthquake forces experienced above the base of a building can be many times larger than those experienced at the base.

When unrestrained or marginally restrained items are shaken during an earthquake, inertial forces may cause them to slide, swing, rock, strike other objects, or overturn (see Figure 2.2.1-1). File cabinets, emergency generators, suspended items, free-standing bookshelves, office equipment, and items stored on shelves or racks can all be damaged as they move and contact other items, fall, overturn or become disconnected from attached components. The shaking can also cause damage to internal components of equipment without any visible damage or movement from its original location.

Analogy: Passenger in a Moving Vehicle

As a passenger in a moving vehicle, you experience inertial forces whenever the vehicle is rapidly accelerating or decelerating. If the vehicle is accelerating, you may feel yourself pushed backward against the seat, since the inertial force on your body acts in the direction opposite to that of the acceleration. If the vehicle is decelerating or braking, the inertia forces may cause you to be thrown forward in your seat.

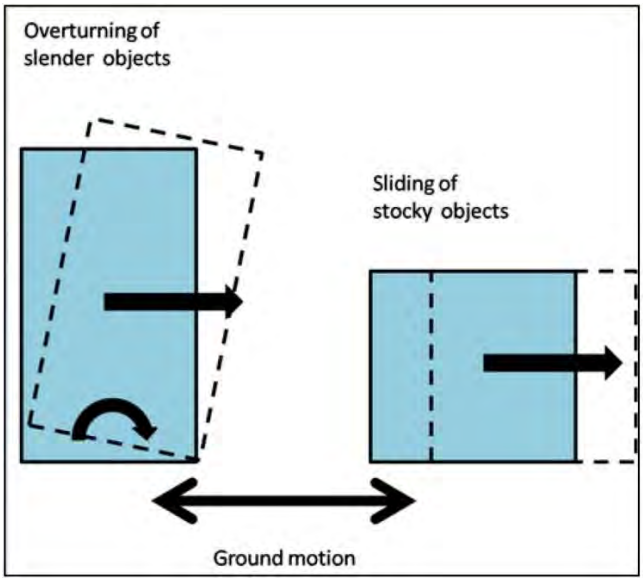


Figure 2.2.1-1 Sliding and overturning due to inertial forces.

2.2.2 Building Deformations

During an earthquake, structural members of buildings can deform, bend or stretch and compress in response to earthquake forces. For example, the top of a tall office tower may lean over a few feet in each direction during an earthquake. The horizontal deformation over the

height of each story, known as the story drift, might range from a quarter of an inch to several inches between adjacent floors, depending on the size of the earthquake and the characteristics of the particular building structure and type of structural system. The concept of story drift is shown in Figure 2.2.2-1.

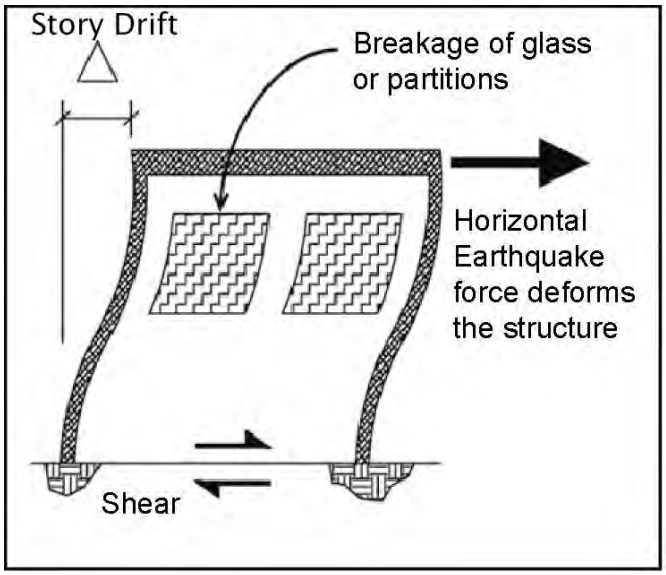


Figure 2.2.2-1 Nonstructural damage due to building deformation.

Structural – Nonstructural Interaction: Problem with Short Columns

There have been many notable examples in past earthquakes where rigid nonstructural components have been the cause of structural damage or collapse. These cases have generally involved rigid, strong architectural components, such as masonry infill or concrete spandrels that inhibit the movement or deformation of the structural framing and cause premature failure of column or beam elements. When a structural column is restrained by nonstructural components, it is often referred to as a "short column" or "captive column." This is a serious concern for the design of structural systems. Designers of nonstructural components must be mindful to isolate their systems from the deformations of the adjacent structural components or to make sure that the structural components have been designed to accommodate the interaction.

When the building deforms, the columns or walls deform and become slightly out of square and thus, any windows or partitions rigidly attached to the structure must also deform or displace the same amount. Brittle materials like glass, plaster partitions, and masonry infill or veneer cannot tolerate any significant deformation and will crack when the space between stops or molding closes and the building structure pushes directly on the brittle elements. Once cracked, the inertial forces in the out-of-plane direction can cause portions of these architectural components to become dislodged and to fall far from their original location, possibly injuring passers-by underneath them.

2.2.3 Building Separations

Another source of nonstructural damage involves pounding or movement across separation or expansion joints between adjacent structures or structurally independent portions of a building.

A seismic joint is the separation or gap between two different building structures, often two wings of the same facility, which allows the structures to move independently of one another as shown in Figure 2.2.3-1.

In order to provide functional continuity between adjacent structures or between structurally independent portions of a building, utilities must often extend across these building joints, and architectural finishes must be detailed to terminate on either side. The separation joint may be only an inch or two wide in older construction or a foot or more in some newer buildings, depending on the expected horizontal movement, or seismic drift between buildings. Flashing, piping, conduit, fire sprinkler lines, heating, ventilation, and air-conditioning (HVAC) ducts, partitions, and flooring all have to be detailed to accommodate the seismic movement expected at these locations when the two structures move closer together or further apart. Damage to items crossing seismic separation or expansion joints is a common type of earthquake damage. If the size of the gap is insufficient, pounding between adjacent structures may result, which can damage structural components but more often causes damage to nonstructural components, such as parapets, veneer, or cornices on the façades of older buildings.

Base-Isolated Buildings

A special type of seismic joint occurs at the ground level of base-isolated buildings, which are separated from the ground by seismic shock absorbers or isolators, in order to reduce the transfer of earthquake accelerations to the building. The seismic joint typically occurs between the foundation below the isolator and the building above. These joints may be as much as several feet wide; special detailing is required for all the architectural finishes and

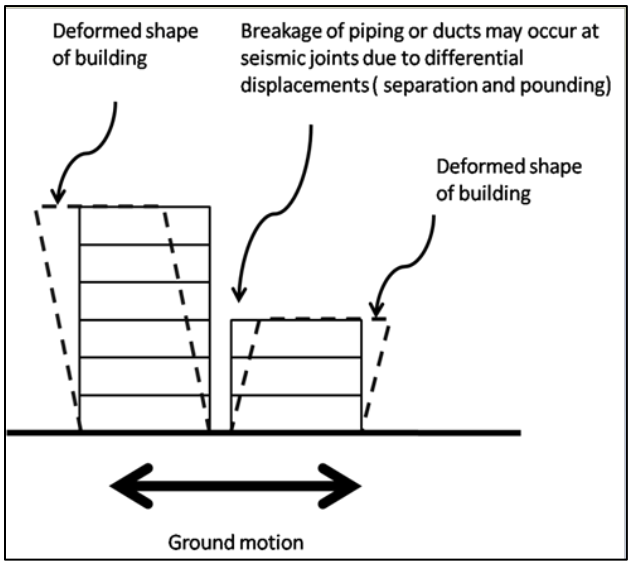


Figure 2.2.3-1 Nonstructural damage due to separation and pounding.

2.2.4 Nonstructural Interaction

An additional source of nonstructural damage is the interaction between adjacent nonstructural systems which move differently from one another. Many nonstructural components may share the same space in a ceiling plenum or pipe chase; these items may have different shapes, sizes, and dynamic characteristics, as well as different bracing requirements.

Some examples of damaging nonstructural interactions include:

- Sprinkler distribution lines interact with the ceiling causing the sprinkler heads to break and leak water into the room below.
- Adjacent pipes of differing shapes or sizes are unbraced and collide with one another or adjacent objects.
- Suspended mechanical equipment swings and impacts a window, louver, or partition.
- Ceiling components or equipment can fall, slide, or overturn blocking emergency exits.

2.3 Extent of Nonstructural Damage

There are many factors affecting the performance of nonstructural components during an earthquake and the extent to which they will sustain damage. The degree of damage caused by the four principal effects previously described depends upon considerations such as the components' dynamic characteristics, their location in the building, and their proximity to other structural or nonstructural components. Other factors include the type of ground motion, the structural system of the building, the location and placement of the loads, the type of anchorage or bracing, if any, the strength of the structural supports used for anchorage, potential interaction with other nonstructural components, and the potential for secondary damage.

A survey of 25 damaged commercial buildings following the 1971 San Fernando Earthquake revealed the following breakdown of property losses: structural damage, 3%; electrical and mechanical, 7%; exterior finishes, 34%; and interior finishes, 56%. A similar survey of 50 damaged high-rise buildings, which were far enough away from the earthquake fault rupture to experience only mild shaking, showed that whereas none had major structural damage, 43 of the buildings suffered damage to drywall or plaster partitions, 18 suffered damaged elevators, 15 had broken windows, and 8 incurred damage to their air-conditioning systems (Steinbrugge and Schader, 1973).

ATC-69 *Reducing the Risks of Nonstructural Earthquake Damage, State-of-the-Art and Practice Report* (ATC, 2008) summarizes the current state of knowledge and practice regarding the seismic performance of nonstructural components of buildings. This study confirmed the lack of systematic and comprehensive post-earthquake documentation of nonstructural performance and recommended development of a standardized framework for the collection of future nonstructural earthquake damage data.

Engineering Considerations: Extent of Damage

- Unique characteristics of the ground shaking at the site (e.g., high or low frequency motion, proximity to fault)
- Characteristics of the structural system supporting the nonstructural elements (e.g., the structure may be tall and flexible, short and stiff, or short and flexible)
- Location of the nonstructural item within the building (e.g., items may be at the basement, at mid-height or roof level; items may cross seismic joints or may be located in close proximity to deforming structural elements)
- Distribution and placement of loads (e.g., heavy loads situated near the bottom of shelving units and lighter items above, or the reverse; countertop lab equipment close or far from the edges of counters)
- Anchorage or restraint conditions (e.g., items may be unanchored, marginally anchored, or well anchored)
- Condition of structural elements used for anchorage (e.g., location and strength of studs in a wall used to anchor tall cabinets or shelving, location of reinforcing bars in concrete used to anchor heavy items, condition of mortar in old masonry walls)
- Potential interaction with structural elements or other nonstructural elements (e.g., rigid granite veneer covering a flexible steel column or a well-anchored ceiling grid with unbraced sprinkler lines).
- Potential for secondary damage caused by release of fluids, gases, toxins, asbestos, and other hazardous substances (e.g., damage to asbestos insulation requires evacuation, a gas leak results in a fire)

2.4 Importance of Nonstructural damage

Historically, earthquake engineers have focused on the performance of structural systems and ways to mitigate structural damage. As the earthquake engineering community moves toward more comprehensive earthquake standards and expectations of improved seismic performance, and as the public demands a higher level of earthquake protection, it is important to understand the significance of nonstructural damage.

The failures of nonstructural components during an earthquake may result in injuries or fatalities, cause costly property damage to buildings and their contents; and force the closure of residential, medical and manufacturing facilities, businesses, and government offices until appropriate repairs are completed. As stated previously, the largest investment in most buildings is in the nonstructural components and contents; the failures of these elements may be both dangerous and costly. The potential consequences of earthquake damage to nonstructural components are typically divided into three types of risk:

- **Life Safety (LS)** *Could anyone be hurt by this component in an earthquake?*
- **Property Loss (PL)** *Could a large property loss result?*
- **Functional Loss (FL)** *Could the loss of this component cause an outage or interruption?*

Damage to a particular nonstructural item may present differing degrees of risk in each of these three categories. In addition, damage to the item may result in direct injury or loss, or the injury or loss may be a secondary effect or a consequence of the failure of the item.

The focus of this guide is on nonstructural hazards; nevertheless, existing structures may also have structural hazards that pose risks to life safety, property, and functionality. While it may make sense to implement simple and inexpensive nonstructural protection measures even in a building with structural hazards, the relative structural and nonstructural risks should be considered, so that limited resources can be used in the most effective manner. It would give little comfort to know that the pipes and ceilings were all well anchored in an unreinforced masonry structure that could collapse during an earthquake.

The three risk categories are also sometimes referred to as:
the **3Ds**: Deaths, Dollars, and Downtime;
the **3Cs**: Casualties, Cost, and Continuity;
or merely Safety, Property, and Function.

2.4.1 Life Safety (LS)

The first type of risk is that people could be injured or killed by damaged or falling nonstructural components. Heavy exterior cladding dislodged during earthquakes has killed passersby (Tally, 1988; Adham and Brent, 1985). Even seemingly harmless items can cause death if they fall on a victim. If a 25-pound light fixture not properly fastened to the ceiling breaks loose during an earthquake and falls on someone's head, the potential for injury is great. Life safety can also be compromised if the damaged nonstructural components block safe exits in a building. Damage to life safety systems such as fire protection piping can also pose a safety concern should a fire start following an earthquake. Examples of potentially hazardous nonstructural damage that have occurred during past earthquakes include broken glass, overturned tall, heavy cabinets and shelves, falling ceilings and overhead light fixtures, ruptured gas lines and other piping containing hazardous materials, damaged friable asbestos materials, falling pieces of decorative brickwork and precast concrete panels, dislodged contents stored overhead, and collapsed masonry parapets, infill walls, chimneys, and fences.

The following anecdotes from past earthquakes will help to illustrate the point. Damage photos are shown in Figures 2.4.1-1 thru 2.4.1-5. Additional damage photos are provided in Chapter 6.

- More than 170 campuses in the Los Angeles Unified School District suffered nonstructural damage during the 1994 Northridge, California earthquake. At Reseda High School, the ceiling in a classroom collapsed and covered the desks with debris. The acoustic ceiling panels fell in relatively large pieces, 3 feet or 4 feet square, accompanied by pieces of the metal ceiling runners and full-length sections of fluorescent light fixtures. Because the earthquake occurred during hours when the building was unoccupied, none of the students were injured (Los Angeles Times, 1994).

- A survey of elevator damage following the 1989 Loma Prieta Earthquake revealed 98 instances in which counterweights came out of the guide rails and six instances where the counterweight impacted the elevator cab, including one case in which the counterweight came through the roof of the cab. No injuries were reported (Ding, 1990). An elevator survey following the Northridge Earthquake indicated 688 instances in which counterweights came out of the guide rails, in addition to reports of other types of elevator damage. An occurrence of a counterweight becoming dislodged and impacting the elevator cab was captured on film during the 2010 Chile Earthquake.

- One hospital patient on a life-support system died during the 1994 Northridge Earthquake because of failure of the hospital's electrical supply (Reitherman, 1994).

- During the 1993 Guam Earthquake, the fire-rated nonstructural masonry partitions in the exit corridors of one resort hotel were extensively cracked, causing many of the metal fire doors in the corridors to jam. Hotel guests had to break through the gypsum wallboard partitions between rooms in order to get out of the building, a process that took as long as several hours. It was fortunate that the earthquake did not cause a fire in the building and no serious injuries were reported.

- Damage to industrial storage racks commonly used in "big box" stores has been reported in most recent earthquakes. Damage has ranged from dislodged contents to partial collapse of racking systems. Collapsed racking systems have been documented in both the 1994 Northridge Earthquake and the 2010 Christchurch New Zealand Earthquake. To date, related deaths and casualties have been avoided due to limited occupancy at the time of earthquake shaking.



Figure 2.4.1-1 Failure of office partitions, ceilings, and light fixtures in the 1994 Northridge Earthquake (FEMA 74, 1994).



Figure 2.4.1-2 Shards of broken untempered glass that fell several stories from a multistory building in the 1994 Northridge Earthquake. Failures of this type can be very hazardous, especially if glazing is located above exit ways (FEMA 74, 1994).



Figure 2.4.1-3 Failure of suspended ceilings and light fixtures in a furniture store (FEMA 74, 1994).



Figure 2.4.1-4 Failure of heavy stucco soffit at building entrance in the 1994 Northridge Earthquake (FEMA 74, 1994).



Figure 2.4.1-5 Damage to overloaded racks during the 1994 magnitude-6.7 Northridge Earthquake (FEMA 460, 2005).

2.4.2 Property Loss (PL)

As discussed previously, nonstructural components, such as mechanical and electrical equipment and distribution systems and architectural components, account for 75-85% of the original construction costs of a typical commercial building. Contents belonging to the building occupants, such as movable partitions, furniture, and office or medical equipment, represent a significant additional value at risk. For example, a high tech fabricating facility may have contents that are worth many times the value of the building and built-in components of the building. Immediate property losses attributable to contents alone are often estimated to be one third of the total earthquake losses (FEMA, 1981).

Property losses may be the result of direct damage to a nonstructural item or of the consequences produced by its damage. If water pipes or fire sprinkler lines break, then the overall property losses will include the cost to repair the piping (a primary or direct loss), plus the cost to repair water damage to the facility (a secondary or indirect loss). If the gas supply line for a water heater ruptures and causes a fire, then clearly the property loss will be much greater than the cost of a new pipe fitting. Many offices and small businesses suffer losses as a result of nonstructural earthquake damage but may not keep track of these losses unless they have earthquake insurance that will help to cover the cleanup and repair costs.



Figure 2.4.2-1 Complete loss of suspended ceilings and light fixtures in the 1994 Northridge Earthquake (FEMA 74, 1994).



Figure 2.4.2-2 Damage to inventory on industrial storage racks in the 1994 Northridge Earthquake (FEMA 74, 1994).

The nonstructural property losses can be much larger if they occur at library and museum facilities whose function is to store and maintain valuable contents. For example, as a result of the 1989 Loma Prieta Earthquake, two libraries in San Francisco each suffered over a million dollars in damage to building contents; the money was spent primarily on reconstructing the library stacks, rebinding damaged books, and sorting and reshelving books. At one of these facilities, $100,000 was spent rebinding a relatively small number of rare books alone (Wong, 1993; Dobb, 1993).

2.4.3 Functional Loss (FL)

In addition to life safety and property loss considerations, there is the additional possibility that nonstructural damage will make it difficult or impossible to carry out the functions that were normally accomplished in a facility. After life safety threats have been addressed, the potential for postearthquake downtime or reduced productivity is often the most important risk. For example, if a business loses the use of its computers, filing system, or other instruments of service as a result of earthquake damage, then the dollar loss of replacing the damaged items may be relatively small, but the loss in revenue associated with downtime during recovery can be tremendous. In light of the global economy, loss of function can also translate to longer term loss of market share for some businesses as consumers find alternate suppliers for needed goods or services.

Many external factors may affect postearthquake operations, including power and water outages, damage to transportation systems, availability of materials and contractors to repair

damage, civil disorder, police lines, and curfews. These effects are generally outside the control of building owners and tenants and beyond the scope of this discussion.

The following are examples of nonstructural damage that resulted in interruptions to postearthquake emergency operations or to businesses:

- During the 1994 Northridge Earthquake, nonstructural damage caused temporary closure, evacuation, or patient transfer at ten essential hospital facilities. These hospitals generally had little or no structural damage but were rendered temporarily inoperable, primarily because of water damage. At the majority of these facilities, water leaks occurred when fire sprinkler, chilled-water, or other pipelines broke. In some cases, personnel were unavailable or unable to shut off the water, and water was flowing for many hours. At one facility, water up to 2 feet deep was reported at some locations in the building as a result of damage to the domestic water supply tank on the roof. At another facility, the emergency generator was disabled when its cooling water line broke where it crossed a separation joint. Other damage at these facilities included broken glass, dangling light fixtures, elevator counterweight damage, and lack of emergency power due to failures in the distribution or control systems. Two of these facilities, shown in the following figures, Los Angeles County Olive View Medical Center and Holy Cross Medical Center, both in Sylmar, California, that had suffered severe structural damage or collapse during the 1971 San Fernando Earthquake had been demolished and entirely rebuilt by the time of the 1994 Northridge Earthquake (Reitherman, 1994).

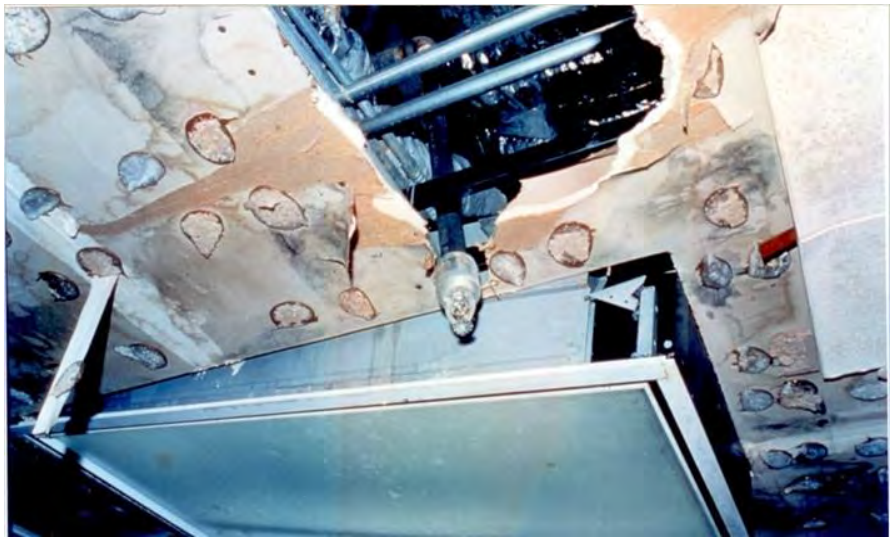


Figure 2.4.3-1 Broken sprinkler pipe at Olive View Hospital in Sylmar, California as a result of the 1994 Northridge, Earthquake. Pipe ruptured at the elbow joint due to differential motion of the pipe and ceiling (FEMA 74, 1994).



Figure 2.4.3-2 HVAC damage at Holy Cross Medical Center in Sylmar in the 1994 Northridge Earthquake. Damage to signage and louvers was caused when suspended fans in the mechanical penthouse swung and impacted the louver panels. HVAC service outage caused the temporary evacuation of patients (FEMA 74, 1994).

- Of 32 commercial data processing facilities surveyed following the 1989 Loma Prieta Earthquake, at least 13 were temporarily out of operation for periods ranging from 4 to 56 hours. The primary cause of outage was loss of outside power. Reported damage included overturning of equipment at two facilities, damage to access floors at four facilities, movement of large pieces of computer equipment over distances ranging from a few inches to 4 feet at 26 facilities, and dislodged ceiling panels at 13 facilities. Twenty of these facilities reported having an earthquake preparedness program in place at the time of the earthquake, three reported having no program, and information was unavailable for nine facilities (Ding, 1990).

- The 1971 San Fernando Earthquake caused extensive damage to elevators in the Los Angeles area, even in some structures where no other damage was reported. An elevator survey indicated 674 instances in which counterweights came out of the guide rails, in addition to reports of other types of elevator damage. These elevators were inoperable until they could be inspected and repaired. Many thousands of businesses were temporarily affected by these elevator outages. The State of California instituted seismic elevator code provisions in 1975 with the intent of allowing for safe elevator shutdown during and after an earthquake (not to make the elevators so earthquake-resistant that they can be relied upon for exiting buildings immediately after an earthquake). While these provisions appear to have helped reduce elevator damage, there were still many instances of counterweight damage in the San Francisco area

following the 1989 Loma Prieta Earthquake, and 688 cases in the Northridge Earthquake in 1994 (Ding, 1990; Reitherman, 1994). . Since the State of California seismic elevator code provisions have not been adopted nationally, elevator damage – including the potential for life-threatening conditions – remains a concern.

In some cases, cleanup costs or the value of lost employee labor are not the key measures of the postearthquake impact of an earthquake. For example, data processing facilities or financial institutions must remain operational on a minute-by-minute basis in order to maintain essential services and to monitor transactions at distant locations. In such cases, spilled files or damage to communications and computer equipment may represent less tangible but more significant outage costs. Hospitals and fire and police stations are facilities with essential functions that must remain operational after an earthquake.

2.5 Common Types of Nonstructural Earthquake Damage

Many types of nonstructural components can be damaged in earthquakes, but the items that are most vulnerable and most likely to result in injuries, significant property losses, and interruption will be described here in terms of the risk posed to life safety, property, and functionality.

2.5.1 Life Safety

Heavy exterior cladding

Cladding is an architectural element used to provide the exterior skin for buildings. Often constructed of heavy precast concrete panels, these panels typically have four support points, two at the top of the panel connecting it to the beam above, and two at its base connected to the level below. Unless specifically designed to accommodate the anticipated inter-story drift and out-of-plane seismic forces, these supports can fail. A female student was killed in the 1987 Whittier Narrows

Threshold for Damage to Unreinforced Masonry:

Masonry damage has long been used to estimate earthquake ground motion intensity in the absence of instrumental recordings. The Modified Mercalli Intensity (MMI) scale identifies levels I to XII to characterize the seismic intensity. MMI Intensity VI and VII both include descriptions of cracked masonry that can be used to estimate the level of ground shaking (Richter, 1957).

Recent efforts to correlate the MMI scale with recorded peak ground accelerations (PGAs) suggest that the threshold for masonry damage, MMI Intensity VI, is associated with low levels of seismic excitation with PGAs in the range 0.10g to 0.15g (CISN, 2009).

Earthquake when a 5,000-pound precast panel fell 25 feet off of the exterior of a parking garage at California State University, Los Angeles. The student was attempting to exit from the ground floor parking level when she was struck by the falling panel (Taly, 1988).

Heavy interior walls

Nonstructural walls in older buildings are often built of heavy, unreinforced masonry materials such as brick, concrete block, or hollow clay tile. These materials are advantageous for fire and sound proofing and thermal insulation, but are brittle since they do not have a grid of horizontal and vertical steel reinforcing bars embedded in them. Falling masonry in hallways and stairwells is a particular hazard for occupants attempting to exit buildings during an earthquake.

Unbraced masonry parapets or other heavy building appendages

Unreinforced masonry parapets are a common feature of vintage commercial construction in many parts of the country. Parapets are the short walls around the perimeter of a roof, constructed to help prevent fire from jumping from one roof to the next, to provide guardrail protection for people on the roof, to hide roof-mounted equipment, or to provide an architectural effect of greater height. While some communities have enforced ordinances that require unreinforced masonry parapets to be braced or anchored, many jurisdictions have no such mandatory provisions. As these parapets often fail at the roofline and fall outwards onto the sidewalk, they represent a particular hazard for pedestrians and occupants attempting to exit damaged buildings. Two children were killed on their way to school due to falling unreinforced stone masonry in Challis, Idaho during the 1983 Borah Peak, Idaho earthquake (Adham and Brent, 1985). Unreinforced masonry parapets have also fallen inward and penetrated through the roof of buildings.

Unreinforced masonry chimneys

Residential chimneys are typically built of brittle unreinforced brick masonry that may be damaged even in relatively small earthquakes. This is also true of many commercial chimneys. Broken chimneys can fall through the roof and pose a safety risk to building occupants. The 1992 Landers Earthquake caused one related fatality where a child was sleeping next to a fireplace. A similar fatality occurred in the 2000 Napa earthquake where a child sleeping next to a fireplace was killed during a slumber party. Chimneys can also fall against the side of the building, onto an adjacent building or onto a public sidewalk, posing a hazard to neighbors or passersby. Use of a cracked flue chimney can cause an indirect hazard when carbon monoxide enters a home or leads to ignition of a fire.

Suspended lighting

Suspended overhead lighting is prone to damage in earthquakes, especially if the lights are supported solely by unbraced suspended ceilings, or if they interact with unbraced piping or other suspended components. There were several instances where suspended lighting fixtures in Los Angeles school district classrooms fell during the 1994 Northridge Earthquake. No casualties occurred since school was not in session at the time of the earthquake.

Large, heavy ceilings

Heavy suspended ceilings and soffits can be damaged during earthquakes, sometimes causing heavy and dangerous material to fall and injure people below. Figure 2.4.1-2 shows a failed stucco soffit above a building entrance damaged in the 1994 Northridge Earthquake. During the 1989 Loma Prieta Earthquake, the proscenium arch ceiling at the Geary Theatre in San Francisco fell and covered the first six rows of seats in the auditorium; the theater was not in use at the time and no one was injured (Ding, 1990).

Tall, slender, and heavy furniture such as bookcases and file cabinets

Tall slender shelving, bookcases, or file cabinets frequently overturn during earthquakes if they are unanchored or poorly anchored. These items are particularly hazardous if they are located adjacent to a desk or bed or located where they can jam doors or block corridors and exits. Recent shaking table tests conducted in Japan predict injuries to occupants represented by mannequins crushed by tall unanchored pieces of furniture.

Heavy unanchored or poorly anchored contents, such as televisions, computer monitors, countertop laboratory equipment, and microwaves

Heavy contents situated above the floor level include a wide range of items that could become falling hazards in an earthquake. Many rooms have overhead wall- or ceiling-mounted televisions and monitors, offices have desktop computer monitors, or microwaves may be perched high on counters or shelves. Any of these items could cause injury if they fell and hit someone; damage to fallen items can add to property loss and downtime. During the 1989 Loma Prieta Earthquake, an overhead monitor fell at the San Francisco International Airport, hitting a passenger on the shoulder.

Glazing

Damage to storefront windows in older commercial buildings is common during earthquakes, often causing hazardous conditions on sidewalks in commercial areas. Glazing failures were relatively common in high-rise buildings in Mexico City in the 1985 Earthquake. U.S. earthquakes have not yet caused numerous high-rise glazing failures, though it remains a possibility.

Fire protection piping

Damage to suspended fire protection piping and other system components can render the system inoperable following an earthquake. The resultant loss of fire life safety protection can pose a serious risk to the life safety of building occupants.

Hazardous materials release

There have been a number of examples of hazardous materials release resulting from earthquake damage to piping, stored chemicals, commercial, medical, or educational laboratory facilities. Breakage of containers of chemicals can cause them to mix and lead to hazardous reactions. Exposure of asbestos materials due to earthquake activity has also resulted in the postearthquake evacuation of facilities that otherwise had little structural damage.

Gas water heaters

Residential and small commercial water heaters have ignited fires following earthquakes, in instances where the gas supply line was damaged. As water heaters are typically tall and slender, the gas supply line can break if the water heater tips over.

Other components

The following components pose a high risk of direct injury requiring hospitalization, or possibly causing death, if installed without seismic bracing, seismic anchorage, seismic restraint or allowance for differential movement in zones of high seismicity. Other components posing indirect risks to life safety are also identified.

- Exterior walls (including veneer, prefabricated panels, glazing, glass block, curtain wall and storefront window systems)
- Partitions (hollow clay tile, unreinforced masonry or similar)
- Ceilings (plaster or other heavy material, particularly if suspended)
- Parapets and appendages (unreinforced masonry)
- Canopies, marquees and signs

- Chimneys and stacks (unreinforced masonry)
- Stairways
- Suspended equipment weighing over 20 pounds
- Fuel tanks
- Fuel or hazardous material piping
- Suspended light fixtures (recessed, surface-mounted or pendant) weighing over 20 pounds
- Elevators
- Tall and slender shelves, bookcases, file cabinets, vending machines, lockers or similar
- Industrial storage racks and contents

The following components pose life safety concern when located in path of egress:

- Glazed partitions
- Demountable partitions
- Metal stud partitions with heavy veneer such as tile or stone
- Suspended acoustic tile ceiling including light or other components supported by the ceiling grid only and weighing 20 pounds or more
- Clay or concrete roof tiles

The following components pose indirect life safety risk:

- Emergency generation system (in hospitals, emergency communication centers or similar)
- Fire protection systems

For a more detailed list of components and risk ratings, refer to Appendix E.

2.5.2 Property Loss

Suspended piping for water or waste

Failures of suspended piping have led to costly property loss in past earthquakes. While such failures are not often associated with life threatening injuries, they often result in costly property loss: both the cost to replace the damaged system and the cost to repair damage caused by the release of both clean and contaminated or hazardous fluids. Secondary damage due to fluid release is often a large component of nonstructural property losses.

Suspended fire protection piping

Failures of suspended fire protection piping have resulted in both direct and indirect property loss following earthquakes. Some of these systems have failed or fallen and had to be replaced. More costly are the failures of sprinkler piping, connections, or sprinkler heads. These have resulted in the release of great volumes of water in plenum or occupied spaces. Flooded plenums have resulted in collapsed ceilings which cause the consequent loss of property and disruption of operations. In extreme cases, entire floors or buildings were abandoned as a result of the water damage. Flooding in occupied spaces has resulted in water damage to furniture, files, computer equipment, and interior finishes. As fire sprinkler lines are widespread in occupied spaces, this type of failure has been one of the most costly types of nonstructural damage.

Unanchored and poorly anchored equipment, particularly roof-mounted equipment and unrestrained vibration-isolated equipment

Roof-mounted HVAC equipment is often vulnerable to earthquake damage, in part because the seismic accelerations are typically larger at the roof level than they are at the lower levels of the building. Such equipment is often mounted on vibration-isolation springs to prevent the transmission of the equipment vibrations to the building and building occupants. While these springs allow the equipment to move vertically a small amount in order to isolate its rapid vibratory motion from the building, this equipment is especially vulnerable to the much larger motions caused by an earthquake, unless it is also designed with seismic restraints. Damage to roof-mounted equipment, as well as other suspended or floor-mounted equipment, can disable the infrastructure of a building.

Partitions

Non-load-bearing gypsum board partitions can be detailed to reduce the impact of seismic distortions of structural systems, with a connection detail at the top of the partition that allows the interface with the floor or roof above to accommodate sliding. However, this often is not detailed properly, resulting in extensive cracking and tearing at joints and points of attachment. Heavy partitions constructed of concrete masonry units, brick, or hollow clay tile are also often damaged in earthquakes and are costly to repair. Even when partition damage is minor to moderate, it may still necessitate complete interior patching and painting and may cause business interruptions in the affected interior spaces. Pacific Gas & Electric Company, which operates throughout much of Northern California, reported close to $50 million in area-wide property damage following the 1989 Loma Prieta Earthquake, much of which was from damage to gypsum board partitions, glazing, and air conditioning units. While this nonstructural

damage represented relatively minor losses for each building, it added up to large aggregate losses for the firm (Ding, 1990).

Ceilings

Suspended ceiling systems have failed in many earthquakes resulting in major repair or replacement costs for the ceilings and interconnected lighting or fire sprinkler lines as well as interruption in the use of the occupied spaces.

Hazardous Materials Release

Release of some hazardous materials can create a point of ignition for a fire. An entire three story university chemistry building burned down to the steel frame as a result of a hazardous materials release in the 2010 Chile Earthquake (see Section 6.5.4.1).

2.5.3 Functional Loss

Emergency generators for critical facilities and related components such as day tanks, batteries, and mufflers

Continued operations of critical facilities following an earthquake depend on the integrity not only of the emergency generator itself but also of many related subcomponents such as batteries, battery racks, day tanks, exhaust and sometimes water-cooling connections, electrical connections to control panels, and mufflers. All of these items must be adequately restrained or anchored in order for the emergency systems to remain operational.

Suspended piping for water or waste

As noted above, damage to these systems results not only in primary damage to the piping and connected systems but also can result in costly outages resulting from the release of fluids into occupied spaces. Also, many facilities cannot operate without water and sanitary sewage service. As an additional concern, process piping may require extensive inspection prior to equipment restart, whether it appears damaged or not, resulting in additional time for functional loss.

Suspended fire protection piping

Failures of suspended fire protection piping have resulted in costly business interruption as well as disabling hospitals in past earthquakes. The small bore lines and sprinkler heads often are built in a grid with ceiling and lighting systems; incompatible motions of these systems have sometimes resulted in damage to the sprinkler heads and subsequent overhead water release.

Hazardous materials release

Breakage of containers of chemicals can cause them to mix and lead to hazardous reactions. Also, due to disruption of building materials, asbestos release has occurred during earthquakes. Any of these types of releases can cause building closures, evacuation, and costly delays until specially trained HAZMAT crews can be brought in to identify and clean the spills.

Failure of equipment needed for functionality, such as computer data centers, controls, servers, hubs, routers, switches, and communication systems

Computer networks form the backbone of many operations. Earthquake damage can result in extended downtime.

Equipment needed for functionality, including HVAC systems

Many facilities cannot maintain operations without HVAC equipment because temperature control and air filtration systems are required in many hospitals, laboratories, and high tech manufacturing facilities.

Equipment needed for functionality, such as elevators and conveyors

Many facilities cannot resume normal operations without the use of passenger and freight elevators or material conveyors. Hospitals need elevators to move gurneys and portable equipment from floor to floor. Occupants of multistory buildings depend upon the use of elevators to move work materials, supplies, and equipment.

3. SURVEY AND ASSESSMENT PROCEDURES FOR EXISTING BUILDINGS

The first step toward reducing the nonstructural hazards in an existing building is to perform a survey to assess the extent and magnitude of the potential risks. This chapter includes survey guidelines for nonstructural components and describes the inventory form, the checklist, and the risk ratings that are included in the appendices. In order to make informed decisions regarding nonstructural seismic risks, owners and managers will need to address the following questions:

- What types of nonstructural components are present in a particular facility?
- Are these items adequately braced or anchored?
- How will a specific nonstructural item perform in an earthquake, and what are the consequences of failure of that item in terms of life safety, property loss, and functional loss?
- If the decision is made to upgrade a facility, which problems should be addressed first?

The focus of this guide is on reducing nonstructural seismic hazards, particularly in those areas where the seismic shaking intensity is expected to be moderate or high and where significant structural hazards do not exist or will be addressed independently. A simplified map of probable shaking intensities is presented in Figure 3.2.1-1. If the expected shaking for the facility in question is minimal, then the survey procedures and seismic protection measures described in this guide might be undertaken on a voluntary basis but may not be necessary, and in most cases they would not be required for new construction.

3.1 Survey of Nonstructural Components

The nonstructural components listed in the tables and checklists provided in the appendices are at least initially within the scope of the construction of a building and its building permit. After occupancy of the building, these are items that are most commonly found in commercial, multiple-unit residential, or public buildings. A complex facility such as a hospital, research laboratory, or industrial plant will contain many additional types of specialized equipment that are not explicitly addressed in this guide.

The goal of a facility survey is to identify nonstructural components that may be vulnerable to earthquake damage. As noted earlier, it may be advisable to seek the help of a professional

with expertise in this area. During the survey, the following three basic questions should be kept in mind as each nonstructural item is considered:

- Could anyone get hurt by this item in an earthquake? (Life Safety)
- Could a large property loss result? (Property Loss)
- Would interruptions and outages be a serious problem? (Functional Loss)

For some components, the answers to these three questions may not be immediately obvious, since failure of an item may result in both direct damage and indirect damage. It is important not only to view each item as a discrete object that could tip or fall and hurt someone directly, but also to consider the consequences of failure. Several examples will serve to illustrate the point:

- If a fire sprinkler line breaks, this may cause minor damage to the sprinkler itself but result in major damage to architectural finishes and contents of the building. Even if the building does not sustain any other damage, the occupants may not be able to use the facility until the fire safety system is repaired. The potential for direct and indirect property losses in this case are much greater than the repair cost for the sprinkler system.
- The battery rack used to start an emergency generator is generally located in a locked mechanical room and is unlikely to hurt anyone, even if the rack and batteries fall on the floor. In this case, even though the direct life safety threat is probably low, if the fallen batteries cannot start the emergency generator, building occupants may be injured attempting to evacuate the building in the dark, or the lives of hospital patients on life-support systems may be jeopardized. Thus the indirect losses are larger than the direct losses.
- Gas-fired residential water heaters have rarely injured anyone as they fall, but they have frequently caused postearthquake fires due to ruptured gas lines.

A word of caution is in order regarding the field survey. While it may be relatively straightforward to assess whether or not an item is positively restrained to resist earthquake forces, the effectiveness of the restraint must also be judged. In the case of bookshelves in an office area, there may be hardware anchoring the shelving to the wall, but unless the hardware is secured to a solid wall or directly to a stud in a partition wall that is also braced, the anchorage may be ineffective in a strong earthquake. The illustrated examples in Chapter 6 show many photos of unanchored, poorly anchored, and well anchored nonstructural components and provide seismic mitigation details for many common situations. As shown in

the flowchart in Chapter 1, the reader is advised to complete Chapters 4 and 5 (as applicable) and to review the illustrations and details in Chapter 6 before performing a facility survey and reviewing the questions in the checklist. If the checklist asks whether or not something is securely anchored, then the existing situation should be compared to the seismic mitigation details shown in Chapter 6 for that or a similar item. Also, the installation notes in Section 6.6 provide general guidance on recommended hardware and procedures.

3.1.1 Survey Forms

The field survey may be performed by using the forms and checklists in Appendices C, D, and E.

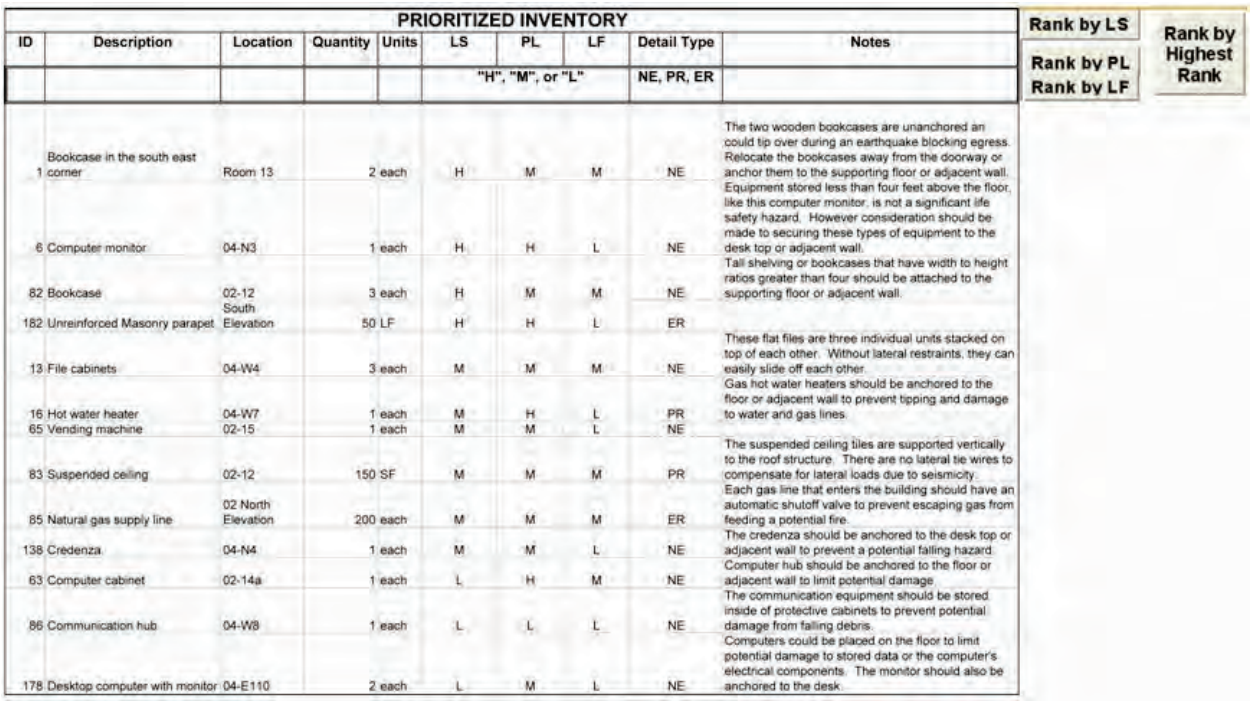
Appendix C, the Nonstructural Inventory Form, shown in Figure 3.1.1-1 contains a blank nonstructural inventory form that can be used to record field observations. At the start of the survey, this form should be filled in, in order to identify the facility. This inventory form provides a place to record field observations made while walking through the facility and reviewing the questions in the checklist in Appendix D. When an item in the checklist is noncompliant, it should be entered as a line item in the inventory form. The form also contains space to add risk ratings from Appendix E according to the facility's seismic shaking intensity; this could be done during the field survey or could be added to the form later. The space provided for notes may be used to identify the type of problem observed, such as "unanchored" or "bolts undersized."

During the initial survey, it may be helpful to create a list containing a large number of items which may be shortened later, perhaps by dropping low-priority items. At the initial stage, it is better to be conservative and to overestimate vulnerabilities than to be too optimistic. In this version, Appendix C is provided as a sample of the inventory form prepared by the U.S. Bureau of Reclamation. The electronic file containing the sorting algorithm can be downloaded from the Bureau's website at http://www.usbr.gov/ssle/seismicsafety/onlineorders.html.

Nonstructural Survey Methods for Engineers

The survey method provided here was developed for use by non-engineers. Nonstructural survey methods for use by engineers are available both in ASCE 31/SEI 31-03 Seismic Evaluation of Existing Buildings (ASCE, 2003) and in Chapter 11 of ASCE/SEI 41-06 Seismic Rehabilitation of Existing Buildings (ASCE, 2006).

The evaluation methods described in these ASCE documents are more quantitative than those presented here and often require that engineering calculations be performed to determine the adequacy of the existing conditions.



PRIORITIZED INVENTORY

Rank by LS | Rank by PL | Rank by LF | Rank by Highest Rank

ID	Description	Location	Quantity	Units	LS	PL	LF	Detail Type	Notes
					"H", "M", or "L"			NE, PR, ER	
1	Bookcase in the south east corner	Room 13	2	each	H	M	M	NE	The two wooden bookcases are unanchored an could tip over during an earthquake blocking egress. Relocate the bookcases away from the doorway or anchor them to the supporting floor or adjacent wall.
6	Computer monitor	04-N3	1	each	H	H	L	NE	Equipment stored less than four feet above the floor, like this computer monitor, is not a significant life safety hazard. However consideration should be made to securing these types of equipment to the desk top or adjacent wall.
82	Bookcase	02-12	3	each	H	M	M	NE	Tall shelving or bookcases that have width to height ratios greater than four should be attached to the supporting floor or adjacent wall.
182	Unreinforced Masonry parapet	South Elevation	50	LF	H	H	L	ER	
13	File cabinets	04-W4	3	each	M	M	M	NE	These flat files are three individual units stacked on top of each other. Without lateral restraints, they can easily slide off each other.
16	Hot water heater	04-W7	1	each	M	H	L	PR	Gas hot water heaters should be anchored to the floor or adjacent wall to prevent tipping and damage to water and gas lines.
65	Vending machine	02-15	1	each	M	M	L	NE	
83	Suspended ceiling	02-12	150	SF	M	M	M	PR	The suspended ceiling tiles are supported vertically to the roof structure. There are no lateral tie wires to compensate for lateral loads due to seismicity.
85	Natural gas supply line	02 North Elevation	200	each	M	M	M	ER	Each gas line that enters the building should have an automatic shutoff valve to prevent escaping gas from feeding a potential fire.
138	Credenza	04-N4	1	each	M	M	L	NE	The credenza should be anchored to the desk top or adjacent wall to prevent a potential falling hazard.
63	Computer cabinet	02-14a	1	each	L	H	M	NE	Computer hub should be anchored to the floor or adjacent wall to limit potential damage.
86	Communication hub	04-W8	1	each	L	L	L	NE	The communication equipment should be stored inside of protective cabinets to prevent potential damage from falling debris.
178	Desktop computer with monitor	04-E110	2	each	L	M	L	NE	Computers could be placed on the floor to limit potential damage to stored data or the computer's electrical components. The monitor should also be anchored to the desk.

Figure 3.1.1-1 Sample nonstructural inventory form (from Appendix C).

Appendix D, Checklist of Nonstructural Earthquake Hazards, shown in Figure 3.1.1-2 is a checklist with questions designed to help identify vulnerable nonstructural items and potential hazards associated with each item. The checklist should be carried during the field survey to help identify vulnerable items. The questions on the checklist are all stated in such a way that a "Noncompliantce (NC)" answer is indicative of a potential problem. Each nonstructural component with a potential problem should be listed as a line item on the nonstructural inventory form of Appendix C showing the location and quantity of the item with any relevant comments. If an example is available for this item in Chapter 6, it may be helpful to note the detail type and example number for future reference.

6.3	Architectural Components						
Item No.	**Component Name**	**Principal Concerns**	**Example**	**C**	**NC**	**NA**	**Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)**
6.3.1	**Exterior Wall Components**						*[Exterior falling hazards are a primary concern, especially items situated above 10 feet and items that may fall over exits, walkways, or sidewalks.]*
	Adhered veneer	Falling hazard	6.3.1.1				Is the adhered veneer adequately attached to the structure? [This includes relatively thin sections of tile, masonry, stone, terra cotta, ceramic tile, glass mosaic units, stucco, or similar materials attached to a structural wall or framework by means of an adhesive].
							Based on visual observations and/or tapping, is the veneer free of cracked or loose sections that may fall during an earthquake?
	Anchored veneer	Falling hazard	6.3.1.2				Is the anchored veneer adequately attached to the structure? [This includes thicker masonry, stone, or stone slab units that are attached to the structure by mechanical anchors].
							Is the masonry or other veneer supported by shelf angles or other elements at each floor?
							Is the masonry or other veneer connected to a structural back-up wall at adequate spacing?
							Has the veneer been adequately maintained? Are the anchors in good condition, free of significant corrosion, and inspected regularly?

Figure 3.1.1-2 Sample checklist questions from Appendix D.

Appendix E, Nonstructural Seismic Risk Ratings, summarizes estimated seismic risk ratings stated as Low, Medium, and High for many common components based on their exposure to Low, Moderate or High levels of shaking intensity map in Figure 3.2.1-1. The risk ratings are based on the risk to Life Safety, Property Loss and Functional Loss for unanchored or unbraced items located at or near the base of a low-rise building of ordinary occupancy. The risk ratings are further explained in Section 3.2.2 and in the introduction to Appendix E. A sample of the risk ratings in Appendix E is shown below.

6.3	Architectural Components					
Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.3.1	Exterior Wall Components[1]					
6.3.1.1	Adhered veneer	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.3.1.2	Anchored veneer	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.3.1.3	Prefabricated panels	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	M	

Figure 3.1.1-3 Sample risk ratings from Appendix E.

3.2 Estimating Seismic Risk

There are two aspects of the estimated seismic risk for a given item:

- What is the seismic shaking intensity that can be expected at the site?
- For a given level of shaking, what is the seismic risk rating of a given nonstructural item in terms of life safety, property loss, and functional loss?

3.2.1 Estimating Seismic Shaking Intensity

Estimating site specific seismic hazards can be a difficult technical problem, requiring many factors to be taken into account. For the purposes of this nonstructural survey, the shaking intensity is based solely on regional seismicity. For a particular geographic location in the United States, the shaking intensity may be estimated by using the map in Figure 3.2.1-1 that shows the areas that are likely to experience minimal, low, moderate, or high levels of ground shaking during future probable maximum considered earthquake events. The ground shaking has been estimated for a stiff soil site. The information in Figure 3.2.1-1 may be summarized as follows:

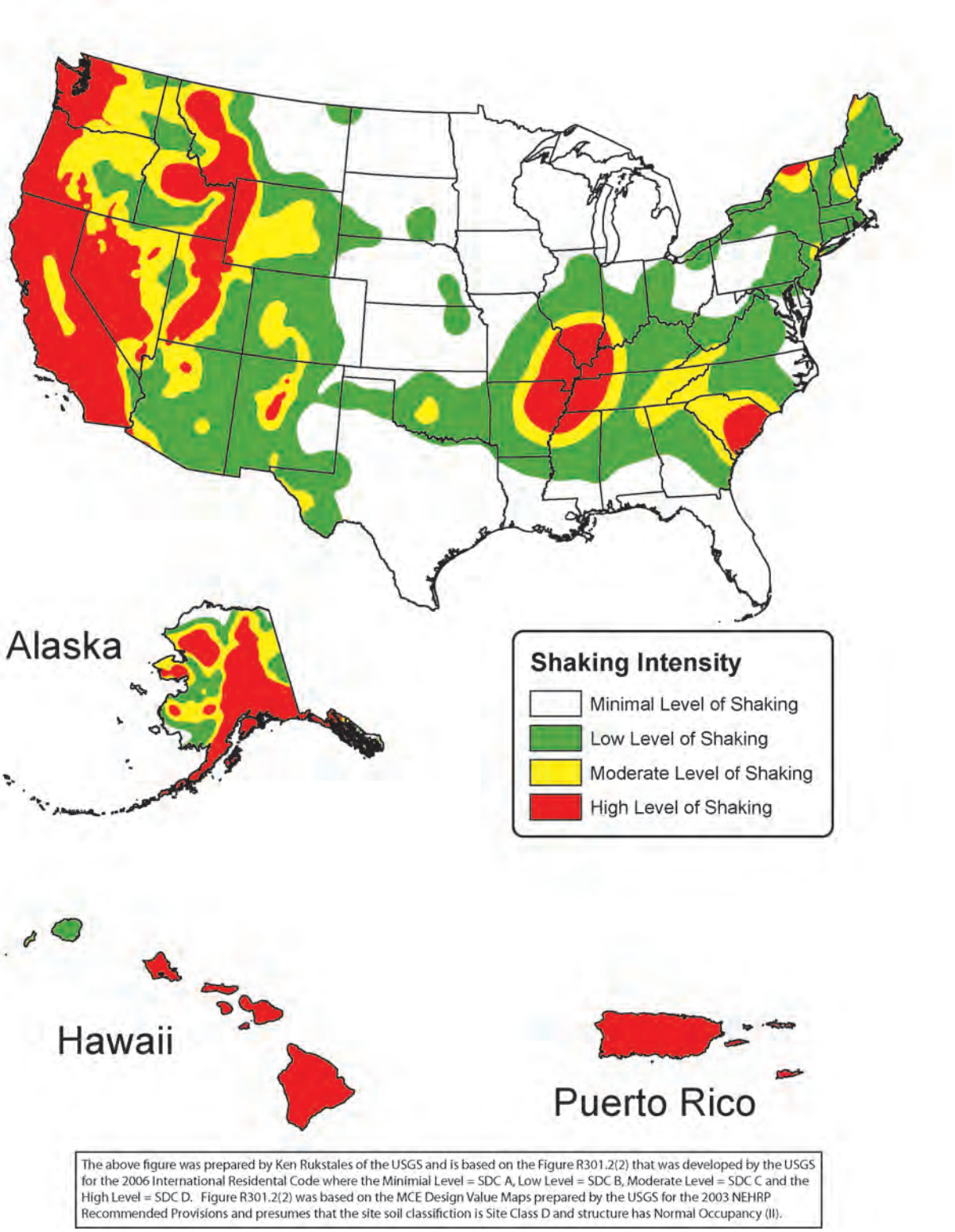


Figure 3.2.1-1 Map of probable shaking intensity in the United States.

- High level of shaking: Most of California and Nevada; significant portions of Alaska, Washington, Oregon, Montana, Wyoming, Idaho, and Utah; the areas near New Madrid, Missouri and Charleston, South Carolina; small pocket areas in Arizona, New Mexico, upper New York, and upper Maine; the islands of Hawaii, Puerto Rico, and Guam (not shown).
- Moderate level of shaking: Areas adjacent to the areas of high shaking plus pocket areas in New England, New Mexico, Arizona, West Texas, Colorado, and Oklahoma.
- Low level of shaking: A portion of the western States, a significant portion of the central region of the continental United States east of the Rockies and most of New England.
- Minimal level of shaking: Remaining portions of mid-western, southern continental United States.

Shaking intensity estimates based on the probable shaking intensity map in Figure 3.2.1-1 should be adequate for evaluating components situated at or near the ground in simple, nonessential facilities. For other situations, it may be advisable to choose the next higher shaking intensity or to seek the advice of professional consultants. Note that in areas with minimal shaking, upgrade of nonstructural components generally would not be warranted unless an owner is particularly risk averse or special circumstances exist; the current code would not require many of the protective measures recommended herein, even for new construction.

Engineering Design Forces

Estimating the earthquake forces acting on a particular item in a particular building can be a difficult technical problem. In order to perform engineering calculations, an engineer may have to consider the following factors:

- the proximity of the building site to an active fault
- soil conditions at the site (other than stiff soil)
- the flexibility of the building structure
- the location of the item in the building
- the flexibility of the floor framing or walls in the immediate vicinity of the item
- the flexibility and strength of the item and its attachments
- the weight and configuration of the item
- the characteristics of any connection details between the item and the structure
- the expected relative displacement between two connection points in adjacent stories or across a seismic gap
- the function of the item
- the function of the facility

Refer to the current International Building Code (IBC) and ASCE/SEI 7 for seismic design requirements for nonstructural components and ASCE/SEI 41 for existing construction.

One reason why the use of professional consultants is recommended for complex facilities is that the generalized shaking intensity map does not take many engineering factors into consideration (see sidebar). Clearly, the complexity and detail of engineering calculations should commensurate with the complexity and importance of the facility and the item in question. It should be noted that current design codes and standards such as the *International Building Code*, ASCE/SEI 7 *Minimum Design Loads for Buildings and Other Structures*, and ASCE/SEI 41 *Seismic Rehabilitation of Existing Buildings*, reference detailed digitized seismic maps of the United States prepared by the U.S. Geological Survey (USGS). These maps consider locations and seismic activity of all known seismic sources and faults which may affect a given site, and the standards provide procedures for adjusting the mapped ground motions for site soil conditions. For designs requiring compliance with building code or national standard requirements, the maps referenced by the code or standard in effect at the time must be used to establish minimum criteria.

In addition, it may be appropriate to consider more than one earthquake scenario for a particular facility, since earthquakes of different magnitudes may occur at different average time intervals. For some facilities, it may be useful to evaluate more probable frequent events, such as those that are likely to occur every 100 years. While new construction projects have to anticipate the most severe shaking, others who are doing voluntary retrofits may find it more economical to plan for a smaller, more frequent event.

3.2.2 Estimating Seismic Risk Ratings

The risk ratings provided in Appendix E are based on a review of damage to nonstructural components in past earthquakes and on the judgment of the authors and their advisory panel. Estimates of future earthquake damage to either the structural or nonstructural components of a building are only that—estimates—and should be used with discretion. The approximations provided in this guide are adequate for the purpose of making an initial determination of the seismic risk of the nonstructural components of a simple facility. For a facility that is more complex, or for one where the potential risk is high, more detailed analyses should be performed by an in-house engineer or a professional consultant. In this document, the seismic risks for life safety, property loss, and functional loss have been rated simply as high, medium, or low for different levels of shaking intensity. Note that these ratings refer to primary losses caused by damage to the item in question; potential consequences or secondary losses are not considered. Appendix E contains more detailed notes concerning the definitions and assumptions used in assigning risk ratings. Stated briefly:

- Life Safety risk is the risk of direct injury by the item.
- Property Loss risk is the risk of incurring a cost to repair or replace the item as a result of damage incurred.
- Functional Loss risk is the risk that the item will not function as a result of the damage incurred.

The estimated risk ratings shown in Appendix E assume that the item is unbraced and unanchored and are intended for buildings with ordinary occupancies, not for essential facilities. The primary purpose of this information is to assist in assigning priority ratings, described below, and to help in identifying the most critical hazards.

3.2.3 Assigning Priority Ratings

Prioritization may be based on budget constraints, risk considerations (i.e., those elements that pose the greatest risks to safety, property or function are retrofitted first), availability of unoccupied space, or to achieve the highest cost to benefit ratio.

A simplified priority rating system might be used to indicate which items are more vulnerable to earthquake damage and to indicate those items whose failure is most likely to have serious consequences. All components could be assigned a high, medium, or low priority, or each item or type of item could be ranked in order from highest to lowest. The highest priority might be assigned to those components for which all three risk ratings are high. If loss of function is not a serious concern, then the highest priority might be assigned to items for which the life safety risk is high and the upgrade cost is lowest, since these hazards could be reduced most cost-effectively. The assignment of priorities may vary widely for different types of facilities, and this document merely provides some guidelines that can be used to establish a ranking system. In assigning the rating priorities, the requirements for new construction should be considered. If it is not required for new construction, then it does not make much sense to do a seismic retrofit of that item in an existing facility.

3.2.4 Application of Nonstructural Guidelines

When estimating seismic risk and assigning priority ratings, it should be noted that current building codes and seismic design standards for new construction do not require seismic design of anchorage and bracing for nonstructural components in every part of the United States.

- In areas denoted as experiencing minimal levels of seismic shaking intensity in Figure 3.2.1-1, no seismic anchorage or bracing of nonstructural components is required.
- For most buildings in areas denoted as experiencing low levels of seismic shaking intensity, only parapets are required to be braced. For essential facilities, all architectural components are required to be anchored and braced.
- In areas denoted as experiencing moderate levels of seismic shaking, all architectural components are required to anchored and braced. However, in most buildings, electrical and mechanical components and systems do not require anchorage and bracing. For essential facilities, mechanical and electrical components are required to be braced.
- In general, in areas denoted as experiencing high levels of seismic shaking intensity, all architectural, mechanical, and electrical components are required to be anchored and braced in all buildings.

In addition, current seismic codes and standards also exempt mechanical and electrical components from bracing or anchoring, regardless of seismic area, in nonessential facilities, if they weigh less than 400 pounds and are mounted at a height 4 feet or less above the floor or, if elevated, weigh less than 20 pounds. Distributed systems in nonessential facilities, such as piping or HVAC ducting, are also exempt from bracing or anchoring if they weigh less than 5 pounds per lineal foot and are provided with flexible connections.

Current seismic codes and standards do not provide much guidance on when seismic anchorage and bracing are required for contents except for cabinets and computer access floors which are treated as architectural components. The reason why they are typically not treated in standards for new construction is that furniture, fixture, equipment and contents are usually installed after the building has been approved for occupancy by the building official; thus, the building official no longer has any control over the installation after occupancy approval has been given.

4. NONSTRUCTURAL RISK REDUCTION FOR EXISTING BUILDINGS

Nonstructural risk reduction programs may vary depending on whether the nonstructural components in question are in an existing building, a historic facility, an essential facility, a facility containing hazardous materials, or are planned for a new building. The current chapter addresses issues related to existing buildings; Chapter 5 addresses issues related to new construction. Portions of these chapters are written in parallel, yet they are unique to each chapter. If portions apply to either situation, they appear only once. For instance, the material on implementation strategies appears only in Chapter 4; the material on current code requirements and code enforcement appears only in Chapter 5.

There is considerable overlap between the *new* and *existing* building categories. For instance, if an existing building undergoes a major alteration and changes to a higher use category, then it would be required to comply with current codes in many jurisdictions and thus, the project requirements would closely resemble those for new construction. Conversely, a new building becomes an existing building as soon as the occupancy permit is issued. Thus, tenant improvements and the installation of furniture, fixtures, equipment, and contents for the first occupants of a leased portion of a new building often take place after the original design team is finished and the major architectural, mechanical, electrical, and plumbing components are installed; for this reason, many of the problems involved in coordinating the anchorage of the tenants' components with preexisting components are the same as for a project in an older existing building.

Historic buildings, essential buildings such as police and fire stations, or facilities that handle hazardous materials have special requirements, which are typically more complex than those for ordinary occupancies. While some issues related to these types of facilities are mentioned here, the treatment of nonstructural components in these facilities is beyond the scope of this guide. The list of references and additional sources of information may help to address these issues for specialized facilities.

4.1 Program Objectives and Scope

Several recent earthquakes in the United States have provided evidence suggesting that nonstructural damage may account for more than 50% of total damage in future domestic earthquakes. As advances are made in the structural design of buildings, and we experience fewer structural failures and fewer collapses as a result, the significance of nonstructural

damage becomes more apparent. In addition, postearthquake operations are of increasing concern not only to essential facilities such as police and fire stations and hospitals, but also to manufacturing facilities, banks, mobile phone providers, and many other businesses concerned with loss of revenue or loss of market share that would result from a lengthy outage following an earthquake. Organizations and owners who want to reduce their seismic exposure will need to address the nonstructural hazards in their facilities.

Seismic improvements to existing buildings might be mandated by a governmental body or might be motivated by a desire to provide for postearthquake operations, to reduce future losses or liability, to reduce insurance premiums, or to increase the resale value of the property. In most cases, seismic improvements to existing facilities are undertaken on a voluntary basis and, as a result, organizations and owners have latitude in setting the objectives and defining the scope of a nonstructural risk reduction program for existing buildings.

4.1.1 Voluntary vs. Mandatory Risk Reduction

In general, a nonstructural risk reduction program for existing buildings would be considered a voluntary upgrade; that is, a program that is voluntarily undertaken by an owner to reduce the potential liability and losses in the event of an earthquake. Although current codes have requirements for bracing and anchorage of nonstructural items, most jurisdictions do not currently require nonstructural hazards to be addressed retroactively in existing facilities.

There are some notable exceptions, in cases where a jurisdiction may require mandatory retrofitting of existing nonstructural components. A few of these are listed below:

- Many jurisdictions in California have ordinances requiring that unreinforced masonry parapets, particularly those adjacent to a public right-of-way, be braced or anchored to prevent collapse in an earthquake.
- Some major cities including Chicago, New York, Boston, and Detroit have façade ordinances that mandate periodic inspection of building façades; while this is not intended as a seismic requirement, it has the benefit that the architectural cladding, veneer, ornamentation, and anchors are inspected and maintained on a regular basis.
- Seismic safety legislation (SB 1953) was passed in California in 1994, following the Northridge Earthquake. That earthquake resulted in the suspension of some or all services at 23 hospitals and in $3 billion in hospital-related damages. This legislation requires California hospitals to comply with specific nonstructural hazard mitigation deadlines, including: (1) major nonstructural items including emergency power supply, bulk medical gas systems, communication systems, fire alarm systems and exit lighting

are to be braced by 2002; (2) most nonstructural items within "critical care areas" are to be braced by 2008; and (3) most nonstructural components within the hospital are to be braced by 2030. This is an unfunded mandate; the burden of financing these improvements rests with the health care providers.

- Major alterations, additions, or changes of use may trigger code requirements to bring existing construction, including the nonstructural items, into compliance with the current code. For instance, conversion of a warehouse to a school building would trigger requirements for current code compliance in many jurisdictions; check for local requirements and exemptions.

The rules that apply for voluntary upgrades to existing facilities are typically different than those that apply to new construction or to mandatory upgrades. While it may be desirable to design the nonstructural anchorage details for existing equipment in existing buildings using the current code, it is not typically required for voluntary upgrades. In order to describe the spectrum of risk reduction objectives, it is useful to introduce some performance-based design concepts.

4.1.2 Performance-Based Design Concepts

The use of performance-based design concepts requires a discussion between building design professionals and their clients about performance expectations and seismic risk tolerance. Performance-based design provides terminology to characterize seismic risk and seismic performance and provides a framework for making comparisons between varying levels of seismic hazard, structural and nonstructural performance, postearthquake functionality, acceptable and unacceptable damage, and total earthquake losses over the expected life of the facility. Design professionals, organizational risk managers, building owners, business owners, and tenants all need to have an understanding of the tradeoffs between risk and reward; an understanding that seismic design and investment choices have a relationship to expected future performance and potential future losses. The parties all need to understand that they make choices, both passive and active, based on their understanding of the issues and their seismic risk tolerance. One may choose to live with known seismic risks or choose to initiate programs to reduce some or all of the known hazards; either way, a choice must be made.

Performance-based design concepts have been in development for several decades; this process is ongoing. These concepts are gradually finding their way into the building codes used for new construction, such as the *International Building Code* and ASCE/SEI 7 *Minimum Design Loads for Buildings and Other Structures*, and into the building standards used for the evaluation and retrofitting of existing structures, ASCE/SEI 31*Seismic Evaluation of Existing Buildings* and ASCE/SEI 41 *Seismic Rehabilitation of Existing Buildings*, respectively. Previous editions of U.S. building codes were based on the philosophy that structures should not collapse in a major earthquake but might suffer severe structural and nonstructural damage; this was a minimum life safety standard and is roughly comparable to the Basic Safety Objective that is now described in ASCE/SEI 41-06 (ASCE, 2006). Although engineers were aware that a "code design" was only meeting minimum standards, it is not clear that building owners and occupants had a similar understanding. What is significant about performance-based design concepts is that they are used to describe a range of objectives and that they make the choice of performance objectives an explicit part of the design process; the design professional and the client need to discuss and agree on those performance objectives.

Analogy: Financial Risk Tolerance

One of the first things most financial advisors do with new clients is to present them with an investment questionnaire to gauge how they feel about risking their money; that is, to assess what is referred to as their "investment risk tolerance." The investment advisor cannot make reasonable recommendations on how to allocate the client's assets without knowing something about their tolerance for financial risk. Is the investor conservative, moderate, or aggressive? Given the tradeoffs between risk and reward, do they have a low, medium, or high tolerance for financial risk?

For existing buildings, ASCE/SEI 41-06 *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) provides a flexible approach for evaluation and improvement of nonstructural components. Nonstructural performance levels are:

- Hazards Reduced – a postearthquake damage state in which nonstructural components are damaged and could potentially create falling hazards, but high hazard nonstructural components are secured to prevent falling into public assembly areas. Other life-safety issues, such as preservation of egress and protections of fire suppression systems are not addressed.

- Life Safety – a postearthquake damage state in which nonstructural components are damaged but the damage is not life threatening. However, significant and costly damage is expected to occur.
- Immediate Occupancy – a postearthquake damage state in which nonstructural components are damaged but building access and life-safety systems generally remain available and operable.
- Operational – a postearthquake state in which nonstructural components are able to support the pre-earthquake functions of the building.

While it is not relevant to describe the engineering design process of ASCE/SEI 41-06 in detail here, it is relevant to describe the decision making process used to determine the scope and desired performance objectives for a voluntary upgrade. Note that in addition to the Basic Safety Objective, the standard provides guidance on choosing objectives for voluntary upgrades that are both more ambitious, "Enhanced," and less ambitious, "Limited," than the Basic Safety Objective. The choice of objective will determine which hazards are addressed, what performance is likely following a major earthquake, and how much structural and nonstructural damage the facility is likely to sustain.

Several key questions as posed in ASCE/SEI 41-06 are listed below. The array of performance options described in ASCE/SEI 41-06 is shown in Table 4.1.2-1:

- What are the retrofitting objectives?
- What earthquake scenario(s) are most relevant for this facility?
- What kind of postearthquake functionality is required for this facility?
- What target structural performance level is required for this facility?
- What target nonstructural performance level is required for the facility?
- What target building performance level is required for the facility, and how does that relate to the target levels of structural and nonstructural performance and to the expected postearthquake damage state for the facility?
- What combination of choices meet the ASCE/SEI 41-06 Basic Safety Objectives? Enhanced Objectives? Limited Objectives?

Table 4.1.2-1 Target Building Performance Levels (after ASCE/SEI 41-06)

Target Building Performance Level	Expected Postearthquake Damage State	Target Structural Performance Level	Target Nonstructural Performance Level
Operational Level	Backup utility services maintain function; very little structural or nonstructural damage	Immediate Occupancy	Operational
Immediate Occupancy	The building remains safe to occupy; any structural or nonstructural repairs are minor	Immediate Occupancy	Immediate Occupancy
Intermediate Level		Damage Control	
Life Safety	Structure remains stable and has significant reserve capacity; hazardous nonstructural damage is controlled	Life Safety	Life Safety
Intermediate Level		Limited Safety	Hazards Reduced
Collapse Prevention	The building remains standing, but only barely; the building may have severe structural and nonstructural damage	Collapse Prevention	Not Considered

As shown in Table 4.1.2-1, buildings are assigned a target performance level, which considers both structural and nonstructural performance objectives.

In contrast to the approach used in ASCE/SEI 7-10 for new buildings where the nonstructural performance level is tied to a single ground shaking hazard, the nonstructural performance levels in ASCE/SEI 41-06 are defined in a manner independent of the ground motion. To establish criteria for a seismic retrofit, a ground shaking hazard level and corresponding structural and nonstructural performance levels are selected. Often, several sets of ground shaking hazards and nonstructural performance levels are established. For example, a building might have target building performance levels of Immediate Occupancy for the design earthquake ground motion and Life Safety for the maximum considered earthquake. Combinations of ground shaking hazard and performance level can be created to suit the needs and resources of the building owner. The engineering approach to nonstructural design ASCE/SEI 41-06 is discussed in Chapter 6 for different types of components.

According to ASCE/SEI 41-06, the Basic Safety Objective is achieved by the following combination:

- Design for *Life Safety Building Performance* for Basic Safety Earthquake 1 (earthquake that occurs every 500 years), AND
- Design for *Collapse Prevention Building Performance* for Basic Safety Earthquake 2 (earthquake that occurs every 2500 years).

All other combinations of performance levels and seismic hazard levels are characterized as either Limited or Enhanced objectives (for more on this, see sidebar at right).

As seen in Table 4.1.2-1, an effort to preserve postearthquake operations at either the *Immediate Occupancy* level or the *Operational* levels require that both structural and nonstructural hazards be addressed. Indeed, the higher *Operational* standard for nonstructural components is what differentiates these two enhanced levels of building performance. Per ASCE/SEI 41-06, the differences in design between the different target levels of building performance are higher or lower seismic design forces and explicit design for more or fewer nonstructural components. Engineering analysis methods, such

Limited and Enhanced Rehabilitation Objectives per ASCE/SEI 41-06

Besides the stated requirements for the Basic Safety Objective, all other combinations of performance levels and seismic hazard levels are characterized as either Enhanced or Limited objectives. In comparison with the Basic Safety Objective, a higher performance level correlates with less damage, lower losses, and increased functionality, whereas a lower performance level correlates with more damage, higher losses, and reduced functionality. The following are examples of Limited Rehabilitation Objectives:

- Address only serious nonstructural falling hazards considering a small, frequent seismic event, i.e., according to ASCE/SEI 41-06 terminology, target for a *Hazards Reduced* nonstructural performance level, considering the 50%/50 year event.
- Address all nonstructural life safety hazards without consideration of structural hazards, i.e., according to ASCE/SEI 41-06 terminology, target for a *Life Safety* nonstructural performance level for any chosen earthquake scenario.

In contrast, the following is an example for an Enhanced Rehabilitation Objective:

- Provide reduced damage and increased functionality, i.e., according to ASCE/SEI 41-06 terminology, design for *Immediate Occupancy* Building Performance for any earthquake hazard level. Note that to achieve this performance level, both structural and nonstructural upgrades may be required.

as nonlinear static and dynamic procedures, are available and can be used to check whether or not the design meets the target performance objectives. There are many other questions that may help refine the project objectives and scope of work, such as:

- What kind of losses can the business or organization tolerate after an earthquake?
- How much downtime can the organization tolerate before employees, clients, or customers go elsewhere?
- Does the organization have earthquake insurance? If so, how much of the losses are covered? What are the deductibles? What is the cost-benefit ratio of doing upgrades versus providing coverage and suffering a loss?
- Is this a historic building, essential facility, or facility with specialized or unique considerations?
- What nonstructural components are under your direct control? Architectural? Mechanical, electrical, and plumbing (MEP)? Furniture, fixtures, equipment (FF&E)? Contents? Or all of these?
- Will the project include upgrades to only MEP and architectural components, or will FF&E and contents be included as well?
- What are the most hazardous nonstructural components?
- For leased facilities, which elements are responsibilities of the owner and which are responsibilities of the occupants?
- If the owner has undertaken any seismic upgrades, is there a report available describing the project objectives or design level? Were nonstructural items addressed?
- Are there any incentives a lessee can offer a building owner to improve the safety of leased space?
- Do you need to consider relocation to another space that provides an increased level of seismic safety?

ASCE/SEI 41-06 is in the last stages of an extensive revision. The new document, ASCE/SEI 41-13, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE/SEI 41-13) merges ASCE/SEI 41-06 and ASCE/SEI 31-03, *Seismic Evaluation of Existing Buildings*. The nonstructural provisions of ASCE/SEI 41-13 will be significantly different than those found in ASCE/SEI 41-06. Major changes include:

- In most cases, the design ground motions for the performance objectives have been reduced. For example, in ASCE/SEI 41-06, the Basic Safety Objective was achieved by meeting Life Safety structural performance criteria when subject to ground shaking having a 10% probability of exceedance in 50 years. In ASCE/SEI 41-13, Life Safety

performance must be met for an earthquake having a 20% probability of exceedance in 50 years, a less severe event.

- The nonstructural performance objectives have been redefined.
  - In ASCE/SEI 41-06, nonstructural performance objectives, from lowest to highest are: Hazards Reduced, Life Safety, Immediate Occupancy, and Operational. While the Operational performance objective is defined, the specific procedures and acceptance criteria were not provided.
  - In ASCE/SEI 41-13, nonstructural performance objectives, from lowest to highest are: Life Safety, Position Retention, and Operational.
  - There is no direct correlation between the old and new nonstructural performance objectives. Table 4.1.2-2 below illustrates the approximate relationship, but only in a general sense. There have been substantive changes to the nonstructural provisions throughout ASCE/SEI 41-13. Note the table is limited to performance objectives for which procedures and acceptance criteria are actually defined:

Table 4.1.2-2 Approximate Relationship of Nonstructural Performance Objectives

ASCE/SEI 41-06	ASCE/SEI 41-13
Hazards Reduced	Life Safety
Life Safety	Position Retention
Immediate Occupancy	-
-	Operational

  - To achieve the Basic Performance Objective in ASCE/SEI 41-13, nonstructural components in essential buildings (Seismic Risk Category IV), such as hospitals, emergency operations centers, and fire stations must meet the "Position Retention" objective - for roughly equivalent to "Life Safety" in ASCE/SEI 41-06. This represents a considerable reduction in requirements compared to the earlier edition.

When FEMA E-74 is used in conjunction with ASCE/SEI 41-13, care must taken to properly determine the appropriate retrofit objective, design procedures, and acceptance criteria. This is of great importance since the term "Life Safety," used throughout this document, has been redefined in ASCE/SEI-41-13 to mean a lower retrofit objective.

The point of including this discussion is not to discourage the reader by presenting the design process as a complex system, tempting the reader to conclude that it would be much easier to do nothing. The point of the discussion is to emphasize that choices need to be made in deciding how to manage seismic risk. Resources are always limited, and seismic risks must be balanced against many other types of risk. Whatever seismic hazard reduction objectives are selected, they should be chosen with an understanding of the risks and rewards. A decision to mitigate known seismic hazards, particularly dangerous life safety hazards, would generally be considered both reasonable and prudent, even if it were not mandated by law. A decision to upgrade a complex facility to *Immediate Occupancy* or *Operational* performance level is a major and complex undertaking, since facility operations may depend on the continued function of hundreds or thousands of individual nonstructural components. Such an upgrade should not be undertaken without an understanding of the costs and benefits of such a program.

4.1.3 Legal Considerations

A common concern voiced by building owners who are considering seismic improvement projects for their building or its nonstructural contents and components is the question of legal liability. A persistent belief is that one should not do anything, because if a life safety issue is uncovered and is made known to the owner, then the owner may be liable for any injuries or deaths that arise due to a severe earthquake damaging their building. This "ignorance is bliss" approach is not supported by legal precedents.

The legal issues involved are not black and white and may depend on the type of the facility, the sophistication of the owner, and the number of occupants at risk. There are two ways of looking at these issues:

- One view is that the standard of care of any owner is to act reasonably and to exercise ordinary care in managing the property. This care includes inspecting and maintaining owned buildings in a safe condition. Safety is usually measured against the building standard in effect at the time when the building was constructed, not the current code or any current evaluation standard for existing buildings. Therefore, if owners choose to evaluate their building using a more modern standard and uncover issues in doing so, it is then at their discretion on how, when, and if to act on these data in a voluntary manner.
- Another view is that if an owner is aware of a dangerous condition on their property, they have an affirmative duty to warn those affected or to mitigate the hazard.

If an owner does undertake a project or program to study and possibly to improve the seismic performance of a building or a building's nonstructural components, then the following is recommended to provide transparency:

- Ensure that any inspection is conducted by competent, qualified, and experienced parties
- Use widely accepted inspection, design, and construction standards such as those from FEMA, ASCE or other national or internationally recognized standard organizations
- Develop clear and complete documentation of decisions and actions
- Establish processes to ensure that all work is performed properly
- Implement any remedial actions through experienced contractors
- Proceed without creating any dangerous conditions and without making the building performance worse than it was before
- Proceed in a reasonable and responsible manner

The position of the authors is that an owner is much better off being proactive and doing something to investigate or improve the performance of a building and its nonstructural components and contents than doing nothing. Ultimately, however, an owner's decision to undertake such a remediation project is his or hers alone, and many considerations, such as public relations, risk tolerance, affordability, and market conditions will undoubtedly be factored into the decision.

It is recommended that an owner concerned with these issues seek appropriate legal counsel with expertise in construction law and seismic mitigation issues, to assist in their decision making process.

4.2 Design considerations

The selection of design solutions must be consistent with the scope and objectives selected for the project. Some design solutions can be implemented without consideration of the building code and without engineering expertise. Other design solutions rely on building codes and standards, such as ASCE/SEI 7-10, ASCE/SEI 31-03, and ASCE/SEI 41-06, that all contain elements of the performance-based design methods discussed above. If engineering consultants are engaged to provide design solutions, the selection of seismic force levels, design coefficients, and design methods depends upon the performance objectives selected.

Specific design solutions for nonstructural items fall into three broad categories:

> NON-ENGINEERED (NE): These are typically simple, generic details or common sense measures that can be implemented by a handy worker or maintenance personnel using

standard items from any hardware store. Many of these solutions apply to contents that are not directly covered by building code provisions. As an example, Chapter 6 contains a detail showing the general configuration for anchoring a bookcase to a stud wall (see Figure 6.5.2.1-4) and identifies the parts needed but does not explicitly indicate the size of the angle bracket or screws needed; this is left to the handy worker based on the size and weight of the particular bookcase and the type and spacing of studs. Some of these types of solutions have failed in past earthquakes, usually due to undersized bolts and hardware or because bolts have failed to engage a structural member. As a result, non-engineered solutions are generally not appropriate for hospitals or other facilities that have chosen operational functionality as a performance level objective.

PRESCRIPTIVE (PR): Prescriptive design details are available in the public domain that have been engineered to meet or exceed code requirements for a set of common conditions and can be used directly in many situations. One prescriptive detail included in Chapter 6 is the anchorage detail for a residential or small commercial water heater (see Figure 6.4.2.4-6). This detail is applicable for the anchorage of a water heater, up to 100 gallons, attached to a wood stud wall. The detail calls out the required hardware and the size and spacing of fasteners.

While there are only a limited number of these details currently available, we anticipate that more such details will be developed as engineers, architects, and specialty contractors become more familiar with the new code requirements for nonstructural components. Some of the prescriptive details have been developed by or for the Office of Statewide Health Planning and Development (OSHPD), the entity in California responsible for overseeing hospital design.

ENGINEERING REQUIRED (ER): These are nonstructural anchorage details specifically developed by a design professional on a case-by-case basis for a specific set of conditions. First, the owner and design professional need to agree on the desired level of protection for the anticipated level of shaking, only then can the design professional develop details consistent with the objectives. Design methods and design coefficients are selected based on the performance objectives as discussed above. An anchorage detail designed for a lateral force of 1.0 g will generally be more robust and more costly than one designed for a lateral force of 0.1g. Higher design forces and more complex engineering methods may be required to meet higher performance objectives.

As part of the design process, it may be important to consider a number of issues:

- **Interaction of nonstructural components**. Many nonstructural systems are interconnected or interdependent; items in close proximity can impact one another and tall or overhead items can fall and damage items below. Lights, ceilings, diffusers, ducts, piping, sprinkler heads, and variable air volume boxes may all share the plenum space above the ceiling and it may be challenging to find ways to keep them separated and to provide independent support for all of them.
- **Interaction of nonstructural and structural components**. Nonstructural components may be damaged by the deformations of structural components. Items that cross seismic separations between buildings, connect at adjacent floor levels, or are located in base isolated structures have special design considerations based on the expected deformations of the structural system.
- **Strength of structural components**. Since nonstructural components typically anchor to structural slabs, walls, and framing, it is important that the capacity of these components be checked for adequacy when tall and heavy items are being anchored to them.
- **Location**. Design forces are typically higher for items located in mid- and high-rise buildings and on roofs. The location of the item in the building may influence the design.
- **Primary vs. secondary effects of failure.** If failure of an item may result in the release of water or hazardous materials such as toxins, chemicals, or asbestos, it may warrant additional attention to address these damaging secondary effects.
- **System performance.** Fire protection systems, emergency power generation systems, and computer and communication networks are systems that depend on the functionality of multiple components; the failure of any part might compromise the functionality of the system. All related components must be checked if the system is required for functionality.
- **Emergency egress.** Items located over exits, in stairways, and along exit corridors may warrant special attention in order to ensure the safe exit of building occupants.

4.3 Project planning and implementation strategies

There are a number of options to consider in implementing a program to reduce the vulnerability of nonstructural components. As described above, one of the critical first steps is to define the project objectives with a clear understanding of what these basic, enhanced, or limited objectives will mean in terms of the expected performance of the facility and amount of structural and nonstructural damage that is expected to occur for a given level of shaking.

It is important to understand at the outset the level of commitment that is required from the organization in order to achieve the desired objectives. In order to achieve the *Hazards Reduced* nonstructural performance level, the bracing or anchoring of several obvious nonstructural falling hazards at a small commercial location may be accomplished by a skilled laborer over several weekends without any employee involvement. On the other hand, achieving the enhanced objectives which would allow for *Immediate Occupancy* or *Operational* performance levels requires a major commitment from the top down in an organization. Achieving a level of readiness that will allow a facility to remain fully operational will likely require both structural and nonstructural upgrades and a commitment of capital, both initial and ongoing; time for employee training; downtime for implementation; incorporation with purchasing, operations, maintenance, facilities, and clear assignment of responsibilities for implementation and ongoing program maintenance.

Additional References for Architects and Engineers

FEMA has published a series of guides addressing the incremental seismic rehabilitation of various types of facilities, including the related nonstructural components, as follows:

FEMA 395	Schools (FEMA, 2003)
FEMA 396	Hospitals (FEMA, 2003)
FEMA 397	Offices (FEMA, 2003)
FEMA 398	Multifamily Apartment Buildings (FEMA, 2004)
FEMA 399	Retail Buildings (FEMA, 2004)
FEMA 400	Hotel and Motel Buildings (FEMA, 2004)

It is also important that someone at the planning stage takes a broad view of what is proposed. A facility survey will identify the items and areas of the facility that will be affected. As the objective is to improve seismic safety, it is important to also take note of existing seismic protections and see that these components are not compromised. It may be necessary to evaluate the strength of existing partition walls and floor or roof framing to see that these components have sufficient capacity to support the nonstructural items to be anchored. In some cases, structural components may need strengthening in order to support the loads from the nonstructural components.

Once the project objectives are defined, there are a range of different strategies that can be used for implementation. Installation of protective measures can be done immediately, in phases, as part of routine maintenance or scheduled remodeling. A comparison of preliminary

cost estimates and schedules for several different implementation strategies consistent with the project objectives may help in deciding which implementation strategy will work best.

4.3.1 Integration with Maintenance Programs

One of the easier means of gradually implementing earthquake protection in an existing building is to train maintenance personnel to identify and to properly mitigate nonstructural hazards that they may discover as they survey the building for other purposes or to mitigate problems identified by an outside consultant engineer. The disadvantages of this approach are that protection is increased only gradually and the potential cost savings from doing several related projects at the same time may be lost.

Once nonstructural bracing and anchorage are installed, maintenance personnel should be trained to inspect and monitor the installations and be responsible for the upkeep of the protective measures where appropriate. For facilities with specialized equipment, this maintenance function must be performed by someone familiar with the equipment to ensure that the protective measures are installed and maintained without compromising the equipment functionality.

4.3.2 Integration with Remodeling

If there are other reasons for remodeling, there may be an opportunity to increase the protection of several nonstructural components at the same time, especially ceilings, partitions, windows, piping, and other built-in features. If an architect, interior designer, or contractor is handling the remodeling, the possibility of incorporating additional earthquake protection into the space should be discussed, and a structural engineer's expertise should be employed where indicated. Newly installed components will need to comply with current code requirements. Depending on the scope, the remodel may also trigger requirements to bring some existing components of the facility into compliance with current code; check the requirements for additions and alterations with the local jurisdiction.

A word of caution: In some cases, remodeling efforts have reduced rather than increased the level of earthquake protection through the accidental modification of components that originally received some seismic protection as a result of the input of a structural engineer or architect. It is important not to compromise existing seismic protections; it is also important not to overload partition walls, floor or roof framing, or an existing ceiling grid by using them to brace or anchor items that are too heavy. In some instances, the remodeling scope may need to be extended to include ceilings, partitions, or structural components so that the strength of these components can be upgraded to support additional loading.

4.3.3 Phased or Incremental Upgrading

In some cases, it may be possible to upgrade different areas within a building at different times or to select one or more types of nonstructural components throughout a building and upgrade them at the same time. Some projects can be completed in a weekend, making it possible to upgrade equipment or other items without interrupting the normal work flow. Companies with annual shutdown periods may find it wise to upgrade the highest-priority items during each annual shutdown. Work that interrupts the use of a space, such as setting up ladders or scaffolding to work on the ceiling or ceiling-located items, could be restricted to limited areas in a facility at a given time, minimizing the overall disruption.

An all-at-once implementation process, similar to that used in new construction, can be used in existing facilities either when the extent of the work required is small or when the work is extensive but the resulting disruption is tolerable. A favorable time for this approach is when a building is temporarily vacant, such as during planned renovations.

4.3.4 Integration with Purchasing

A guideline with a list of nonstructural items could be created to indicate special purchasing considerations. For example, file cabinets should have strong latches and wall or floor attachments, bookcases should have bracing and floor or wall attachments, and server racks should come with seismic detailing. Increasingly, vendors are marketing items with "seismic-resistant" details such as predrilled holes for anchorage. There are also many vendors that supply hardware and kits for seismic anchorage of equipment and furniture; these items should be stockpiled or ordered routinely along with each new equipment purchase. The effective use of these guidelines requires coordination between the purchasing and facilities or operations functions.

Integration with purchasing may be used in conjunction with any of the other strategies. If used alone, it will improve the safety of newly purchased items, but will not enhance the safety of existing items or address architectural items such as parapets, partitions, or ceilings. Over time, the safety of the facility will gradually improve as new items are purchased and existing items are replaced.

4.4 Responsibility and Program Management

4.4.1 Responsibility

Successful implementation of a nonstructural risk reduction program may involve many steps, including integration of the risk reduction program with the overall mission or business plan

and balancing the seismic risks with other risks that businesses and organizations face. Program tasks may include planning, budgeting, scheduling, allocation of in-house resources and personnel, selection of outside consultants and contractors, contract negotiation and administration, coordination of numerous trades, managing outages or disruption, facility surveys, installation, inspection, oversight, purchasing, evaluation, and ongoing maintenance of the seismic protection measures. Assigning clear responsibility for each task is important to the success of any risk reduction program. Figure 4.4.1-1 shows an example of a responsibility matrix that could be readily adapted by listing the nonstructural components for a particular project. This example format can be used to track who is responsible for design, design review, installation, and observation. If special inspection is required, this could also be added to the table. Appendix B contains templates for use in assigning responsibility for design, construction and inspection of nonstructural installations governed by ASCE/SEI 7-10. The responsibility matrices are intended to be used in conjunction with the construction specification in Appendix A.

One of the initial tasks is to assess the capabilities of in-house resources and the need for outside consultants. The answer depends on the nature of the physical conditions in the facility and the characteristics of the organization.

- In-house implementation can be adequate where the potential hazard is small or the in-house familiarity with engineering and construction is greater than average.
- Specialized consultants with experience in the evaluation and reduction of nonstructural risks may be required for essential facilities or larger and more complex facilities where the potential hazards or potential losses are high.
- Facilities with moderate risk may fall in between these two examples and use a combination of expert advice and in-house implementation. For example, after an initial survey is conducted and a report is prepared by an expert, the remainder of the implementation might be handled in-house without further assistance.

Job Aid:
Nonstructural Component Seismic Resistance Responsibility Matrix
Who is Responsible for:

Type of Nonstructural Component or System	Design	Design Review	Installation	Observation
■ Access Floor (raised)				
■ Ceilings				
Suspended T-bar				
Gypsum Board (hung)				
■ Electrical Equipment				
Busduct / Cable Trays				
Power Generator				
Light fixtures				
Main Service Panel				
Transformers				
■ Elevator				
Cable guides				
■ Escalator				
■ Exterior Cladding:				
EIFS				
GFRC				
Metal Panels				
Precast Concrete				
■ Exterior Window Walls				
■ Fire Sprinkler System				
■ Fluid Tanks				
■ Mechanical Equipment				
Air Handlers				
Boilers				
Chillers				
Cooling Tower				
Condensers				
Ductwork / VAV box				
Fans				
Furnaces				
Piping Systems				
Pumps				
■ Interior Partitions				
■ Other Equipment				
■ Stairs				
■ Storage Racks				
■ Veneer				
Brick				
Stone				
■ Water Heater				

Figure 4.4.1-1 Example responsibility matrix.

One of the larger nonstructural earthquake hazard evaluation and upgrade programs is that of the U.S. Department of Veterans Affairs (VA) for its hospitals. The typical procedure followed by the VA is to hire consultant experts to assess the seismic risk at the site, to review the facility and list specific nonstructural items that are vulnerable to future earthquakes, and to provide estimated upgrade costs and group the items by priority. Once the consultants have established the program outline, the VA maintenance staff at each hospital is given many of the implementation tasks. As mentioned in the introduction, there are limits to the self-help diagnosis and prescription approach; especially if larger buildings or more serious safety hazards, property risks, or critical functional requirements are involved, the use of consultants may be advisable.

Consultants and design professionals could be used to assist with any or all of the tasks from program planning through implementation. Outside consultants that could facilitate planning, design, and implementation may include the following:

- Risk managers
- Earthquake engineers
- Structural engineers
- Civil engineers
- Architects
- Mechanical engineers
- Electrical engineers
- Interior designers
- Specialty contractors
- Special inspectors
- Vendors of specialty hardware and seismic protection devices

Many architects and engineers are qualified to design bracing or anchorage for simple nonstructural items. However, the design of anchorage and bracing for specialized equipment or for the systems needed to maintain operations in a hospital or manufacturing facility requires specialized experience with seismic design for nonstructural components. While there currently is not a recognized professional designation for someone with this type of experience, there may be one in the future. The job requires familiarity with MEP equipment and piping, architectural components, issues such as fire protection, and requirements of the Americans with Disabilities Act, computer networks, industrial storage racks, and all the other categories of nonstructural components and contents. When selecting outside consultants, check that they have experience with nonstructural seismic design, preferably specific experience with the type of equipment or facility in question.

4.4.2 Sustaining Protection

On an organizational level, sustaining protection generally requires a serious commitment from management and may include development of seismic planning guidelines for the organization, development of purchasing guidelines, ongoing personnel training, periodic facility audits, and incorporation into annual staff reviews. It is sometimes more problematic to maintain the human aspects than hardware aspects of nonstructural protection. Over time, interior fastenings and restraints may be removed as people move equipment or other items and fail to reinstall the protective devices. Chains used to restrain gas cylinders or elastic shock cords on bookshelves are effective only when they are in use. This is also true of tethers on office copiers, countertop lab equipment, or vending machines. Some nonstructural protection devices, such as anchorage hardware for exterior objects, may deteriorate with time if not protected from rust. New items may be purchased and installed without seismic protection in the absence of purchasing guidelines. As noted above, remodeling projects can sometimes result in the elimination of protective features if there are no seismic guidelines.

Training is required to ensure that gas cylinders, storage rack contents, lab and office equipment, and chemicals are properly stored. Maintenance personnel may periodically survey the building to find out whether or not earthquake protection measures are still effectively protecting mechanical equipment such as emergency generators, water heaters, and specialized equipment. Additionally, supervisors can be made responsible for an annual review of their work spaces. If there is a separate facility or physical plant office in an organization, it may be a logical place for the responsibility for sustaining protection to reside. Organizations with safety departments have successfully assigned the role of overseeing nonstructural earthquake protection to this functional area.

An earthquake risk reduction program should conform to the nature of the organization. In the case of the University of California, Santa Barbara, the implementation and maintenance of a campus wide program to address nonstructural earthquake hazards was initiated by a one page policy memo from the chancellor. Each department head was made responsible for implementation of the policy, and the campus Office of Environmental Health and Safety was given the job of advising departments on implementation, making surveys, and evaluating the program's overall effectiveness (Huttenbach, 1980; Steinmetz, 1979).

4.4.3 Program Evaluation

To assess whether the nonstructural risk reduction program was worth the cost, the strong points and deficiencies of the program need to be established. There are two program evaluation techniques to employ in accomplishing this task. The first is to ask:

- How well has the program met its stated objectives?
- Have the costs been within the budget?
- Have the tasks been completed on schedule?
- Is the scope of the effort as broad as was originally intended, or have some items been neglected that were targeted for upgrades?
- Have employee training exercises or other features of the plan all been implemented?
- How well have the measures been implemented?
- Have the upgrade details been correctly installed?
- Is the training taken seriously?
- Do we need to modify (either enhance or reduce) our objectives going forward?

The second evaluation technique is to ask:

- If the earthquake happened today, how much would the losses be reduced by due to the nonstructural protection program?
- Have the costs been worth the benefits?

4.5 Cost benchmarks – Examples

4.5.1 Example 1 – Manufacturing Facility

The nonstructural components throughout a 500,000 square foot manufacturing facility located in the heart of the New Madrid Seismic Zone were upgraded for improved seismic performance. The facility was originally built in the late 1970's with several periodic expansions constructed into the early 1990's. The project included anchorage and bracing of existing nonstructural components in both manufacturing and office space.

Following a structural evaluation confirming life safety structural performance, a facility-wide nonstructural earthquake risk assessment was conducted and concluded that many of the nonstructural components failed to satisfy the life safety performance objective defined in ASCE/SEI 41-06. A subsequent engineering design phase was performed to design bracing and anchorage for nonstructural components not meeting the performance objective. The strengthening measures included bracing for all natural gas piping and equipment, fire protection piping systems, and emergency power systems as well as items whose damage could pose a threat to the life safety or the egress of building occupants. This included restraints for overhead office lights, bracing of tall unreinforced masonry walls and equipment suspended overhead, and anchorage of floor mounted equipment whose overturning or sliding could block the emergency exit routes for the facility.

The design began in 2006 with an 8 month construction schedule completed in mid-2008. The facility was fully operational throughout construction. Regular communication between the owner, design team, and contractor were cited as key to the project success. Scheduling requirements such as night shifts and work sequencing were incorporated into the design documents and the construction schedule to give the entire construction team a clear understanding of the challenges of working in a 24/7 manufacturing facility.

The approximate cost breakdown for the project in 2007 dollars is summarized in Table 4.5.1-1.

Table 4.5.1-1 Approximate Cost Breakdown for Manufacturing Facility Upgrade Project

	Project Cost
Consultant Fees (Design & Construction)	$200,000
Construction Costs	$700,000
Inspection and Testing	$25,000
Total	$925,000
Average Cost	$2/square foot

4.5.2 Example 2 – School District

A pilot project was undertaken to determine the magnitude of costs associated with implementation of nonstructural damage mitigation measures in a California school district. The pilot project addressed contents and equipment, overhead components and hazardous materials. Nonstructural hazards were surveyed and prioritized in three groups. The highest priority category included those items judged to pose the greatest safety risk. Among the components included were tall bookshelves and filing cabinets, suspended lighting, heavy ceiling systems, and hazardous materials. Roughly half of the items at risk were judged to be in the highest priority category.

A total of seventeen schools were included in the pilot program. The current cost to address the highest priority items ranged from roughly $20,000 per school (primarily to address tall cabinets and files) to $400,000 per school in 2008 dollars (requiring work on suspended components as well as floor- and wall-mounted items).

4.5.3 Example 3 – California Hospital

Seismic upgrading of nonstructural components was undertaken as a stand-alone project in response to SB 1953 regulations, which require California Hospitals to comply with specified nonstructural hazard reduction milestones by December 31, 2008 (see discussion in Section 4.1.1).

The subject hospital is a 228-bed acute care hospital of roughly 230,000 gross square feet, built in the 1970s. The project included anchoring and bracing nonstructural components in designated areas throughout the hospital including central and sterile supply, clinical laboratory service spaces, pharmacy, radiology, intensive care units, coronary care units, angiography laboratories, cardiac catheterization laboratories, delivery rooms, emergency rooms, operating rooms, and recovery rooms. Also included in the scope was the anchorage and bracing of mechanical and electrical equipment serving the designated areas.

Floor-mounted equipment, wall-mounted items weighing over 20 pounds, suspended equipment, piping, and ceilings were included among the items addressed in the project. Seismic anchorage was designed for compliance with 2001 California Building Code requirements.

The primary project challenge was to maintain uninterrupted hospital services 24/7 while accomplishing the mandated work. This required planning efforts by hospital administrators, doctors, nurses, the design team consisting of architects, structural, mechanical, and electrical engineers, contractors and subcontractors. Planning commenced in mid-2003; construction was completed at the end of 2007. The work was successfully completed by working in small areas at a time, often at nights for short durations. In order to complete the work in the intensive care unit, an available wing of the hospital was completely remodeled as “swing space” to enable patients to be relocated from the intensive care unit to the remodeled wing, thereby providing the contractor unrestricted access to complete nonstructural upgrading in the intensive care unit. Work throughout the hospital was complicated by the presence of asbestos in the fireproofing at the underside of the floors. Hazardous material abatement preceded all work.

The cost breakdown for the project in 2007 dollars is summarized in Table 4.5.3-1.

Table 4.5.3-1 Cost Breakdown for California Hospital Upgrade Project

	Base Project	Swing Space	Total
Consultant fees	$2,600,000	$795,000	$3,395,000
Construction	$8,844,000	$5,190,000	$14,034,000
HAZMAT abatement	$986,000	$140,000	$1,126,000
User equipment	$0	$760,000	$760,000
Permits, inspection, testing	$2,014,000	$810,000	$2,824,000
Total	**$14,444,000**	**$7,695,000**	**$22,139,000**

Most of the project cost was attributable to the logistics of making improvements while maintaining uninterrupted hospital operations. The total construction cost of roughly $100 per square foot demonstrates that the most cost effective nonstructural mitigation is undertaken when space is unoccupied such as during planned renovations.

5. Nonstructural Risk Reduction for New Buildings

Nonstructural risk reduction programs may vary depending on whether the nonstructural components in question are in an existing building, an historic facility, an essential facility, a facility containing hazardous materials, or are planned for a new building. The current chapter addresses issues related to new buildings; Chapter 4 addresses issues related to existing construction. Portions of these chapters are written in parallel, yet they are unique to each chapter. If portions apply to either situation, they appear only once. For instance, the material on implementation strategies appears only in Chapter 4; the material on current code requirements and code enforcement appears only in Chapter 5.

There is considerable overlap between the *new* and *existing* building categories. For instance, if an existing building undergoes a major alteration and changes to a higher use category, then it would be required to comply with current codes in many jurisdictions and thus, the project requirements would closely resemble those for new construction. Conversely, a new building becomes an existing building as soon as the occupancy permit is issued. Thus, tenant improvements and the installation of furniture, fixtures, equipment and contents for the first occupants of a leased portion of a new building often take place after the original design team is finished and the major architectural, mechanical, electrical, and plumbing components are installed; for this reason, many of the problems involved in coordinating the anchorage of the tenants' components with preexisting components are the same as for a project in an older existing building.

Historic buildings, essential buildings such as police and fire stations, or facilities that handle hazardous materials have special requirements, which are typically more complex than those for ordinary occupancies. While some issues related to these types of facilities are mentioned here, the treatment of nonstructural components in these facilities is beyond the scope of this guide. The list of references and additional sources of information may help address these issues for specialized facilities.

5.1 Program Objectives and Scope

For new construction, it is possible to anchor, brace, or restrain all of the critical nonstructural items at the same time according to a chosen set of performance objectives and in conformance with current building code requirements. It is generally more efficient and less costly to install anchorage details during construction and at the time of initial occupancy than to upgrade them after the fact.

The planning stage for new construction is the ideal time to consider the desired seismic performance of a facility. It is an opportunity to coordinate the structural and nonstructural aspects of the design, for instance by selecting a structural system that provides a greater level of seismic safety and that will provide for a higher level of both structural and nonstructural performance. It is also critical to communicate concepts of seismic performance, risk, and related options to a building owner, in order to establish project specific design and construction strategies.

The following questions might help define the project objectives, including the nonstructural risk reduction objectives:

- What type of organization or business will occupy the facility?
- What type of functionality is needed during and after a minor, major, or severe earthquake?
- How much structural and nonstructural damage can be tolerated after a minor, major, or severe earthquake?
- Do the design professionals have experience with bracing and anchorage of the types of nonstructural components proposed for the facility, particularly if the facility will need to be operational following an earthquake?
- For an important project, is there a third party peer reviewer for the seismic design, including the design for the nonstructural components?
- What is the value of proposed architectural finishes? MEP systems? Furniture, fixtures & equipment (FF&E) and contents? What would

Additional Questions for an Architect or Engineer to Consider

- What is the design life of the facility?
- What are the magnitudes and frequency of earthquakes the building is likely to experience during its life?
- Has a structural system been chosen that will provide the level of structural and nonstructural protection required? Is the structural system very stiff? Very flexible? Are the inter-story drifts large? Does the structural design include base isolation or energy dissipation devices such as structural dampers?
- What types of nonstructural components are proposed? Would damage to or failure of the proposed components be a life safety hazard or result in heavy property loss, or compromise building function? What is the cost of upgrading to more seismically resistant components and detailing?
- Does the design team have any control over future FF&E and contents? If not, who will have control? Can the design team coordinate the design and installation of these components with design representatives for the initial building occupants?

be the financial impact of damage to or failure of each of these items?

- How much of the potential earthquake losses will be covered by insurance?

It is worth repeating that the nonstructural components and contents typically represent the major portion of the capital investment for new construction; per Figure 2.1.3-1, this is 82% for office buildings, 87% for hotels, and 92% for hospitals (Whittaker and Soong, 2003). Incorporating seismic damage control measures into the design for new construction makes good business sense, particularly for buildings that have a high probability of experiencing damaging earthquakes several times during their life span. For new construction of essential buildings in high seismic areas, damage control measures are now required, in order to increase the likelihood that these facilities will remain functional following a major earthquake.

5.1.1 Voluntary vs Mandatory Risk Reduction

Although code provisions historically have been written with the primary intent to provide a minimum level of life safety and to avoid legislating property damage control measures, code provisions now mandate an increasing level of damage control for certain types of essential and high occupancy facilities. In ASCE/SEI 7-10*, Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) structures are assigned to a Risk Category. The Risk Category is related to the consequences of failure, from the lowest risk to human life (Risk Category I) to the highest (Risk Category IV). Most structures are placed in Risk Category II. Facilities where higher standards are currently mandated include hospitals, aviation control towers, designated emergency shelters, police and fire stations, power generating stations, water storage or pumping facilities, facilities that handle hazardous materials, and a number of others identified as (Risk Category IV in ASCE/SEI 7-10. Except in areas with the lowest seismicity, the structural and nonstructural design of these facilities must meet more stringent design requirements than for standard construction.

For standard construction, a "code design" is intended to provide a minimum level of life safety, now considering both structural and nonstructural components, but it does not provide for significant damage control.

The seismic performance goals for ASCE/SEI 7-10 for typical structures (Risk Category II), designed to the minimum requirements are:

- To avoid serious injury or loss of life
- To minimize repair costs to the extent practical.

In order to achieve enhanced performance (e.g., *Operational*, *Immediate Occupancy*, or a higher level of structural and nonstructural damage control), the design objectives must be targeted higher than the life safety level implicit in the minimum code provisions. Essential structures (Risk Category IV) are designed for higher forces, and more of the nonstructural components must be designed for seismic loads.

Although new construction must meet the minimum life safety standards, owners concerned with building functionality or future earthquake losses may choose to implement a higher standard and to incorporate damage control measures into the design for new construction on a voluntary basis.

Voluntary Adoption of Enhanced Performance Criteria

At their discretion, owners may adopt more stringent seismic design standards than those in the prevailing code.

- Beginning in the late 1970s, some owners of high tech research and manufacturing facilities in California started to use higher standards for the seismic design of critical buildings and nonstructural components on a voluntary basis.
- In the mid-2000s, several thermoelectric power plants in Chile were designed using a special seismic performance criteria stipulated by the owners that require that any damage to the plants from a major earthquake be limited to that which could be inspected and repaired within 14 days time; further, the criteria require that these plants remain operational during moderate seismic events.

In these examples, the owners developed special seismic design criteria to meet the needs of their organizations, primarily motivated by a desire to limit costly postearthquake outages.

5.1.2 Performance-Based Design concepts

The use of performance-based design concepts requires a discussion between building design professionals and their clients about performance expectations and seismic risk tolerance. Performance-based design provides terminology to characterize seismic risk and seismic performance and provides a framework for making comparisons between varying levels of seismic hazard, structural and nonstructural performance, postearthquake functionality, acceptable and unacceptable damage, and total earthquake losses over the expected life of the facility. Design professionals, organizational risk managers, building owners, business owners, and tenants all need to develop an understanding of the tradeoffs between risk and reward; that is, an understanding that seismic design and investment choices have a relationship to expected future performance and potential future losses. The parties all

need to understand that they make choices, both passive and active, based on their understanding of the issues and their seismic risk tolerance. One may choose to live with known seismic risks or choose to initiate programs to reduce some or all of the known hazards; either way, a choice must be made.

Performance-based design concepts have been in development for several decades; this development is ongoing. These concepts are gradually finding their way into the building codes used for new construction, such as IBC 2012 *International Building Code* (ICC, 2012) and ASCE/SEI 7-10). These codes now specify higher seismic design forces and more comprehensive requirements for nonstructural components while at the same time imposing more stringent drift limits on the building structural systems in certain types of facilities in an effort to reduce the earthquake damage and improve the performance of these facilities. Nevertheless, the code generally does not address damage control or postearthquake operations for standard occupancies. If an owner wants to specify higher performance standards than those embodied in the code, it is important that those performance expectations be identified early in the planning process. For example, some owners interested in enhancing the structural and nonstructural performance of their facility will choose a structural system incorporating seismic isolation and/or supplemental damping. Seismic isolation provides the most significant benefit by greatly reducing both drift and acceleration demands imposed on nonstructural systems as well as demand on the structural system itself. Seismic isolation is discussed in more detail in Section 6.1.

Borrowing some terminology used in ASCE/SEI 41-06 *Seismic Rehabilitation of Existing Buildings* (ASCE, 2006) for the rehabilitation of existing construction and previously described in Chapter 4, target building performance levels may be described as *basic* or *enhanced*. Limited performance objectives, those that provide less than the minimum life safety standard, while permissible for existing construction, are not allowed for new construction.

- A *basic* level of safety is achieved by following the code requirements for standard occupancies. This type of design should not be expected to provide significant damage control for structural or nonstructural components or to provide for continued operations or immediate occupancy after an earthquake.
- An *enhanced* performance level is achieved by following both structural and nonstructural code requirements for essential facilities. Enhanced performance could be achieved for nonessential facilities by using some or all of these additional requirements.
- Enhanced performance might also be provided by developing project-specific seismic design criteria to meet the needs of a particular organization (see sidebar on previous

page). These criteria should be developed and implemented by design professionals with specific experience with performance-based design. Engineering analysis methods, such as those using nonlinear or push-over techniques, are available that can be used to check whether or not the design meets the target performance objectives.

It is important that the performance objectives be clear from the outset, so that the owner and design professionals are in agreement on what they are trying to achieve. Design and construction contracts must all include language describing the responsibilities of the designers, contractors, subcontractors, specialty subcontractors, vendors, and inspectors to provide systems and details that will meet the project objectives; this is particularly important if these are enhanced performance objectives that are higher than for a "code design." Budgets and schedules will all have to take into account the resources and time required to achieve the project goals.

5.2 Design Considerations

The selection of design solutions must be consistent with the scope and objectives selected for the project. For all items covered by the code provisions, design solutions must meet or exceed the applicable building codes and standards, such as ASCE/SEI 7-10. For the engineering consultants engaged to provide design solutions, the selection of seismic force levels, design coefficients, and design methods depends upon the Seismic Design Category. The design team and owner need to be clear about the performance objectives and the level of seismic protection that will be targeted. There may be items that are not explicitly covered by the code, for which some design solutions can be implemented by the owner or the initial tenants without consideration of the building code and without engineering expertise.

Specific design solutions for nonstructural items fall into three broad categories. These were described in Chapter 4 and are repeated here because the application is somewhat different for new construction.

NON-ENGINEERED (NE): These are typically simple, generic details or common sense measures that can be implemented by a skilled laborer or by maintenance personnel using standard items from a hardware store. Although these solutions are not appropriate for essential facilities, they may be useful for the restraint of items not directly covered by code provisions, such as furniture and contents that lie below the code threshold but that may still fall and injure occupants. Some of these solutions might be implemented by the owner and the original design team; others by the initial tenants.

PRESCRIPTIVE (PR): Prescriptive details are available in the public domain and have been engineered to meet or exceed code requirements for a set of common conditions; they can be used directly in many situations. While there are only a limited number of these details currently available, we anticipate that more such details will be developed as engineers, architects, and specialty contractors become more familiar with the new ASCE/SEI 7-10 requirements for nonstructural components. Some of the prescriptive details have been developed for hospitals, schools and residences in California, and have been successfully implemented for many years. Examples are provided in Chapter 6.

ENGINEERING REQUIRED (ER): These are nonstructural anchorage details specifically developed by a design professional on a case-by-case basis for a specific set of conditions. Design methods and design coefficients are selected based on the Importance Factor and Seismic Design Category, per IBC 2012 and ASCE/SEI 7-10, as discussed in Section 5.3.1 below. Higher design forces and more complex engineering methods may be required to meet performance objectives higher than those embodied in the building code provisions.

5.3 Building code requirements

5.3.1 2012 Edition of the International building code (IBC 2012)

Structures designed to the provisions of IBC 2012 are expected to have a low likelihood of collapse in the very rare seismic event defined as the Risk-Targeted Maximum Considered Earthquake (MCE_R) ground motion. Nonstructural components and systems are designed to protect occupants from life threatening damage or failures of nonstructural elements in an unusual but less rare earthquake ground motion, which is referred to as the Design Earthquake ground motion (defined as two-thirds of the MCE_R). There is no implicit performance goal associated with the MCE_R for nonstructural components in IBC 2012.

The current code requirements for nonstructural components are contained in ASCE/SEI 7-10 Section 13 which is adopted by reference in IBC 2012 *International Building Code* (ICC, 2012). In recent years, engineers, researchers, and code committees have paid increasing attention to the issues of nonstructural performance. As a result, ASCE/SEI 7-10 now includes a 15-page chapter devoted to nonstructural components and contains design requirements for both force- and displacement-controlled nonstructural components. In contrast, the 1994 UBC *Uniform Building Code* (ICBO, 1994) covered the nonstructural requirements in less than two pages, where the focus of the requirements was primarily on position retention of the components.

The requirements are now more detailed and include explicit provisions for more items that apply to facilities that require postearthquake functionality.

The performance expectations for noncritical nonstructural components (those with an importance factor, $I_p = 1.0$) complying with ASCE/SEI 7-10 are:

- Minor earthquake ground motions – minimal damage; not likely to affect functionality
- Moderate earthquake ground motions – some damage that may affect functionality
- Design Earthquake ground motions – major damage but significant falling hazards are avoided; likely loss of functionality.

Note that only the Design Earthquake ground motion is defined. Minor and moderate ground motions are qualitative descriptions.

Alternative Methods

The code formulas used to compute the design forces on nonstructural components in buildings contain a number of simplifying assumptions regarding damping, response amplification, possible resonance between the equipment and the structure, and the distribution of forces over the height of the structure. For some facilities, more sophisticated analyses may be warranted. The Tri-Service Manual "Seismic Design Guidelines for Essential Buildings" (TM 5-810-10-1) describes an approximate floor response spectrum method that considers two earthquake levels and takes the multi-mode response of the building into account. Beyond that, an analytical model of the building can be used to generate floor response spectra at critical equipment locations, and these spectra can be used to determine the design forces for the nonstructural components and equipment.

For architectural components, the component itself and the attachment of the component to the structure are considered in the seismic design. For mechanical and electrical systems and components, the design is limited to bracing and attachment to the structure, but the structural capacity of the component or system itself is not evaluated.

It is important to note that for some building owners or occupants, loss of functionality in the Design Earthquake (which is a likely performance result of a code minimum design) may not meet their needs. A higher level of performance can be achieved, by using the design requirements intended for essential structures.

The most stringent design provisions are driven by the Component Importance Factor, I_p. Any component with an I_p of 1.5 is considered a "Designated Seismic System" for which special provisions apply. This includes systems required to function for life safety purposes after an

earthquake, including sprinkler systems and egress stairways and components used to convey, support or contain toxic, highly toxic, or explosive substances or hazardous materials. Risk Category IV structures are intended to be functional following a Design Earthquake; critical nonstructural components and equipment in such structures that are needed for continued operation following an earthquake are designed with $I_p = 1.5$.

Components designed with $I_p = 1.5$, have a more robust attachment to the structure and are expected to remain in place sustaining little or no damage. When necessary, they are expected to function following an earthquake. The structural capacity of the component itself (stresses in a piping system, for example) are also evaluated. Active mechanical or electrical components that must remain operable following an earthquake are required to be seismically qualified, usually by shake table testing.

While the building code requires the higher importance factor in essential buildings only for components that must function following an earthquake, the higher importance factor will apply to most of the other components and equipment in the structure as well. Damage to vulnerable unbraced systems or equipment may disrupt operations following an earthquake even if they are not directly classified as essential to continued function. For nonessential and nonhazardous components, which cannot disrupt operations in the event of failure, the requirements focus solely on supports and attachments. Additional distinctions in the design provisions are based on the Seismic Design Category, which ranges from A through F and depends on the Risk Category (I, II, III, or IV) and the ground motion parameters (S_{DS} and S_{D1}) generally as follows:

- Seismic Design Category A: All Risk Categories in areas with minimal seismicity; these facilities are exempt from the nonstructural requirements.
- Seismic Design Category B: Risk Categories I, II, and III in areas with low seismicity
- Seismic Design Category C: Risk Categories IV in areas with low seismicity and Occupancy Categories I, II and III in areas with moderate seismicity
- Seismic Design Category D: Risk Categories IV in areas with moderate seismicity and All Occupancy Categories in areas with high seismicity
- Seismic Design Category E: Risk Category I, II or III in areas of very high seismicity and near an active fault
- Seismic Design Category F: Risk Category IV in areas of very high seismicity and near an active fault

The seismic design forces are based on a variety of factors including the weight of the item, the ground acceleration and soil type, the flexibility of the component and its attachments, the

location in the building, and an importance factor. In general, design forces are higher for flexible components and flexible attachments; higher for items anchored in the upper levels of the building; higher for items that contain hazardous materials, that are needed for life safety functions, or that are needed for continued operations of an essential facility; and lower for items with high deformability or high ductility.

Minimum and maximum limits on design forces are specified in the code. For a given acceleration and importance factor, the range from minimum design forces ($0.3S_{DS}I_pW_p$) to maximum design forces ($1.6S_{DS}I_pW_p$) is a factor slightly greater than 5. Thus, a flexible item anchored at the roof of a building might be designed for up to 5 times more force than a rigid item anchored at the base of the same building.

For items affected by differential movement and building story drift, the code requires that the design consider the relative lateral displacements both within and between structures. This will affect the design of such components as pipe risers and precast panels, which are connected to adjacent floors, and piping, cable trays, ductwork, or architectural finishes crossing seismic joints.

The code includes provisions for architectural, mechanical, and electrical components, supports, and attachments. Tables of design coefficients a_p and R_p are provided for dozens of architectural, mechanical, and electrical components. Where design of nonstructural components or their supports and attachments is required by code, such design must be shown in construction documents prepared by a registered design professional. It is not sufficient to provide a note saying "All ceilings to be braced"; the bracing details must be included on the plans and covered in the project specifications.

Earlier provisions related to nonstructural components in the 2000 and 2003 IBC were concerned primarily with position retention, i.e., preventing components from becoming dislodged or overturned during an earthquake. ASCE/SEI 7-10 contains additional provisions related to postearthquake functionality that are applicable to components with hazardous contents and to equipment that is required to remain operational following an earthquake. For such designated seismic systems, where I_p is 1.5, certification based on approved shake table testing or experience data must be submitted to the authority having jurisdiction.

The code contains a number of significant exemptions (see sidebar). Exemptions are granted for:

- Structures that are subject to low-level earthquake demands (accelerations and relative displacements).
- Components that possess inherent strength and stability
- Items that are not part of the building architecture. This includes items such as temporary or movable items, equipment that is not permanently attached to the structure such as desktop items (computers, copiers, lamps, etc.), and most furniture, except permanent floor-supported storage cabinets, shelving or book stacks over 6 feet tall.
- Lighter nonstructural components that meet certain prescriptive requirements provided they are positively attached to the structure.

Although the building code does not contain requirements for many components, such as furniture, and movable fixtures, equipment and contents that are supplied by tenants and building occupants, these may still pose a significant risk in a strong earthquake, and consideration should be given to tethering or anchoring these items to reduce damage and disruption. For areas with moderate or high seismicity, the risks associated with many of these components can be reduced by following the suggestions contained in Chapter 6.

5.3.2 Enforcement of Code Requirements

The effectiveness of model code requirements governing seismic design of nonstructural components depends on technically sound code provisions, proper

Exemptions for Nonstructural Components

The following items are specifically exempt from the ASCE/SEI 7-10 seismic design requirements for nonstructural components:

1. Most furniture and temporary or movable equipment.
2. Most components in Seismic Design Categories B and C (i.e., normal occupancies in areas of moderate seismicity).
3. Mechanical and electrical components in Seismic Design Categories D, E and F, where all of the following apply:
   a. I_p is equal to 1;
   b. The component is positively attached to the structure;
   c. Flexible connections are provided between the components and associated ductwork, piping and conduit are provided, and either
      i. The component weighs 400 lb or less and has a center of mass located 4 feet or less above the adjacent floor level; or
      ii. The component weighs 20 pounds or less or, in the case of a distributed systems, weigh 5 pounds per foot or less.

application by designers, and code enforcement. Proper enforcement requires both comprehensive plan review and thorough construction inspection.

Plan Review

A comprehensive plan review includes determination of which items require seismic design; and an examination of the details for compliance with code requirements. Determining which items require seismic bracing involves a review of the construction drawings and specifications for each discipline (e.g., architectural, electrical, mechanical, plumbing, and other specialties). Few jurisdictions, if any, have resources devoted to such a comprehensive review of construction documents, and few jurisdictions have reviewers qualified to comprehensively evaluate compliance with all nonstructural code requirements.

An additional challenge in plan review arises from the many items that are commonly excluded from construction drawings, but are identified in the project specifications to be procured from the contractor on a "design-build" basis, or may be "owner furnished and installed." Unless these items are carefully tracked and submitted for review, building department plan review can be nonexistent. Few jurisdictions have mechanisms in place to track and support ongoing review of nonstructural seismic bracing designs developed during construction. The responsibility matrices included in Appendix B are intended to aid project managers in the assignment and tracking of responsibility for nonstructural seismic protection. Used in conjunction with the specification section provided in Appendix A, the responsibility matrices can be used to facilitate compliance with nonstructural performance objectives.

Construction Inspection

Enforcement of nonstructural seismic requirements is often lacking in the construction inspection process. Since details associated with seismic restraint of nonstructural components are not often fully shown on approved drawings, inspectors are left without the tools necessary to evaluate the adequacy of as-built installations. Historically, building inspectors have not been systematically trained to inspect the seismic restraint of nonstructural components, and few inspectors have sufficient experience to field review seismic restraints of nonstructural components that are not covered by a well known standard.

Many design professionals have the necessary training and experience to evaluate the adequacy of nonstructural seismic restraints; however, field observation of nonstructural component installations is often not included in their scope of work. As a result, it is not uncommon for nonstructural components to be installed without inspection.

IBC 2012 contains requirements for special inspection of designated seismic systems. For most buildings, a written statement of special inspection must be prepared by a registered design professional. In buildings assigned to Seismic Design Categories C, D, E or F, the statement of special inspection must include seismic requirements for selected HVAC components, piping systems and electrical equipment. These code requirements are expected to increase the construction oversight of nonstructural installations and ultimately, to improve the seismic performance of nonstructural components.

5.3.3 Requirements for Contents

Building contents, such as furniture, kitchen and laundry equipment, movable partitions, and storage shelving are typically considered separate from the building and are usually the responsibility of the building occupant, not the owner or the original design team. Many such items are specifically exempted from seismic provisions in model building codes (e.g., furniture, floor-mounted equipment weighing less than 400 pounds, and suspended items weighing less than 20 pounds). Regulated by the code or not, contents can pose an additional risk to safety and continuity of operations after an earthquake. The seismic protection of contents is dependent upon an understanding of potential seismic risk, followed by action to mitigate that risk on the part of business owners, homeowners, and tenants. The content examples included in Chapter 6 provide guidance for the bracing and anchorage of many common furniture and content items and can be adapted for other similar items. Building code provisions, guidance documents, or other resources listed in the references can be effectively applied to the design and installation of seismic protection measures for building contents.

5.3.4 Other Standards and Protocols

Many of the challenges related to design, plan review, and construction inspection are resolved when installation in accordance with nationally accepted standards becomes a construction standard of practice. For example, 2012 IBC accepts seismic restraint of fire protection systems designed in accordance with the National Fire Protection Association's NFPA 13 *Standard for the Installation of Sprinkler Systems* (2010). As a result, verification of NPFA 13 compliance is a common occurrence in the field. Similar examples exist for other major nonstructural components: Installation of suspended ceilings in accordance with ASTM C635, ASTM C636, and the *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions (*ASTM E580/E 580M-09a) is included in the IBC by reference.; Selected additional industry standards are listed in Appendix B of the ATC-69 *State-of-the-Art and Practice Report* (ATC, 2008).

Qualification testing is an acceptable alternative to the analytical requirements of the code. IBC 2012 accepts seismic qualification based on nationally recognized testing procedures, such as the, ICC-ES AC 156 *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems* by the International Code Council Evaluation Service. Standard 171-2008 *Method of Test of Seismic Restraint Devices for HVAC&R Equipment* (ANSI/ASHRAE, 2008) provides additional test methods used in the HVAC industry. Selected additional testing protocols, such as FEMA 461 report, *Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components,* are listed in Appendix B of the ATC-69 *State-of-the-Art and Practice Report* and repeated here in Appendix F.

5.3.5 Validation and Refinement of Code Requirements

Seismic design requirements for structural systems have evolved over time as a result of documented earthquake performance and laboratory testing. Seismic design requirements for nonstructural components have also evolved over time; however, comprehensive evaluation of these requirements, either by testing or through postearthquake observations, has been limited. Future earthquakes might be able to provide the information necessary to validate or refine current design requirements, but comprehensive and systematic postearthquake documentation of nonstructural performance is needed. Obstacles to gathering such perishable data will need to be overcome before a quantitative review of nonstructural seismic design requirements can become possible.

5.4 Responsibility and Project Management

Who is responsible for ensuring that nonstructural components are protected from earthquake damage and that design solutions are consistent with the chosen performance objectives? Who is responsible for the design of which types of components? Who provides oversight for the design of the many, potentially interconnected nonstructural items? Who resolves conflicts in cases where different design solutions in different disciplines are incompatible? Who provides oversight for the installation, and inspection for all of the nonstructural items?

Architects, mechanical, electrical and civil or structural engineers, interior designers, landscape architects, construction managers, contractors, specialty subcontractors, equipment manufacturers, vendors, inspectors, testing agencies, plan reviewers, developers, owners, tenants – all these parties may be involved. Coordination of this effort is not a trivial task; the issue of nonstructural seismic risk reduction must be part of the initial planning, so that decisions regarding the structural system, the architectural finishes, the MEP systems, the

landscaping immediately adjacent to the building, and the equipment purchases are all made in accordance with a unified plan that is consistent with the performance goals and the project objectives. It may be advisable to assign a dedicated design professional to the oversight of the design and installation of the nonstructural items.

Questions such as the following must be addressed from the beginning:

- Would a seismically isolated building provide the best and most reliable option for protecting the costly equipment in this facility and allow for continued operations?
- Would a stiff structural system or a flexible structural system be more compatible with the performance objectives for the nonstructural items? Can this structural system be adapted for the architectural design? Can the architectural design be adapted to a more appropriate structural design?
- If the structural system is flexible, will the architect specify flexible finishes and avoid the use of adhered veneers, marble panels, stucco soffits or other items likely to be damaged by inter-story drift?
- If the architect specifies exterior adhered veneer, can the landscape architect provide a wide planting strip around the building perimeter to protect against falling hazards? Will the architect be willing to specify something other than the adhered veneer above exits?

Potential Issues for Specialized Facilities

The following are additional considerations for highly specialized or essential facilities:

- For facilities that depend on unique or specialized equipment that would take a long lead time to replace, is there a way to incorporate a secondary or backup system into the design that would reduce potential outages if the equipment were damaged? Would higher design forces or base-isolation reduce the equipment damage? Is there a need to provide budget and space to stock spare parts or spare equipment?
- For facilities that must remain operational following an earthquake, does the design incorporate elements that would be needed in the event of a catastrophe with lengthy infrastructure outages? The hospital that fared the best following Hurricane Katrina in New Orleans had the following elements in place prior to the hurricane: reserve tanks with water to flush toilets, diesel fuel to run the emergency generators, and gasoline for company vehicles.
- The following questions should also be considered: Would space be needed to provide temporary accommodations for employees? Would a forklift, a backhoe, or other construction supplies and equipment for emergency repairs, backup communications equipment such as ham radios, emergency food supplies, and a designated place for sanitary and waste disposal be needed?

- For facilities that need to provide certification for specified MEP equipment, is certified equipment already available that is appropriate for the facility, or will money need to be budgeted for detailed analysis or shake table testing?
- At what point in the design process will information be available from the structural engineer regarding the behavior of the structural frame, such as inter-story drifts and other information required for the nonstructural design?
- Since lateral forces are higher on the roof, what MEP items are required to be located at the roof level and what items can be relocated lower in the building?
- Are there architectural finishes available that would facilitate the inspection of earthquake damage? Can hatches, openings, or removable panels be provided that would make it easier to inspect structural framing, precast panel connections, piping, or ducts after an earthquake and thus, get occupants back into the building sooner?

5.4.1 Example: Responsibility Matrix

New construction projects typically involve the coordination of numerous parties with overlapping responsibilities and competing or conflicting interests; adding a comprehensive program to brace and anchor nonstructural components and contents makes a new construction project even more complex. Assigning clear responsibility for each nonstructural component and tracking the design, peer review, plan review, installation, observation, and special inspection is very important.

Figure 4.4.1-1 shows an example of a responsibility matrix that could be readily adapted by listing the nonstructural components for a particular project. This sample format can be used to track who is responsible for design, design review, installation, and observation. If peer review or special inspection is required, these could be added to the table. More comprehensive responsibility matrices, developed for each Seismic Design Category and compliance with ASCE/SEI 7-10, are provided in Appendix B. These matrices are intended to serve as templates for use by project managers in assigning and tracking design, construction and inspection responsibilities. They can be used in conjunction with the specification provided in Appendix A and are intended to serve as a roadmap for implementation. Successful use of these tools starts with development of a comprehensive project-specific list of nonstructural components to be addressed.

5.4.2 Example: Seismic Code Block, Saint Louis county, Missouri

When the 2003 International Building Code (ICC, 2003) was adopted in Saint Louis County, Missouri, enforcement of the seismic requirements for nonstructural components was complicated by varying interpretations by design professionals, code compliance plan reviewers, contractors and building inspectors. In response, the County established rules and regulations intended to provide a common set of standards for compliance with the Building Code. A cornerstone of the rules and regulations that were adopted is the requirement for a "Seismic Code Block" on the mechanical, electrical, and plumbing drawings (Figures 5.4.2-1 and 5.4.2-2). The seismic code block requires that the engineer(s) responsible for the design of the mechanical, electrical, and plumbing systems identify the location of the details for anchorage and sway bracing of equipment and system components on the plans, or indicate that they will be furnished by subsequent submission, which will be reviewed by the engineer responsible for the design. Saint Louis County requires accountability for the design and documentation of nonstructural bracing requirements. Installation and building inspection is facilitated by the availability of project-specific bracing details. Use of the Seismic Code Block on all projects could significantly enhance the enforcement of code requirements for seismic bracing of nonstructural components and systems. The Saint Louis County model is expected to serve as a model for other jurisdictions throughout the country.

MECHANICAL AND PLUMBING EQUIPMENT COMPONENTS
EARTHQUAKE LOAD RESISTANCE

Occupancy Category ( ) **Seismic Design Category ( )**

LISTING OF EQUIPMENT AND SYSTEM COMPONENTS	ANCHORAGE TO FLOORS, ROOFS, ETC. (See Note 1 below)		SWAY BRACING (See Note 1 below)		LOCATION OF PROFESSIONALLY SEALED ANCHORAGE AND SWAY BRACING DETAILS			COMMENTS
					ON CONST. DOCUMENTS	SUBSEQUENT SUBMITTAL (See Note 2 below)		
	Not Provided For Project	Provided For Project	Not Provided For Project	Provided For Project	Drawing No. or Spec. Section	Shop Drawings	Separate Permit & Plans	
FIRE PROTECTION, DETECTION & ALARM EQUIPMENT & SYSTEM COMPONENTS: * See Chapter 4, Table 4.1 (List items such as: fire sprinkler system equipment & system components, smoke control & evacuation equipment & system components)								
HAZARDOUS EQUIPMENT & SYSTEM COMPONENTS: * See Chapter 4, Table 4.1 (List items such as: gas piping, piping containing flammable, combustible liquids & gasses or toxic chemicals. Include items such as flammable & combustible tanks, vats & other industrial equipment containing hazardous or toxic liquids, gasses, chemicals, etc.)								
OTHER EQUIPMENT & SYSTEM COMPONENTS NEEDED FOR CONTINUED OPERATION OF OCCUPANCY CATEGORY IV FACILITIES OR WHOSE FAILURE COULD IMPAIR THEIR CONTINUED OPERATION * See Chapter 4, Table 4.1 (List items)								
OTHER GENERAL EQUIPMENT & SYSTEM COMPONENTS (List items such as: boilers, furnaces, AHU's, tanks, heat exchangers and pressure vessels, suspended piping, water heaters, VAV boxes, HVAC ducts, drain, waste & vent piping, pumps, etc.)								

Notes:
1. It is the basic intent of this Code Block to declare whether or not anchorage and sway bracing is being provided on the project. If so, to declare whether or not the details are shown on the plans or will be shown on a subsequent submission. If seismic restraint of a component is not required by code this should be stated in comments. If seismic restraint, which is not required by code, is being provided due to owner/designer requirements this should also be stated in the comments.
2. Shop drawings need to be submitted to the County a minimum of two weeks prior to the planned installation to allow for plan review and distribution to the inspector. Additional time may be needed if such submissions are deficient.

Figure 5.4.2-1 Seismic Code Block worksheet.

ELECTRICAL SYSTEM COMPONENTS
EARTHQUAKE LOAD RESISTANCE

Occupancy Category ( ) **Seismic Design Category ( )**

LISTING OF EQUIPMENT AND SYSTEM COMPONENTS	ANCHORAGE TO FLOORS, ROOFS, ETC. (See Note 1 below)		SWAY BRACING (See Note 1 below)		LOCATION OF PROFESSIONALLY SEALED ANCHORAGE AND SWAY BRACING DETAILS			COMMENTS
					ON CONST. DOCUMENTS	SUBSEQUENT SUBMITTAL (See Note 2 below)		
	Not Provided For Project	Provided For Project	Not Provided For Project	Provided For Project	Drawing No. or Spec. Section	Shop Drawings	Separate Permit & Plans	
FIRE PROTECTION, DETECTION & ALARM EQUIPMENT, & SYSTEM COMPONENTS: * See Chapter 4, Table 4.1 (List items such as fire alarm panels, electric conductors powering fire protection equipment, etc.)								
EMERGENCY OR STANDBY EQUIP. AND SYSTEM COMPONENTS: * See Chapter 4, Table 4.1 (List items such as emergency generators, panel boards, single hanger and trapeze supported system components, bus ducts, primary cable systems, motors control centers and devices, switch-gears, transformers, unit substations, cable tray, conduit, lighting fixtures, etc.)								
OTHER EQUIPMENT & SYSTEM COMPONENTS NEEDED FOR CONTINUED OPERATION OF OCCUPANCY CATEGORY IV FACILITIES OR WHOSE FAILURE COULD IMPAIR THEIR CONTINUED OPERATION: * See Chapter 4, Table 4.1 (List items)								
OTHER GENERAL EQUIPMENT & SYSTEM COMPONENTS (list items such as panel boards, single hanger & trapeze supported system components, communication systems, electrical bus ducts, primary cable systems, electrical motor control centers, motor control devices, switchgear, transformers, unit substations, cable tray, conduit, lighting fixtures, etc.)								

Notes:
1. It is the basic intent of this Code Block to declare whether or not anchorage and sway bracing is being provided on the project. If so, to declare whether or not the details are shown on the plans or will be shown on a subsequent submission. If seismic restraint of a component is not required by code this should be stated in comments. If seismic restraint, which is not required by code, is being provided due to owner/designer requirements this should also be stated in the comments.
2. Shop drawings need to be submitted to the County a minimum of two weeks prior to the planned installation to allow for plan review and distribution to the inspector. Additional time may be needed if such submissions are deficient.

Figure 5.4.2-2 Seismic Code Block worksheet.

The code block above, adopted in 2006, only addresses MEP components that are explicitly covered on the construction documents. Nevertheless, it provides a model for keeping track of these items. The project architect or design professional responsible for the general oversight of the nonstructural protective measures could expand this table to cover the various architectural, FF&E, and content items that are within the control of the original design team and use this as a tool for tracking the design and plan review for these items. Revised May 2010, the St. Louis County Rules and Regulations include requirements for architectural and MEP components and provide a standardized form to be used to track construction inspections (see http://www.co.st-louis.mo.us/YourGovernment/CountyDepartments/PublicWorks/Documents/PublicNotices/#Seismic Notices). This document includes examples of forms filled out as intended, with each equipment item provided a separate line item in the code block. As with any tool, the seismic code block is only effective if the design team provides a complete list of the relevant items covered by the code provisions.

6. SEISMIC PROTECTION OF NONSTRUCTURAL COMPONENTS

6.1 Protective Measures

Reducing nonstructural hazards requires a combination of common sense measures and additional protective measures that involve the installation of seismic anchorage and bracing. These measures are typically applied on a component basis, or on a systems basis when continuity of service is desired. The protective measures recommended in this Chapter will go a long way toward reducing the earthquake hazards from nonstructural components. There are additional technologies available to reduce seismic forces and deformations that cause earthquake damage at the building level. Seismic isolation (commonly also referred to as base isolation) is one such technology that can be used to protect both structural systems and nonstructural components and contents from damage by altering the building response to earthquakes. While this chapter focuses on individual components, the performance of system depends on the collective behavior of the components comprising the system.

6.1.1 Common Sense Measures

A facility survey may identify components that represent a high or moderate risk in their present location but that could readily be relocated or rearranged, in order to reduce the potential risk. The answers to the following questions may help identify common sense measures available to reduce many of these risks:

- Which areas of the building have a higher occupant load and hence a potentially higher life safety risk?
- Are there heavy, unstable items currently located near a desk or bed, which could be moved?
- Are the exits and exit pathways clear, or are there items that could block doors, corridors, or stairways if they were to fall?
- What is the probability that someone will be injured by falling objects?
- Can items no longer serving a useful function be removed?
- Are all hazardous materials stored properly?
- Which items can be relocated to prevent possible injury and do not need to be anchored, in order to prevent damage or loss?
- If something slides or falls, in what direction is it likely to move?

- Is a suspended item currently hanging where it may impact a window, wall, or another item?

While the answer to these questions may not always be obvious, some simple steps may go a long way toward reducing the related nonstructural risks. The primary investment here is the time required to relocate furniture, reshelf items, or rearrange hazardous chemicals. For instance:

- Tall or heavy objects can be relocated, so that they cannot block an exit or fall onto a desk or bed.
- Shelved items might be rearranged so that heavier items are near the bottom and lighter ones are near the top.
- Falling hazards, such as curios, potted plants, and flower vases can be relocated, so that they will not fall on a bed or desk.
- Hanging objects can be relocated to a place where they will not impact one another or a window.
- Incompatible chemicals can be separated, in order to prevent mixing if the containers should break.
- Excess supplies or inventory can be stored in their original shipping containers until ready for use, in order to reduce the possibility of breakage.
- Rarely used files or materials can be moved to an offsite storage facility or be disposed of.
- Important electronic files should all be backed up to an offsite facility in a different geographic area, which would not be affected by the same earthquake.

6.1.2 Nonstructural Component Protection Measures

There are many techniques available to reduce potential nonstructural earthquake damage. Possible upgrade schemes might include one or more of the following seismic protection measures:

- Using anchor bolts to provide rigid anchorage to a structural floor or wall
- Bracing the item to a structural floor or wall
- Providing a tether or safety cable to limit the range of movement if the item falls or swings
- Installing bracing or anchors for architectural appendages such as chimneys, parapets, canopies, marquees, or signs; anchoring masonry veneer and cornices

- Providing stops, bumpers or snubbers to limit the range of movement if the item is on vibration isolators or can slide or swing
- Providing flexible connections for piping and conduit where they cross seismic joints or connect to rigidly mounted equipment
- Attaching contents to a shelf, desktop, or countertop
- Providing base isolation or seismic shock absorbers for individual pieces of vital equipment

Some of these methods are designed to protect the functional integrity of a particular item; some are designed merely to reduce the consequences of failure. It is important to understand the applicability and limitations of the various upgrade schemes and to select an appropriate scheme for a particular item in a specific context. It is also important to select upgrade details that are consistent with the program objectives: measures required for immediate occupancy or continued operations are typically more complex than those required solely to reduce falling hazards. Measures used to restrain new items may differ from those used to restrain existing items, particularly if the restraint for the existing items is intended to meet only limited objectives and to reduce falling hazards. Critical and expensive items, library and museum collections, hospitals, essential facilities, laboratories, and industrial clean rooms may all require special attention.

Requirements for Postearthquake Operations

Facilities to be upgraded to *Immediate Occupancy* or *Operational* performance level followinga major earthquake may require extensive modifications and implementation of an ongoing risk reduction program. In order to achieve these enhanced objectives, any or all of the following elements may be needed in order to provide an appropriate level of nonstructural protection:

- Specialized engineering expertise from design professionals experienced with nonstructural seismic protection
- Higher design forces than those required by code for the basic safety objective
- Experienced specialty contractors
- Special construction inspection
- Load-rated hardware and specialty seismic restraint items
- Active equipment that is certified by the vendor to remain operational either by, shake table testing, or experience data
- Components with hazardous contents that are certified to maintain containment either by analysis, shake table testing, or experience data
- Equipment or piping with special design details such as dampers or base isolation

Some structural upgrades may also be required in order to meet the operational objectives such as larger seismic gaps to prevent pounding between adjacent structures, or stiffer structural systems such as shear walls to avoid excessive distortion of the structural framing. Structural measures to reduce seismic hazards are addressed in ASCE 31-03 and ASCE 41-06 but are beyond the scope this document.

6.1.3 building Protection Measures

It is possible to greatly reduce nonstructural damage and improve the probability of operability following an earthquake by reducing the earthquake demands that nonstructural components are subjected to. Conventional seismic design of building structures is based on the concept of increasing resistance against earthquake forces through the use of shear walls, braced frames, or moment resisting frames. Stiffer building systems often result in higher floor accelerations that are potentially damaging to many nonstructural components. More flexible buildings tend to have increased interstory drift that is potentially damaging to other nonstructural components. One building design concept that has been successfully used to resist earthquakes and greatly reduce both acceleration and drift demands (by factors of 4 or more) and therefore corresponding reducing or eliminating damage to nonstructural components is seismic isolation. Both floor accelerations and interstory drift are reduced in seismically isolated buildings through the use of specially designed interfaces that are typically located at the structure base. These interfaces take advantage of the properties of known earthquake ground motion and trade off significant displacement demands at the base of the structure with reduced acceleration and structure deformation above the base by significantly increasing the fundamental period of the building system. Seismic isolation essentially decouples the building response from the earthquake ground motions in a controlled manner.

The benefits of seismic isolation have been demonstrated in recent large earthquakes including the 1994 Northridge, 2010 Chile and 2011 Japan Earthquakes. The benefits have been most recently observed in full-scale testing of a 5-story building conducted on the large outdoor shake table at University of California San Diego in 2012. In this project (in part sponsored by the National Science Foundation and FEMA), a full-scale reinforced concrete building was constructed and outfitted with an array of nonstructural components included cladding, interior partitions, mechanical and electrical equipment, stairs and elevator and floors dedicated to hospital facilities, servers facilities, laboratories and residential areas. The building was tested with identical strong earthquake motions with and without seismically isolators. The building response with isolators was dramatically reduced with seismic isolators as compared to building response without isolators. More data, papers, reports, and videos from the testing project are expected to be made available in 2013 and 2014.

6.2 Nonstructural Component examples

The tables in this chapter and the checklists and risk ratings in the appendices all have similar numbering; illustrated examples are provided for many, but not all, of the components listed. The components addressed herein have been grouped under three major headings:

- Architectural Components
- Mechanical, Electrical & Plumbing (MEP) Components
- Furniture, Fixtures & Equipment (FF&E) and Contents

Each of these three major categories includes a number of subcategories. The checklists and risk ratings in Appendices D and E address all of the subcategories; examples are also provided here for each of the components listed. This document has been prepared as a web-based document with the idea that additional examples may be added in the future.

The nonstructural component examples typically consist of the following elements:

- **Typical Causes of Damage**: A brief description relevant to the particular item.
  - **Damage Examples:** The photographs presented here cover a variety of situations and have been taken over a 39-year period. Photographs from the 1971 San Fernando Earthquake generally show damage to components that were not restrained, while some of the more recent photographs depict damage to components that appeared to be braced or anchored but whose bracing and anchoring details were apparently inadequate to resist the severity of the shaking. Photos from the 2010 Haiti, Chile, Eureka, California, Baja California, and Christchurch, New Zealand Earthquakes have been included, illustrating the ongoing problems with nonstructural performance.
- **Seismic Mitigation Considerations:** A description of issues relevant to the mitigation of the particular item.
  - **Mitigation Examples:** The photographs presented here show braced and anchored components. Most are examples of properly anchored components; some show improper installations with an explanation of the problem(s).
  - **Mitigation Details:** Usually one or more suggested details that can be used to reduce the seismic vulnerability of the item. These details are not engineering drawings; in general, they have been drawn with shading to represent the appearance of the properly anchored item. The protection measures or seismic anchorage details are classified as Non-Engineered (NE), Prescriptive (PR), or Engineering Required (ER); these terms are described below.

6.2.1 Typical Mitigation Details

Non-Engineered (NE) Details

These are simple, generic seismic protection details that do not require engineering design to determine the requirements. Some examples of types of nonstructural protection that can be designed and implemented without an engineer include:

- Restraints for tenant-supplied movable equipment and furniture
- Restraints for cabinet doors and drawers
- Restraints for shelved items

For these types of elements, generic restraint details are usually sufficient to provide adequate protection. The earthquake forces on these elements are generally small compared to the strength of the restraint methods that are usually recommended. Together with the installation guidelines at the end of this chapter, enough information is provided to enable someone without specialized expertise in the field to install the restraint shown using common tools and readily available materials. Many vendors now sell off-the-shelf seismic restraints that can be used for these Non-Engineered details; check the internet for available hardware.

There are limitations to the use of non-engineered seismic protection measures: this method should only be used for elements that are relatively lightweight. Non-engineered restraints should not be used for elements that are considered critical, such as emergency power systems, large inventories of hazardous materials, or in hospitals, where immediate postearthquake operations are desired.

Prescriptive (PR) Details

These mitigation solutions rely on standard restraint details that have been previously developed and can be implemented without the need for an engineer. Together with the installation guidelines at the end of the chapter, enough information is provided to enable a contractor or skilled individual to install the restraints shown.

Examples of elements that can be mitigated by prescriptive methods include:

- Water heaters, up to 100 gallons capacity
- Suspended acoustic ceilings, up to 4 pounds per square foot in weight

While the underlying design of the prescriptive details has been reviewed by experienced engineers, some judgment is required on the part of the user to ensure that their use is appropriate for the situation. For instance, the ceiling bracing detail shown may not be

appropriate for ceilings weighing more than 4 pounds per square foot; the user will need to verify the weight of the ceiling in question.

Engineering Required (ER) Details

Bracing, anchorage, or restraint details for these components require design by an engineer or design professional experienced in the seismic design of nonstructural elements. The details provided in this document are schematic details showing common solutions for the components in question. These figures do not contain sufficient information for installation; they are provided primarily as an illustration of the required scope of work and the necessary elements for proper seismic restraint. Information regarding the size and spacing of bolts, type and size of steel shapes, appropriate configuration, required restraint capacity, and capacity of the structural elements to which they are attached needs to be determined by an engineer, or in some cases, by a specialty contractor.

The designation Engineering Required has been used for components for which the non-engineered approach is most likely to be ineffective. The recommendation of this guide is that design professionals be retained to evaluate the vulnerability of these components and to design appropriate anchorage or restraint details, particularly when safety is an issue. As stated earlier, this recommendation may apply to all components of specialized facilities such as hospitals and emergency operations or communications centers, where interruption or loss of function is unacceptable. Recent experience has shown many instances in which fire sprinkler and other water lines, HVAC equipment, emergency generators, water tanks, ceilings, parapets, glazing, and such were damaged when subjected to severe shaking and failed to perform as expected. The lesson learned from this experience is that the protection of many items, particularly MEP equipment and architectural components in facilities that are expected to be functional after an earthquake, or could be immediately restored to operation by routine means, is a complex undertaking that should be addressed by engineers and architects with specific expertise in this area. As a result, most MEP systems and architectural components have been given the designation Engineering Required. Several of the items listed under FF&E and contents have also been given this designation.

The following table lists the subcategories and the component examples included in the following sections:

Table 6.2.1-1 List of Nonstructural Components

Subcategory	Example	Component Type	Type of Detail
SECTION 6.3		**ARCHITECTURAL COMPONENTS**	
6.3.1		**Exterior Wall Components**	
	6.3.1.1	Adhered veneer	ER
	6.3.1.2	Anchored veneer	ER
	6.3.1.3	Prefabricated panels	ER
	6.3.1.4	Glazed exterior wall system	ER
	6.3.1.5	Glass Blocks	ER
6.3.2		**Interior Partitions**	
	6.3.2.1	Heavy	ER
	6.3.2.2	Light	ER
	6.3.2.3	Glazed	ER
6.3.3		**Interior Veneers**	
	6.3.3.1	Stone and Tile	ER
6.3.4		**Ceilings**	
	6.3.4.1	Suspended lay-in tile ceiling systems	PR
	6.3.4.2	Ceilings applied directly to structure	NE
	6.3.4.3	Suspended heavy ceilings	PR
6.3.5		**Parapets and Appendages**	
	6.3.5.1	Unreinforced masonry parapets	ER
6.3.6		**Canopies, Marquees, and Signs**	
	6.3.6.1	Canopies, marquees, and signs	ER
6.3.7		**Chimneys and Stacks**	
	6.3.7.1	Unreinforced masonry chimney	ER
6.3.8		**Stairways**	
	6.3.8.1	Stairways	ER
6.3.9		**Freestanding Walls and Fences**	
	6.3.9.1	Freestanding masonry wall or fence	PR
SECTION 6.4		**MECHANICAL, ELECTRICAL, & PLUMBING (MEP) COMPONENTS**	
6.4.1		**Mechanical Equipment**	
	6.4.1.1	Boilers, furnaces, pumps, and chillers (HVAC wet	ER
	6.4.1.2	General manufacturing and process machinery	ER
	6.4.1.3	HVAC equipment with vibration isolation	ER

Subcategory	Example	Component Type	Type of Detail
	6.4.1.4	HVAC equipment without external vibration isolation	ER
	6.4.1.5	HVAC equipment suspended in-line with ductwork	ER
	6.4.1.6	Suspended equipment	ER
6.4.2		**Storage Tanks and Water Heaters**	
	6.4.2.1	Structurally supported tanks and vessels	ER
	6.4.2.2	Flat bottom tanks and vessels	ER
	6.4.2.3	Compressed gas cylinders	NE
	6.4.2.4	Water heaters	PR
6.4.3		**Pressure Piping**	
	6.4.3.1	Suspended pressure piping	ER
	6.4.3.2	In-line valves and pumps	ER
	6.4.3.3	Flexible connections, expansion joints, and seismic	ER
	6.4.3.4	Pipe risers	ER
	6.4.3.5	Floor-mounted supports	ER
	6.4.3.6	Roof-mounted supports	ER
	6.4.3.7	Wall-mounted supports	ER
	6.4.3.8	Penetrations	ER
6.4.4		**Fire Protection Piping**	
	6.4.4.1	Suspended fire protection piping	ER
6.4.5		**Fluid Piping, not Fire Protection**	
	6.4.5.1	Hazardous materials piping	ER
	6.4.5.2	Nonhazardous materials piping	ER
6.4.6		**Ductwork**	
	6.4.6.1	Suspended ductwork	ER
	6.4.6.2	Air diffusers	NE, ER
6.4.7		**Electrical and Communications Equipment**	
	6.4.7.1	Control panels, motor control centers, and	ER
	6.4.7.2	Emergency generator	ER
	6.4.7.3	Transformers	ER
	6.4.7.4	Batteries and battery rack	ER
	6.4.7.5	Photovoltaic (PV) power systems	ER
	6.4.7.6	Communications Antennae	ER
6.4.8		**Electrical and Communications Distribution**	
	6.4.8.1	Electrical raceways, conduit, and cable trays	ER
	6.4.8.2	Electrical distribution panels	ER
6.4.9		**Light Fixtures**	

Subcategory	Example	Component Type	Type of Detail
	6.4.9.1	Recessed lighting	PR
	6.4.9.2	Surface-mounted lighting	PR
	6.4.9.3	Pendant light fixtures	NE
	6.4.9.4	Heavy light fixtures	NE
6.4.10		**Elevators and Escalators**	
	6.4.10.1	Hydraulic elevator	ER
	6.4.10.2	Traction elevator	ER
	6.4.10.3	Escalators	ER
6.4.11		**Conveyors**	
	6.4.11.1	Conveyors	ER
SECTION 6.5		**FURNITURE, FIXTURES, & EQUIPMENT (FF&E) COMPONENTS**	
6.5.1		**Storage racks**	
	6.5.1.1	Light duty shelving	NE, ER
	6.5.1.2	Industrial storage racks	ER
6.5.2		**Bookcases, Shelving**	
	6.5.2.1	Bookshelves	NE
	6.5.2.2	Library and other shelving	ER
6.5.3		**Computer and Communication Equipment**	
	6.5.3.1	Computer access floors and equipment	ER
	6.5.3.2	Computer and communication racks	NE
	6.5.3.3	Desktop computers and accessories	NE
	6.5.3.4	Televisions and video monitors, wall-mounted	NE
6.5.4		**Hazardous materials storage**	
	6.5.4.1	Hazardous materials storage	NE
6.5.5		**Miscellaneous FF&E**	
	6.5.5.1	File cabinets	NE
	6.5.5.2	Demountable partitions	NE
	6.5.5.3	Miscellaneous furniture and fixtures	NE
6.5.6		**Miscellaneous Contents**	
	6.5.6.1	Shelf-mounted items	NE
	6.5.6.2	Desktop, countertop items	NE
	6.5.6.3	Fragile artwork	NE
	6.5.6.4	Fire extinguisher and cabinet	NE

6.3 Architectural Components

6.3.1 Exterior Wall Components

6.3.1.1 Adhered Veneer

Adhered veneers are typically thin materials such as tile, masonry, stone, terra cotta, ceramic tile or stucco that are attached to a backing substrate using an adhesive. These may pose a significant falling hazard. The risk to life safety rises significantly for thicker, heavier veneers.

Provisions

BUILDING CODE PROVISIONS

Building code provisions for adhered veneers are prescriptive, and have not changed substantially since the late 1960's. The current provisions are found in TMS402-11/ACI530/ASCE 5-11, *Building Code Requirements for Masonry Structures* (ACI, 2011). The code limits the thickness, size, and weight of adhered veneers.

- The code specifies minimum shear strength between the adhered veneer unit and the backing substrate. Performance of adhered veneers depends on the adhesion of the veneer to the backing substrate.
- Out-of-plane deflections of walls with brittle finishes (including adhered veneers) under wind or seismic loads are limited to the span length, L, divided by 240 (L/240). It should be noted that this deflection limit is not sufficient to prevent cracking of the veneer, and many industry groups recommend more conservative limits. For example, the Tile Council of America recommends a limit of L/360, and Brick Industry Association recommends limiting out-of-plane deflections to a range between L/600 and L/720. The less conservative deflection criteria in the building code reflect the assumption that even if the veneer cracks under lateral load, safety performance should be adequate if there is a good bond between the veneer and the substrate.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies adhered veneers as primarily deformation sensitive. Adhered veneer is subject to the requirements of ASCE/SEI 41-06 when:

- The performance level is Immediate Occupancy or Life Safety.

- The performance level is Hazards Reduced and heavy veneer is located over areas of public access or egress.

Acceptance criteria focus on limiting the in-plane and out-of-plane deflections of the anchored veneer.

Typical Causes of Damage

- Adhered veneers are generally deformation sensitive in-plane and out-of-plane and may crack or become dislodged due to deformation of the backing substrate. Adhered veneers placed directly over shear walls or structural elements that are designed to undergo large deformations may be particularly vulnerable.
- Poorly adhered veneer may come loose due to direct acceleration out-of-plane. This may be a particular problem where the adhesive bond has deteriorated due to water intrusion or degradation of the backing substrate.

DAMAGE EXAMPLES



Figure 6.3.1.1-1 Failure of adhered masonry veneer at the Atascadero City Hall in the 2003 magnitude-6.5 San Simeon Earthquake (Photo courtesy of Mike Mahoney, FEMA).



Figure 6.3.1.1-2 Close-up of failed adhered veneer. (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.3.1.1-3 Cracked and spalled adhered veneer reveals incipient structural damage to concrete piers in Viña del Mar following the 2010 magnitude-8.8 Chile Earthquake. In this case, the areas of structural and nonstructural damage coincide; the adhered veneer remained intact over portions of the shear wall that did not deform significantly (Photo courtesy of Santiago Pujol, Purdue University).





Figure 6.3.1.1-4 Failed adhered veneer fallen from parapet in Santiago following the 2010 magnitude-8.8 Chile Earthquake. (Photos courtesy of Antonio Iruretagoyena, Rubén Boroscheck & Associates)

Seismic Mitigation Considerations

- Repair any cracked or loose veneer; repair any damage or deterioration of the backing substrate.
- Remove adhered veneer above exits or pedestrian walkways, especially larger units if they are mounted above 10 feet.
- Design a structural canopy to resist the weight and impact of falling veneer; particularly above exits or walkways.
- Restrict pedestrian access below the veneer by providing a barrier or wide landscaping strip.
- Provide positive connections to attach the veneer to the structure; see Figure 6.3.1.2-5, in the Anchored Veneer example or Figure 6.3.3.1-3 in the Interior Veneer example.
- If the expected seismic building drifts are substantial and replacement of the veneer is an option, consider substituting anchored veneer for adhered veneer. Anchored veneer can be designed accommodate larger story drifts.

MITIGATION EXAMPLES



Figure 6.3.1.1-5 Landscaping strip restricts pedestrian access adjacent to adhered veneer façade. Larger units used within lower 6 feet; smaller units used above (Photo courtesy of Cynthia Perry, BFP Engineers).

MITIGATION DETAILS

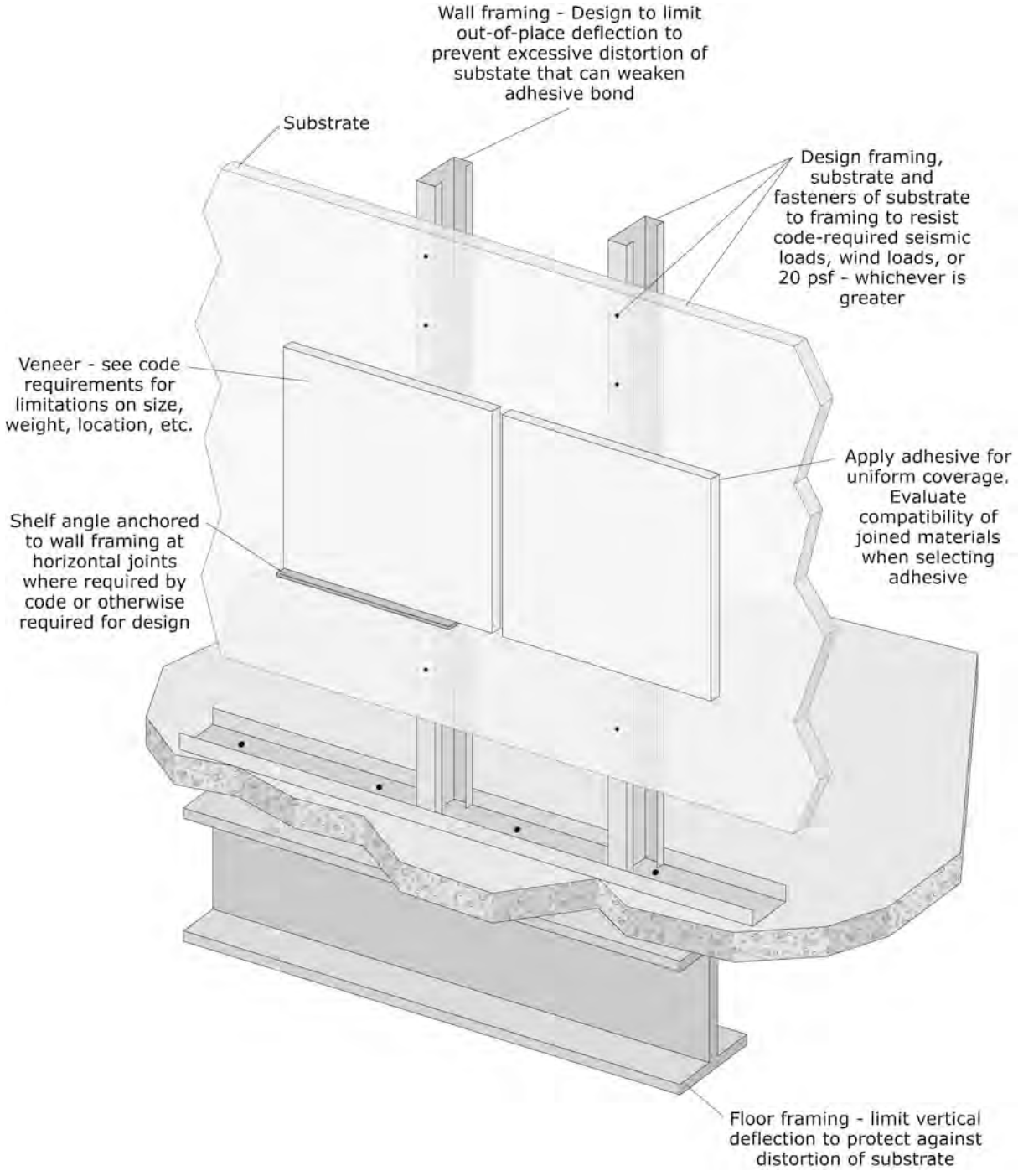


Figure 6.3.1.1-6 Adhered veneer (ER).

6.3 Architectural Components

6.3.1 Exterior Wall Components

6.3.1.2 Anchored Veneer

Anchored veneers are typically masonry, stone or stone slab units that are attached to the structure by mechanical means. These units and their connections must be designed to accommodate the anticipated seismic drift; otherwise they may pose a significant falling hazard.

Provisions

BUILDING CODE PROVISIONS

2012 IBC, *International Building Code*, (ICC, 2012) and TMS 402-11/ACI 530/ASCE 5-11, *Building Code Requirements for Masonry Structures* (ACI, 2011) contain a number of prescriptive requirements and limitations on the use of anchored veneer. These include height limits, drift limits, deflection limits, limits on the use of combustible structural supports such as wood, limits on basic wind speed, cavity size limits, mortar bed minimum thickness limits, and minimum tie spacing limits.

- Seismic loads for anchored veneer are calculated using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13.
- The seismic provisions for masonry veneer in TMS 402-11/ACI 530/ASCE 5-11 are organized based on the severity of potential ground shaking at the site. The requirements are cumulative, adding requirements in areas of higher risk. The provisions require the veneer to be isolated from the structure to prevent accidental loading and accommodate building deformation. Veneer anchors (sometimes referred to as ties) are designed to allow movement in the plane of the wall but resist out-of-plane forces. Spacing of the anchors is dependent on the weight of the veneer and the seismic load.
- Seismic provisions for stone veneer are found in Chapter 14 of the 2012 IBC.
- The structural element or backing supporting anchored veneer (usually a wall) must have sufficient strength and stiffness to support the vertical and lateral loads imposed by the veneer. Many of the prescriptive limits for anchored veneer are triggered by the nature of the support backing. Veneer anchored directly to concrete or masonry walls

has the fewest limitations. Anchored veneer supported by wood or light frame steel walls has more restrictions.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies anchored veneers as both acceleration and deformation sensitive.

- Anchored veneer is subject to the requirements of ASCE/SEI 41-06 when it is over 48 inches above the ground or adjacent exterior area. and
    - The performance level is Immediate Occupancy or Life Safety.
    - The performance level is Hazards Reduced and heavy veneer is located over areas of public access or egress.
- Acceptance criteria focus on checking the anchorage of the veneer under seismic loading and limiting in-plane deflections.

Typical Causes of Damage

- Anchored veneers and their connections may be damaged by inertial forces and by building distortion; units located at corners and around openings are particularly vulnerable.
- Rigid connections may distort or fracture if they do not have sufficient flexibility to accommodate the seismic drift; veneer units may crack, spall, or become completely dislodged and fall.
- Deterioration or corrosion of the mechanical connections is a significant concern; corroded connections may fail prematurely. Maintaining watertightness at joints is important for the longevity of the anchors.

DAMAGE EXAMPLES



Figure 6.3.1.2-1 Fallen sandstone veneer as a result of a magnitude-4.4 earthquake in northern California. Post-earthquake investigation revealed missing dovetail anchors, missing pencil rods, and weak stone-to-mortar bond (Photo courtesy of Simpson Gumpertz and Heger).



Figure 6.3.1.2-2 Fallen sandstone veneer as a result of a magnitude-4.4 earthquake (Photo courtesy of Simpson Gumpertz and Heger).



Figure 6.3.1.2-3 Rubble from failed anchored veneer as a result of the 1994 Northridge Earthquake (Photo courtesy of Robert Reitherman).

Seismic Mitigation Considerations

- Check the applicable code requirements when considering seismic mitigation options.
- Existing veneer anchors should be checked periodically and corroded anchors should be replaced. Tie spacing should be compared with current code requirements to evaluate whether the anchorage is sufficient. Additional anchors may reduce the falling hazards.
- There are many vendors who supply veneer anchors; these are typically metal wires or clips with a positive attachment to the structural backing that are embedded in the veneer mortar bed. The seismic version of these anchors requires an additional horizontal wire placed in the mortar bed and attached to the anchor. Some examples of these seismic veneer anchors are shown, others can be found online.

MITIGATION EXAMPLES



Figure 6.3.1.2-4 Installation of stone veneer showing anchorage to steel dovetail clips which are fastened to steel studs bolted to the grouted reinforced masonry wall behind (Photo courtesy of Simpson Gumpertz and Heger).

MITIGATION DETAILS

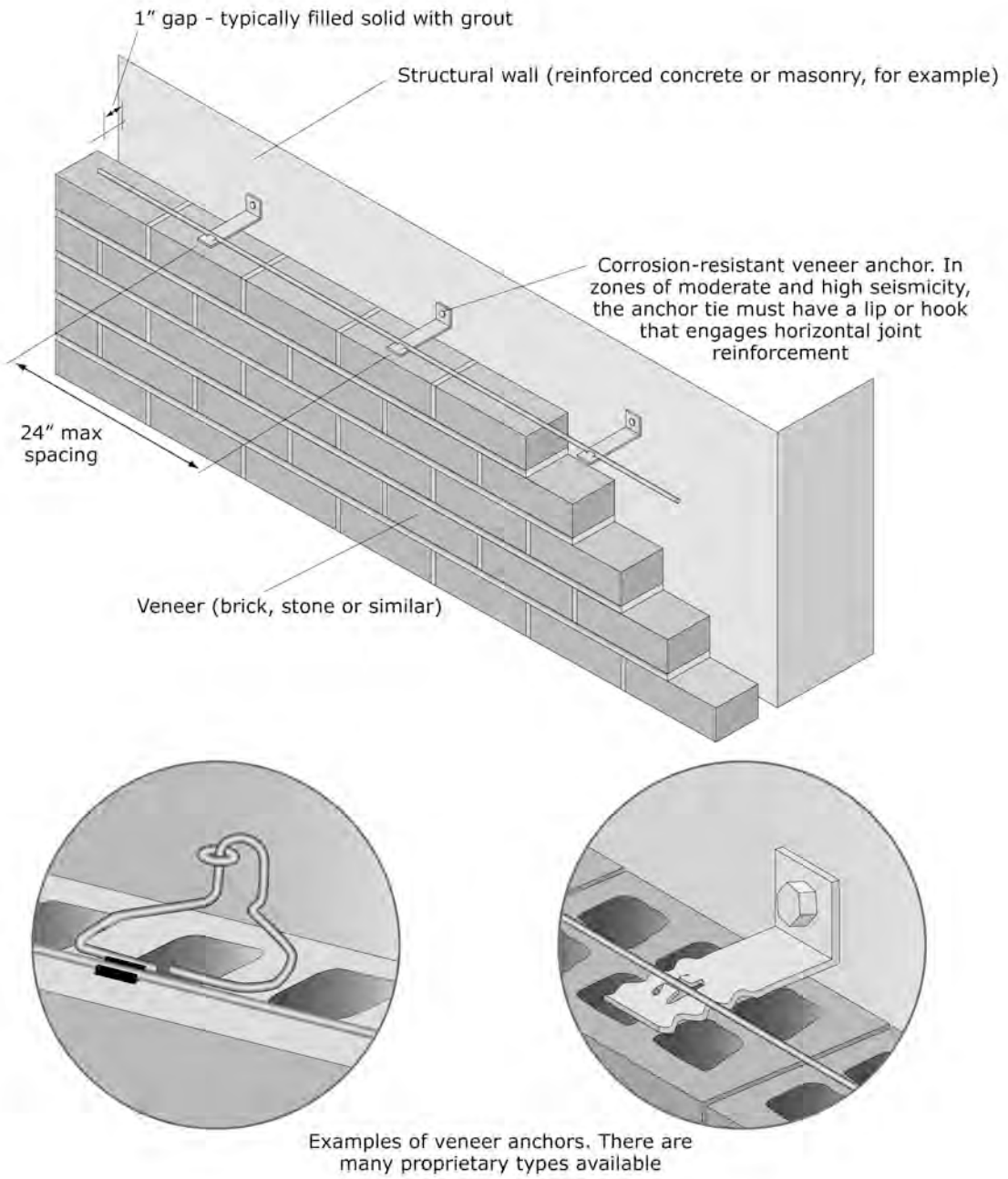


Figure 6.3.1.2-5 Anchored veneer (ER).

6.3 Architectural Components

6.3.1 Exterior Wall Components

6.3.1.3 Prefabricated Panels

This category covers any type of prefabricated exterior panel that is attached to the perimeter structural framing. These may be lightweight metal panels, glass fiber reinforced concrete panels (GFRC) supported by cold-formed steel framework, stone or tile supported by steel frames, or precast concrete panels that may have adhered or anchored veneer.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) focuses on providing adequate strength in the connections and providing a mechanism to accommodate building deformations.

- Fasteners in the connections (bolts, welds, and items embedded in concrete or masonry) are designed for amplified forces to prevent premature failures in potentially brittle connection elements.
- Prefabricated panels must be designed to accommodate the expected deformations of the structure. Story drift can be resisted by rocking or sway mechanisms. In a rocking mechanism, the corners of the panels are permitted to move vertically when the building deforms horizontally. In a sway mechanism, the panel is attached rigidly to one level, while attachment points on other levels of the structure allow lateral movement by sliding or bending of ductile steel elements.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies prefabricated exterior panels as both acceleration and deformation sensitive.

- Prefabricated exterior panels are subject to the requirements of ASCE/SEI 41-06 when:
  - The performance level is Immediate Occupancy or Life Safety in high, moderate, and low seismicity areas.
  - The performance level is Hazards Reduced in high, moderate, and low seismicity areas and prefabricated panels are located over areas of public access or egress.

- Acceptance criteria focus on performing a drift analysis to determine if the panels can accommodate the expected story drifts, and the anchorage of the panels under seismic loading.

Typical Causes of Damage

- Both lightweight and heavier panels may be damaged by deformations of the building frame. GFRC systems and other cladding units that have a cold-formed steel support frame are more tolerant of building deformations, due to the inherent flexibility of the steel support frame.
- Heavier cladding panels may be damaged by direct acceleration.
- Unless the panel connections are specially detailed to allow the panel to move independently of the building, both the connections and the panel may be damaged as they attempt to restrain the lateral movement of the building. Panels may be racked, damage adjacent panels, connections may fracture, and panels may become dislodged or displaced.
- Separations (joints) between adjacent panels are intended to limit contact and resulting panel misalignment and/or damage under all but extreme building response, In strong shaking, some contact between adjacent cladding units is expected.
- Deterioration or corrosion of the mechanical connections is a significant concern; corroded connections may fail prematurely. Maintaining watertight joints is important for the longevity of the anchors.

DAMAGE EXAMPLES



Figure 6.3.1.3-1 Failure of precast panel at parking garage that resulted in fatality in the 1987 magnitude-5.9 Whittier, California earthquake (Photo courtesy of Degenkolb Engineers).



Figure 6.3.1.3-2 Precast panel failure at the top floor of a hospital in the1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of OSHPD).



Figure 6.3.1.3-3 Precast panel damage at a building corner in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).



Figure 6.3.1.3-4 Interior view of precast panel showing response of three sets of push-pull connections in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).



Figure 6.3.1.3-5 Close-up photo of two fractured connection bolts in a prefabricated panel in the 1994 Northridge Earthquake; corrosion of the rods may have contributed to the failure. (Photo courtesy of OSHPD).



Figure 6.3.1.3-6 Residential building with precast concrete corridor and balcony railing panels. Some panels were damaged and subsequently many were removed to prevent falling. Location in Rancaqua, Chile 154 miles northeast of the epicenter; estimated PGA of 0.3g during the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).



Figure 6.3.1.3-7 Numerous precast panels removed to prevent falling; detail from residential building in Rancagua, Chile above. These panels had a bearing seat at the center and supported on steel dowels at either end (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- Precast panel connections and panel joints require specialized design based on the expected inter-story drift of the structural system supporting them or 0.5 inch, whichever is greater. The connections must be detailed with sufficient ductility and rotation capacity to prevent failure. Typically, the panels are seated on two bearing connections at either the top or bottom floor and then have "push-pull" connections at the adjacent floor which resist out-of-plane loading but move laterally in the plane of the panel. In this way, the panels move with the floor where the bearing connections are located and the drift is accommodated by the rod at the "push-pull" connection. In order to work effectively, the "push-pull" connection must be able to accommodate the expected drift without extensive inelastic action. For sliding-type connections, this has traditionally been accomplished by using an oversize hole or slot large enough to accommodate the design drift in each direction, but recent testing has shown that this configuration can bind and restrict movement and not work as well as anticipated. For connections utilizing threaded rods, the length of the rod should be sufficient to prevent extensive yielding of the rod in bending, since this may result in premature fracture of the rod due to low-cycle fatigue.
- Prefabricated panels can be installed in a manner that forces the building deformations to occur over a distance substantially less than the story height. For example, "banded" precast concrete wall systems often feature spandrels at each floor level and with glazing and precast column covers spanning from the top of one spandrel to the bottom of the spandrel on the floor above. When the building displaces laterally, the spandrels move with the floors, acting as rigid bodies. The story drift has to be accommodated by the glazing and column covers.
- While both the rocking and sway mechanisms, as illustrated in Figures 6.3.1.3-8a through c, are effective methods of accommodating story drift, mixing mechanisms in adjacent panels may potentially close the joints between units, resulting in a collision between adjacent panels. To avoid this, the joints between panels have to be sized to allow for panel rotation and translation.Architectural Design for Earthquake, A Guide to Nonstructural Elements, (Charleson, 2007) has a detailed discussion of issues related to exterior cladding. Sliding connections with slotted or oversized holes are commonly used in New Zealand as an alternative to push-pull connections.
- DN-21, *Behavior of Architectural Precast Panels in Response to Drift* (PCI, 2011) contains an extensive discussion of the different mechanisms used to accommodate story drift.

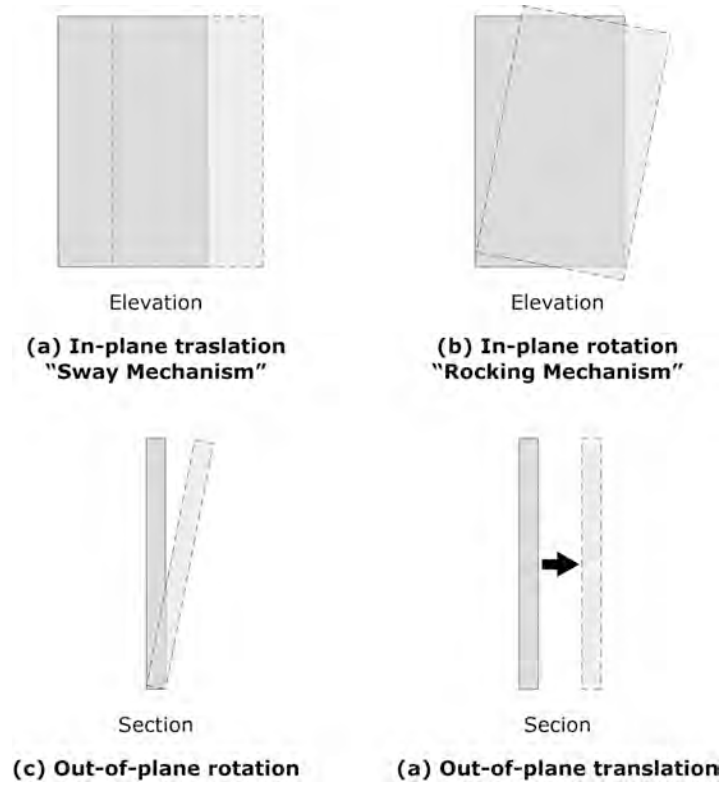


Figure 6.3.1.3-8a Modes of panel response to displacement.

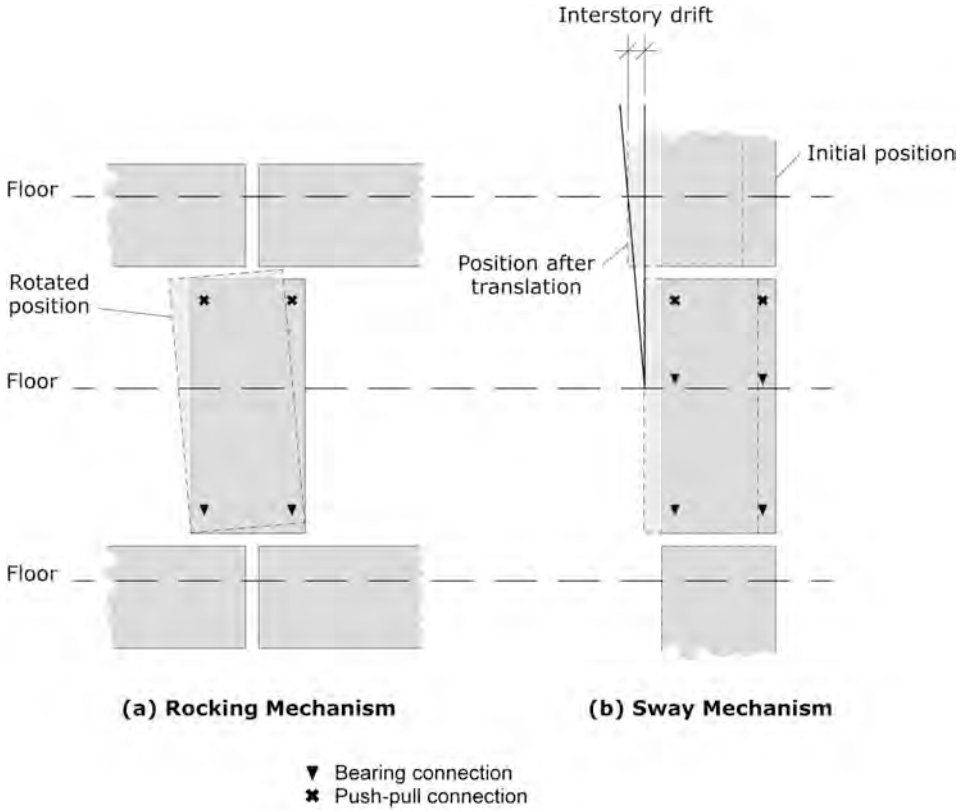


Figure 6.3.1.3-8b Tall and narrow panels designed to accommodate seismic drift.

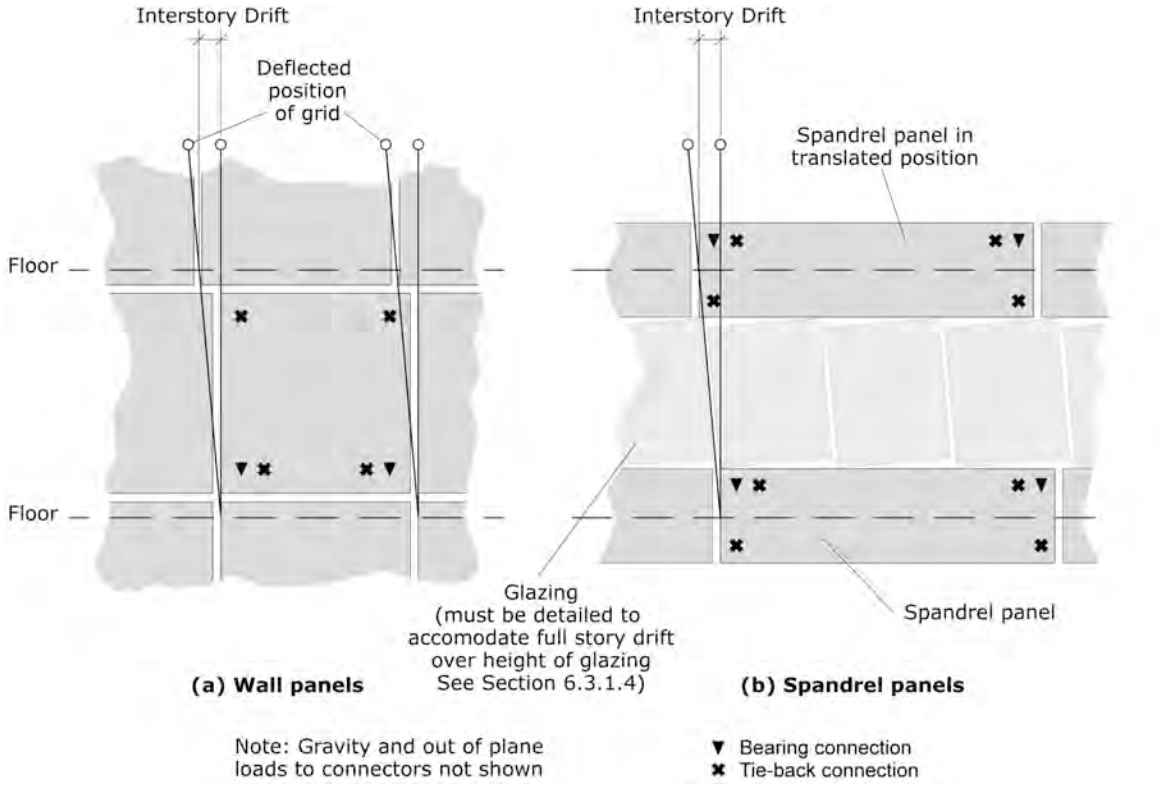


Figure 6.3.1.3-8c Low aspect ratio panels designed to accommodate seismic drift.

Mitigation Details



Figure 6.3.1.3-9 Precast spandrel panel in San Francisco parking garage supported by bearing connections near top of panel (left) and slotted connections at bottom of panel (right); panels have four connections each. The remnants of a previous nonductile connection detail are visible in the photo at left (Photo courtesy of Cynthia Perry, BFP Engineers).

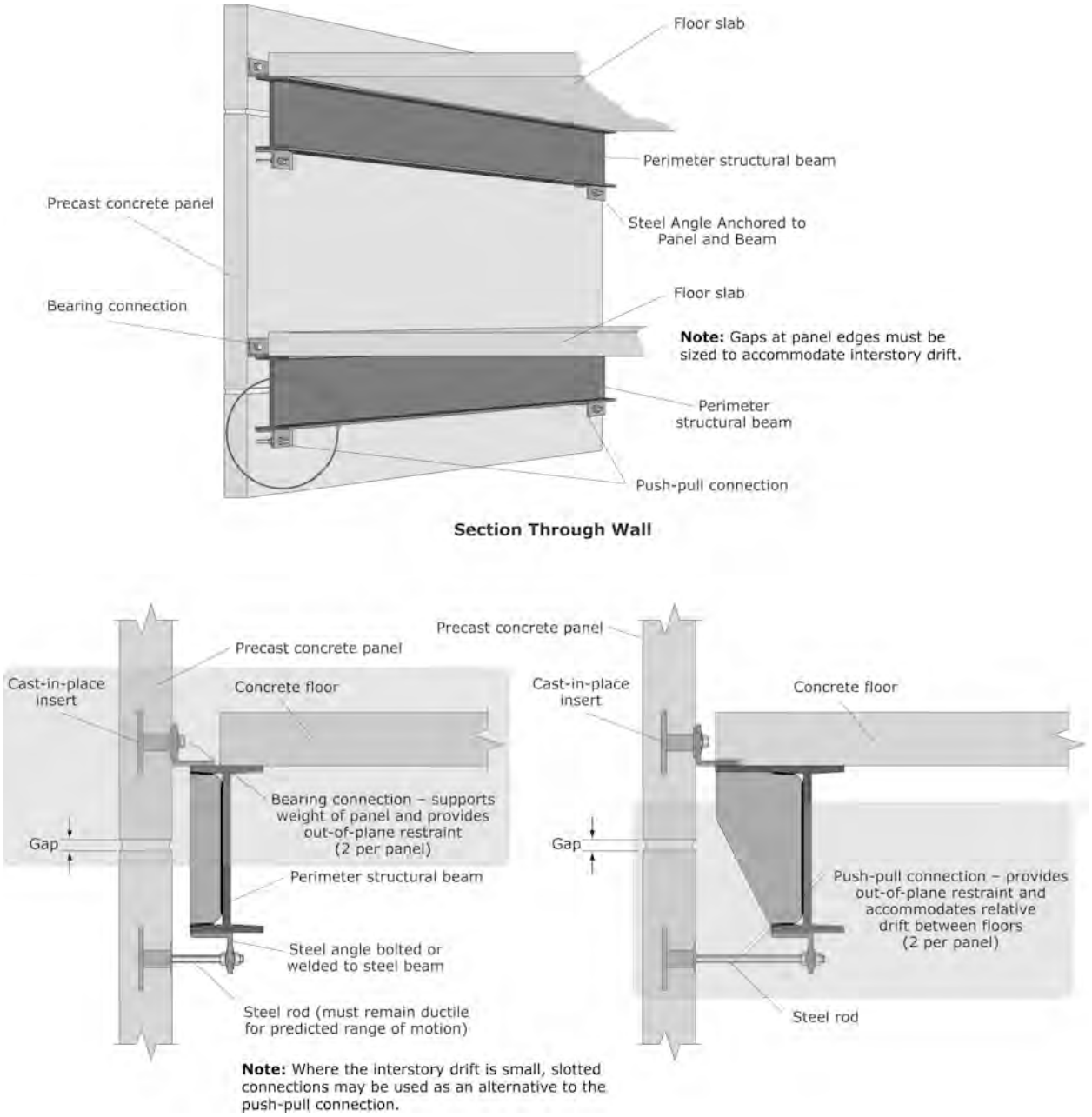


Figure 6.3.1.3-10 Prefabricated panels (ER).

6.3 Architectural Components

6.3.1 Exterior Wall Components

6.3.1.4 Glazing

Glazing includes glass curtain walls on multistory buildings, large storefront windows, as well as small, operable wood framed windows. Glass may be annealed, heat-strengthened, tempered, laminated or in sealed, insulating glass units. Glazing can be installed using either wet or dry glazing methods. Any of these may pose a significant falling hazard if not designed to accommodate seismic forces and displacements.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010) focuses on providing a mechanism to accommodate building deformations, or sufficient ductility to accommodate drift without a failure of the glazing system.

- The building code has specific requirements on the type of glazing that may be used in different areas. Tempered glass is required within 10' above a walking surface under some circumstances; check applicable code requirements. Wired glass with a grid of steel wire embedded in the pane is an option for some situations where fire and impact rating are not also required. ANSI A97.1 *Safety Glazing Materials Used in Buildings* (ANSI, 2004) is the standard that defines different kinds of safety glass.
- The design of glazing assemblies depends on the calculated inter-story drift for the building, and the type of glass.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies glazed exterior wall systems as both acceleration and deformation sensitive.

- Glazed exterior wall systems are subject to the requirements of ASCE/SEI 41-06 when:
  - The performance level is Immediate Occupancy or Life Safety in high, moderate, and low seismicity areas, or
  - The performance level is Hazards Reduced in high, moderate, and low seismicity areas and the glazing is located over areas of public access or egress.

- Acceptance criteria focus on performing a drift analysis to determine if the glazing can accommodate the expected story drifts, and the anchorage of the panels under seismic loading. The evaluation approach is similar to that used in ASCE/SEI 7-10.

Typical Causes of Damage

- Glazing assemblies are sensitive to both accelerations and deformations and are subject to both in-plane and out-of-plane failures. Glazing is particularly vulnerable in flexible structures with large inter-story drifts; large storefront windows are also vulnerable.
- The performance of glazing in earthquakes generally falls into one of four categories:
    - The glass remains unbroken in its frame or anchorage
    - The glass cracks but remains in its frame or anchorage while continuing to be a weather barrier
    - The glass shatters but remains in its frame or anchorage in a precarious position, liable to fall out at any time
    - The glass falls out of its frame or anchorage. Glass can fall in shards, shatter into small pieces, or broken panes may be held in place by film. Many of the glazing performance issues in earthquakes are a result of poor installation techniques. These include failure to provide clearances, use of improper shims, and failure to hold dimensional tolerances.

DAMAGE EXAMPLES



Figure 6.3.1.4-1 Shard of broken untempered glass that fell several stories from a multistory building in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Jenney, Elstner Associates).



Figure 6.3.1.4-2 Scenes in Ferndale, California following the 2010 magnitude-6.5 Eureka Earthquake. 50% of the glazing on Main Street was cracked (Photos courtesy of Bret Lizundia, Rutherford & Chekene).



Figure 6.3.1.4-3 Glazing damage was observed in many residential and commercial buildings and hospitals throughout central Chile following the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Miranda, Stanford University).



Figure 6.3.1.4-4 Glazing damage, due in part to pounding with the structure at right during the 2010 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Rubén Boroscheck & Associates).



Figure 6.3.1.4-5 Overhead glazing damage from the 2010 Chile Earthquake (Photo courtesy of Eduardo Miranda, Stanford University).

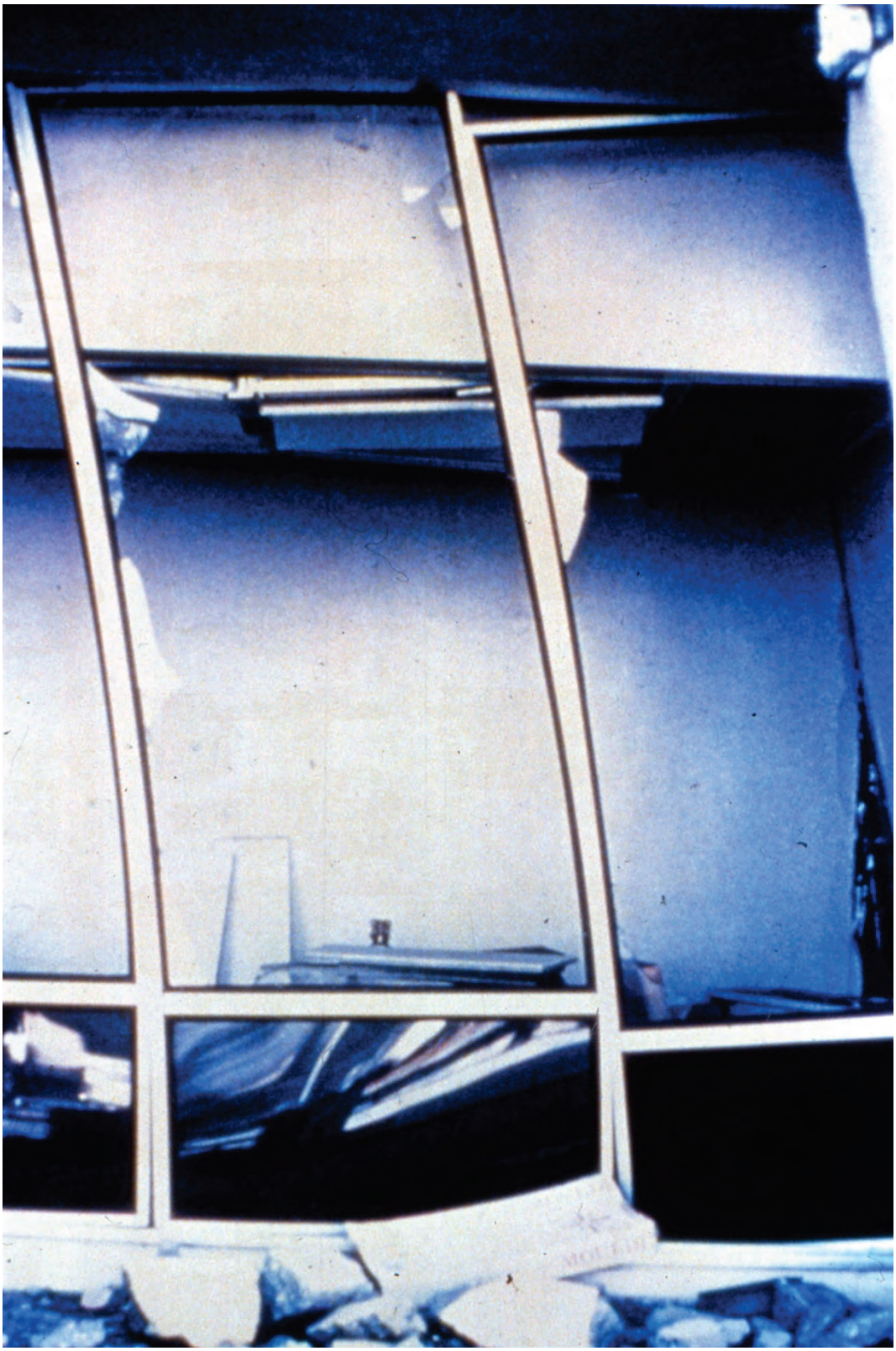


Figure 6.3.1.4-6 Broken glass and bent window mullions in flexible building which experienced large inter-story drift in the 1994 Northridge Earthquake (FEMA 310, 1998).

Seismic Mitigation Considerations

- The current glazing design provisions are the result of extensive testing. A full description of the test program can be found in FEMA 450-2, *NEHRP Recommended Provisions and Commentary for Seismic Regulations for New Buildings and Other Structures, Commentary. 2003 Edition* (BSSC, 2004).
- Glazing that remains in place and acts as a weather barrier (even if cracked) satisfies both immediate occupancy and life-safety performance objectives. If the glass shatters or falls, the level of hazard depends on the post-breakage characteristics of the glass and the height from which it falls.
- The term safety glass refers to tempered or laminated glazing and is required by code in a number of applications such as glazing in or adjacent to exits, within 10' of a walking surface, etc. Use of tempered glass will greatly reduce the seismic hazard because tempered glass breaks into small dull fragments instead of large hazardous shards. However, since the tempered glass fragments tend to fall from the frame or anchorage in clusters, they are potentially harmful to humans if they fall from greater heights. Laminated glass will typically remain in place when broken and will prevent people or objects from falling through the opening. Storefront windows are often vulnerable as the windows occupy a large structurally unsupported area at the ground floor, often resulting in soft story or torsion problems. Use of laminated glass for storefront windows reduces the seismic risk and also increases protection from burglary and vandalism.
- Plastic films that help hold glass fragments together even if the pane breaks are available. These films may reduce seismic risk associated with dislodged fragments, which pose a safety risk, particularly if they fall from great heights. Strategic application of plastic films where glazing is directly over an exit way, within 10' of an exit way, or along interior corridors may provide sufficient risk reduction if other areas surrounding the building have limited public access. Plastic films may be a cost effective way to retrofit an existing pane of glass and are often installed for other reasons, such as security or reducing solar heat gain. Extending the film over the edge of the surrounding frame is advisable not only to hold broken fragments in place but also to prevent the entire pane from falling out. Avoid placing beds, desks, chairs or couches that are typically occupied many hours a day near large plate glass windows.
- Liberal use of landscaping strips or areas with restricted pedestrian access may help to reduce the seismic risk beneath large glass panes or tall curtain walls.

Mitigation Details

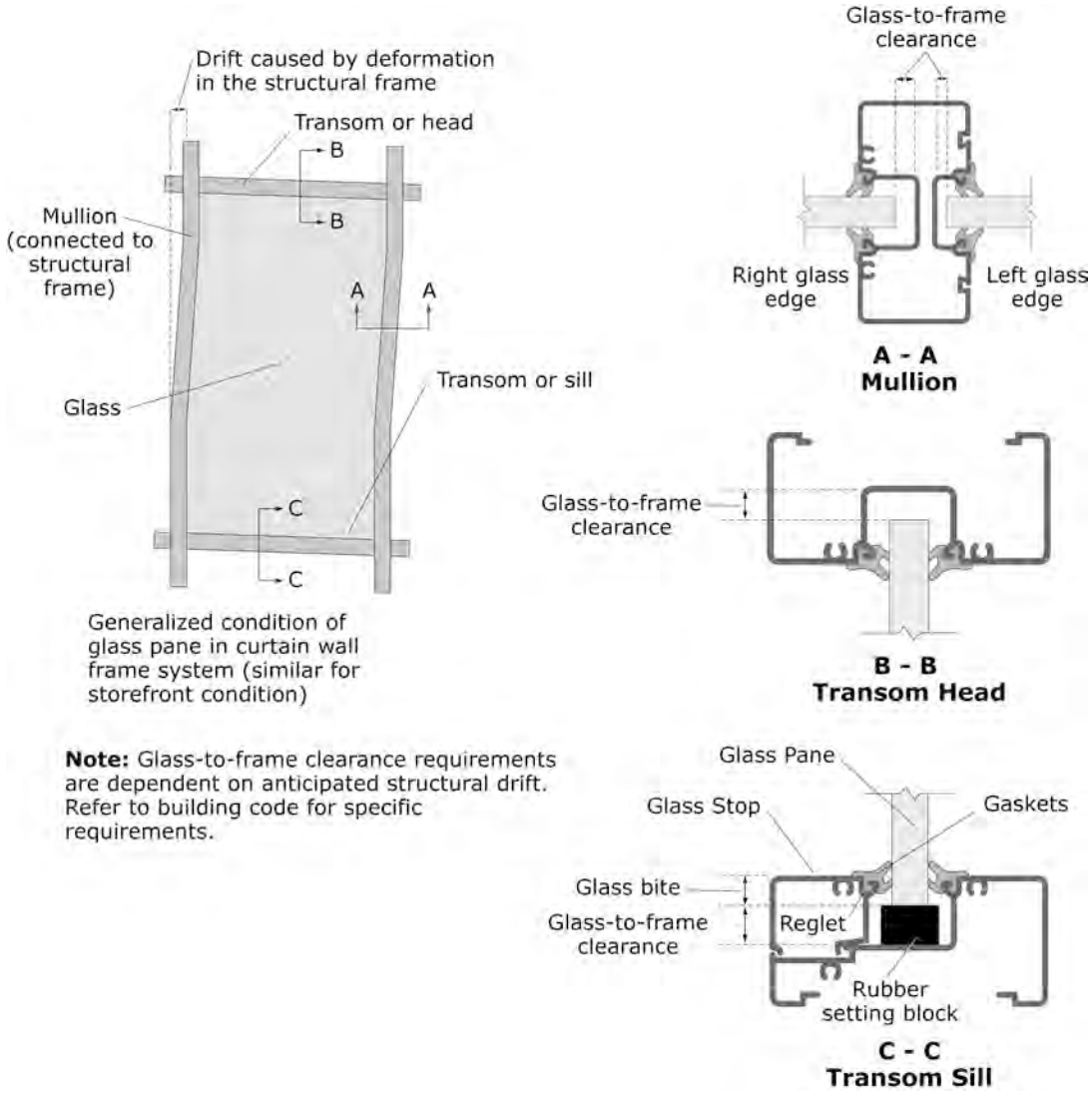


Figure 6.3.1.4-7 Glazed exterior wall system (ER).

6.3 Architectural Components

6.3.1 Exterior Wall Components

6.3.1.5 Glass block

Glass block, or glass unit masonry, is used to construct a variety of nonbearing walls or used as nonbearing infill in window openings. If not properly detailed to accommodate movement, glass block units may break and pose a falling hazard.

Provisions

BUILDING CODE PROVISIONS

The design provisions for the design and construction of glass unit masonry are empirical and prescriptive, with limits on panel size, the spacing between structural supports, deflections of supports, and prescriptive joint reinforcing requirements. There are additional code limitations on material properties of the glass unit masonry, sealant, and mortar; and properties, spacing, and details of anchorage hardware; and spacing and details of expansion joints.

- Design requirements are found in TMS 402-11/ACI 530-11/ASCE 5-11, *Building Code Requirements and Specification for Masonry Structures and Related Commentaries* (MSJC, 2011), Chapter 7. There are also limitations on the use of glass block in Section 2110 of the 2012 IBC, *International Building Code*, (ICC, 2012)..
- Seismic design forces on the nonbearing wall assembly are determined from ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13, Nonstructural Components.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies glass block as primarily deformation sensitive in the in-plane-, and acceleration sensitive in the out-of-plane direction. Glass block is subject to the requirements of ASCE/SEI 41-06 when:

- The performance level is Immediate Occupancy or Life Safety.
- The performance level is Hazards Reduced and glass block is located over areas of public access or egress.

Acceptance criteria requires conformance with in-plane drift limits and out-of-plane forces.

The rehabilitation approach depends on the size of the individual walls. Walls less than 144 SF or 15 feet in any dimension may be retrofitted using prescriptive procedures. Larger walls must be analyzed,

Typical Causes of Damage

- Glass block panel assemblies are subject to both in-plane and out-of-plane failures. If the glass block panels are not reinforced and isolated from the movement of the structural surround or structural supports, the panel consisting of brittle glass blocks may be damaged. Older glass block panels may be installed with rigid mortar along all four sides and in the mortar joints. Damage to these rigid installations, or installations without the capacity to accommodate seismic deformations, may result in glass block breakage, falling glass block units, or possibly failure of the whole panel.
- If glass block panels are rigidly attached at the sill with mortar, but allowed to slip along the top and sides, and installed with panel reinforcing in alternate mortar joints, there may be damage to the panel anchors, angles, or channels surrounding the panel. The fire-rating or weatherproofing may also be compromised and should be inspected if there are signs of movement.
- A survey of glass block installations after the 1994 Northridge Earthquake found that glass block panels installed per the UBC provisions since the late 1970's had performed well (Hart, 1994).

DAMAGE EXAMPLES



Figure 6.3.1.5-1 Damage to glass block in building with reinforced concrete frame and concrete masonry infill in the magnitude-7 2010 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Note some blocks failed at rigid mortar joints and stayed in the frame, others fell out of the frame, and others broke in place. This building also suffered structural damage.



Figure 6.3.1.5-2 Damage to glass block with rigid mortar on all sides and in all joints in the 2010 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). About 25% of the glass block units are cracked or broken but entire panel will need to be removed and replaced.



Figure 6.3.1.5-3 Damaged glass block panel from the Los Angeles Hospital in the 2010 Chile Earthquake; relatively new hospital building that had to be evacuated for repairs (Photo courtesy of Bill Holmes, Rutherford & Chekene). Blocks were installed with steel reinforcing bars in the top and bottom horizontal joints.

Seismic Mitigation Considerations

- The design of glass block panels must meet the applicable code requirements for glass masonry construction. The glass block panel should be isolated for seismic, wind and thermal movement from the nonstructural surround, and the nonstructural surrounding wall should be isolated from the seismic inter-story drift of the structure.
- For seismic resistance, the panels must be supported for both in-plane- and out-of-plane loads but should be isolated from the movement of the surrounding structure. Glass block units are inherently brittle and must be supported in a manner that does not allow structural loads from the building to be transmitted to the glass blocks. This typically involves providing a rigid mortar attachment to the sill at the bottom of the panel and providing slip joints along the top and sides. In addition, horizontal reinforcing is placed in alternate mortar joints. Typical glass block panel details are

shown in Figure 6.3.1.5-6. Slip joints at the top and sides may be accomplished with steel angles, steel channels, or panel anchors (see three alternate head details in Figure 6.3.1.5-7). Jamb details are similar.

- Note that the fire-rated head detail A in Figure 6.3.1.5-7 is very similar to Figure 6.3.2.1-9 used for full-height heavy partitions. This type of detail with steel angles provides the most robust seismic restraint where large displacements are expected.
- Special care must be taken to detail glass block panels on intersecting planes such as corners or reentrant corners. Simultaneous motion in two directions makes these joints particularly vulnerable to damage.
- Glass block vendors often have proprietary hardware, standard specifications, and standard downloadable details available to assist designers. Manufacturer's standard slip joint details are typically designed to accommodate thermal expansion and wind forces and may not have not been explicitly designed for seismic deformations. Thus, these details should be used with caution if large inter-story drifts are expected.
- It may be prudent to avoid using glass block near exits and to restrict pedestrian access below or adjacent to a large expanse of glass block by providing a barrier or wide landscaping strip.

MITIGATION EXAMPLES



Figure 6.3.1.5-4 Use of glass block panels for select exterior and interior walls at the North Hollywood Police Station in California, utilizing standard details provided by Pittsburgh Corning Glass (Photo courtesy of Pittsburgh Corning Corporation).



Figure 6.3.1.5-5 Glass block panels divided into numerous subpanels at the Chula Vista Police Headquarters, California (Photo courtesy of Pittsburgh Corning Corporation). In addition, the nonbearing glass block panel partition wall is isolated from seismic movement of the building structure.

MITIGATION DETAILS

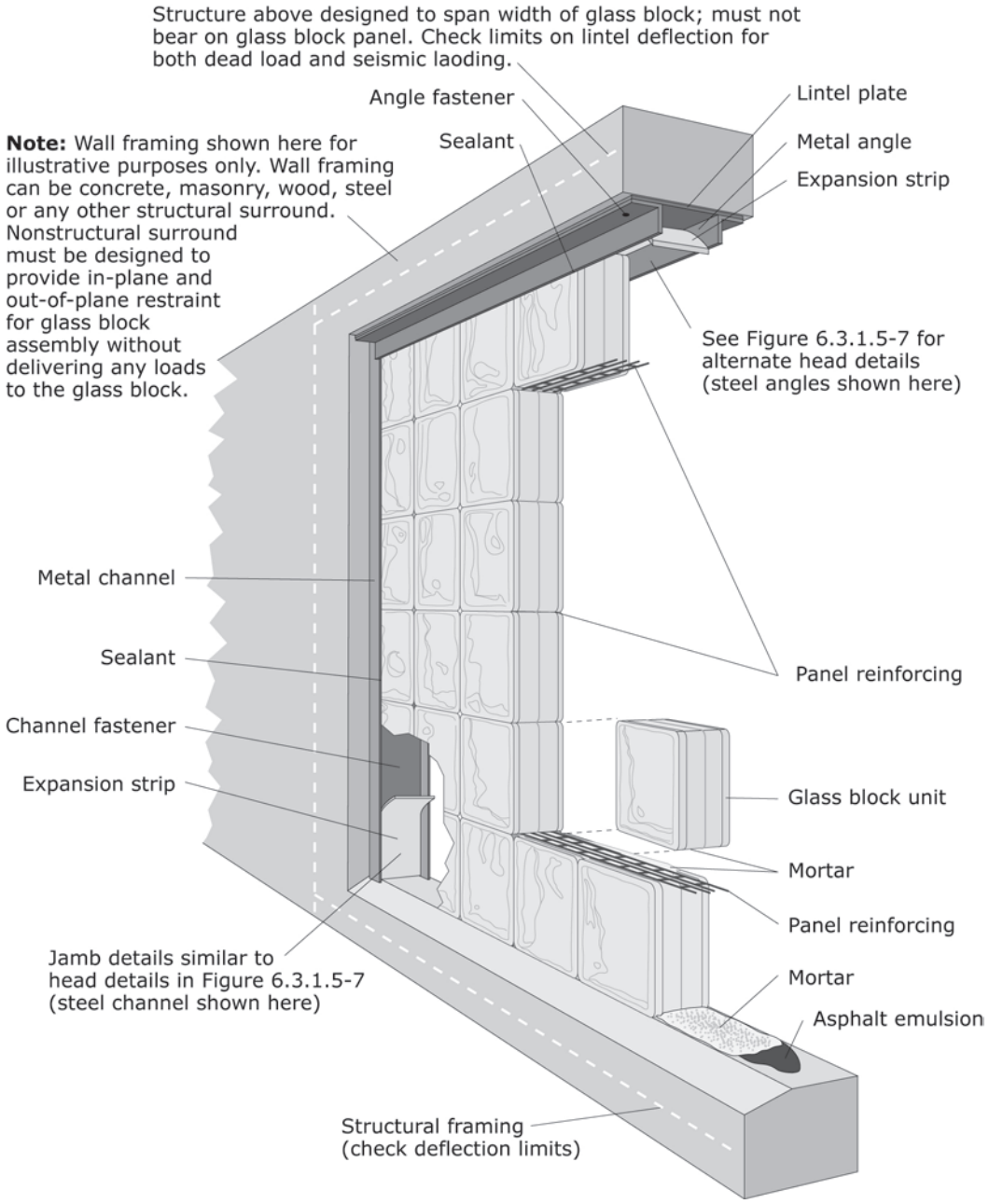
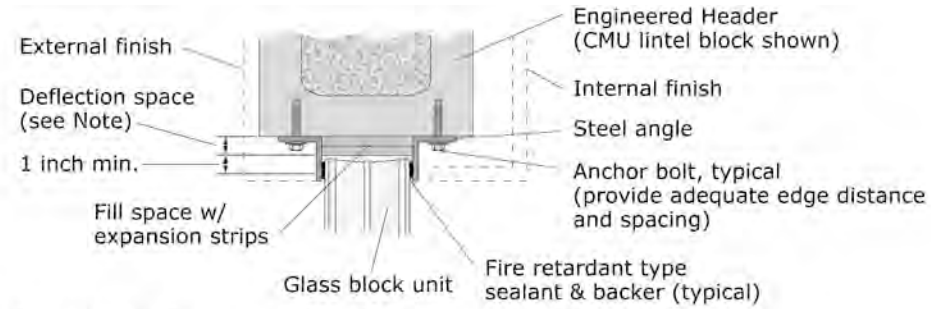
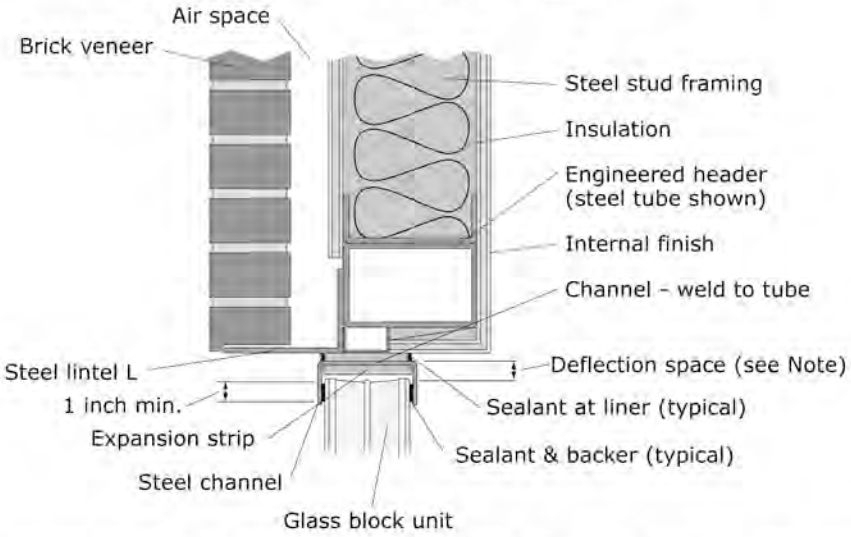


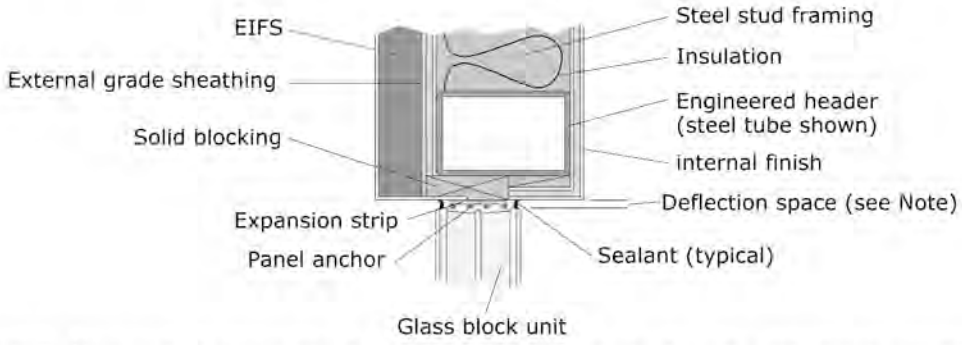
Figure 6.3.1.5-6 Typical glass block panel details (shown here with steel angles or channels to provide lateral restraint (ER).



Head Detail A: Fire rated glass block assembly in CMU wall; lateral restraint provided by steel angles



Head Detail B: Non-rated glass block assembly in steel stud wall with brick veneer; lateral restraint provided by steel channel



Head Detail C: Non-rated glass block assembly in steel stud wall with lightweight finish; lateral restraint provided by panel anchors

Note: The dimension "deflection space" for both jamb and head joints is determined by the anticipated deflection (gravity, seismic, thermal, etc.) of the structural members adjacent to the glass block panel.

Figure 6.3.1.5-7 Alternate head details for glass block panels (jamb details similar) (ER).

6.3 Architectural Components

6.3.2 Interior Partitions

6.3.2.1 Interior Partition Walls, Heavy

Heavy partitions may be full or partial height and may be constructed of reinforced or unreinforced masonry. Older office buildings were often built with hollow clay tile partitions throughout much of the interior. These elements are found as infill along column lines or located away from the structural framing or walls. In modern construction, these types of partitions may be found where an area separation for fire safety is required. Although "nonstructural" in their intended function, masonry partitions often become "structural" in the sense that they affect the overall response of the building to earthquakes and thus require the expertise of a structural engineer to properly assess. Unless rigid partitions are located in a stiff building with very small inter-story drifts, they should be isolated from the structural system or be explicitly included in the lateral force design of the building.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) focuses on providing adequate strength for out-of-plane forces and providing details that isolate the partition from building deformations.

- All heavy partitions greater than 6 feet in height must be laterally braced to the structure, independent of any ceiling lateral bracing.
- Partitions must be designed for wind and seismic forces acting out-of-plane on the wall.
- The partition must be detailed so that it does not interact with the structural system or other nonstructural elements when the building displaces laterally under wind or seismic loading.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies heavy interior partitions as both acceleration and deformation sensitive.

- Heavy interior partitions are subject to the requirements of ASCE/SEI 41-06 when:
    - The performance level is Immediate Occupancy or Life Safety in high or moderate seismicity areas.

  - The performance level is Hazards Reduced in high or moderate seismicity areas and heavy interior partitions are located over areas of public access or egress.
- Acceptance criteria focus on verifying that the partitions have sufficient strength to resist out-of-plane forces, and verifying that the partitions can accommodate in-plane story drift. If the building drift exceeds certain limits, the connection conditions at the edges of the partition require retrofit to accommodate the building movements.

Typical Causes of Damage

- Heavy partitions are both acceleration and deformation sensitive and may fail either in-plane or out-of-plane if not properly detailed. Partial height partitions may fail unless they are laterally braced to the structure above or engineered to cantilever from below. Full height partitions may fail unless they are isolated from the building deformations and provided with out-of-plane restraint.
- Masonry may crack and spall, walls may collapse creating falling hazards and blocking corridors and exits with debris. Masonry debris may be particularly hazardous in stairwells and elevator shafts.
- Where partitions are used as lateral support for piping, electrical cabinets, storage shelves, or other nonstructural items, the failure of the partition wall may result in damage to these other components.

Where partitions are built tight against structural columns, there is a potential for the masonry wall to unintentionally create a “captive column” thereby changing the intended earthquake response of the building. A structural engineer is needed to evaluate the implications of such conditions.

DAMAGE EXAMPLES



Figure 6.3.2.1-1 Damage along the top of a reinforced concrete masonry unit partition built flush with soffit of metal deck at an industrial facility in the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.3.2.1-2 Damage to reinforced concrete masonry partition used to support fire protection cabinet and piping in the 2001 Peru Earthquake; loose stucco and masonry were removed prior to photo (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.3.2.1-3 Damage to structural column ("captive column") due to restraint caused by partial height masonry wall in the 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.3.2.1-4 View of stairway in the Banco Central Building, Managua, Nicaragua after the 1972 magnitude 6.2 Managua Earthquake. Most of the stairs were covered with debris that resulted from the failure of the hollow tile partitions surrounding the stairs (Photo courtesy of PEER Godden Collection, No. J94).



Figure 6.3.2.1-5 Damage to unreinforced brick partitions in patient rooms, and other mostly nonstructural damage, resulted in the evacuation of the Felix Bulnes Hospital in Santiago in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Gilberto Mosqueda, University of Buffalo, SUNY).



Figure 6.3.2.1-6 An infill masonry wall collapsed onto the distilled water equipment spilling two 150 gallon containers; water leaked past the perimeter edge of the floor slab into the operating room suite below resulting in the closure of 3 of 6 the operating rooms. Replacement gypsum board partition seen in photo. Hospital built in 2005 in Los Angeles, Chile. Damage from the 2010 Chile Earthquake (Photo courtesy of Bill Holmes, Rutherford & Chekene).

Seismic Mitigation Considerations

- Heavy full height partitions need out-of-plane restraint with an in-plane slip joint. This can be provided with steel angles on either side attached to the structural slab above as shown. Steel angles may be continuous or intermittent; check code requirements. Note that special details may be required to meet fireproofing, sound proofing, weatherproofing or insulation requirements.
- Care must be used in detailing slip joints for a series of interconnected perpendicular walls since the out-of-plane restraints for one wall will prevent in-plane slip along the perpendicular wall; vertical isolation joints may be required. Similarly, special details are required where the soffit of the structure above has an irregular profile that would prevent slip such as the metal deck in Figure 6.3.2.1-1, or a sloping profile such as a ramp.

- If the partition will be used to provide lateral restraint for other nonstructural items, check that the wall and the lateral restraints at the top are adequate to resist the additional loading.
- Heavy partial height partitions are often used in exterior walls with glazing above or used as guardrails along exterior corridors. In buildings with structural frames, these walls should be self supporting and isolated from the structural framing at both ends. Failure to provide appropriate seismic isolation for these partial height walls has resulted in thousands of structural "captive column" failures in past earthquakes.

MITIGATION EXAMPLES



Figure 6.3.2.1-7 Detail of isolation joint to prevent creation of "captive column" condition (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.3.2.1-8 Full-height concrete masonry unit walls detailed with steel clip angles (3 angles visible in photo). Configuration shown includes perpendicular walls, sloping ramp above, and column with column capital. Although wall detailed with sealant joints along edges of column and column capital, it is not clear that the concrete frame can move independently of these CMU walls (Photo courtesy of Cynthia Perry, BFP Engineers).

MITIGATION DETAILS

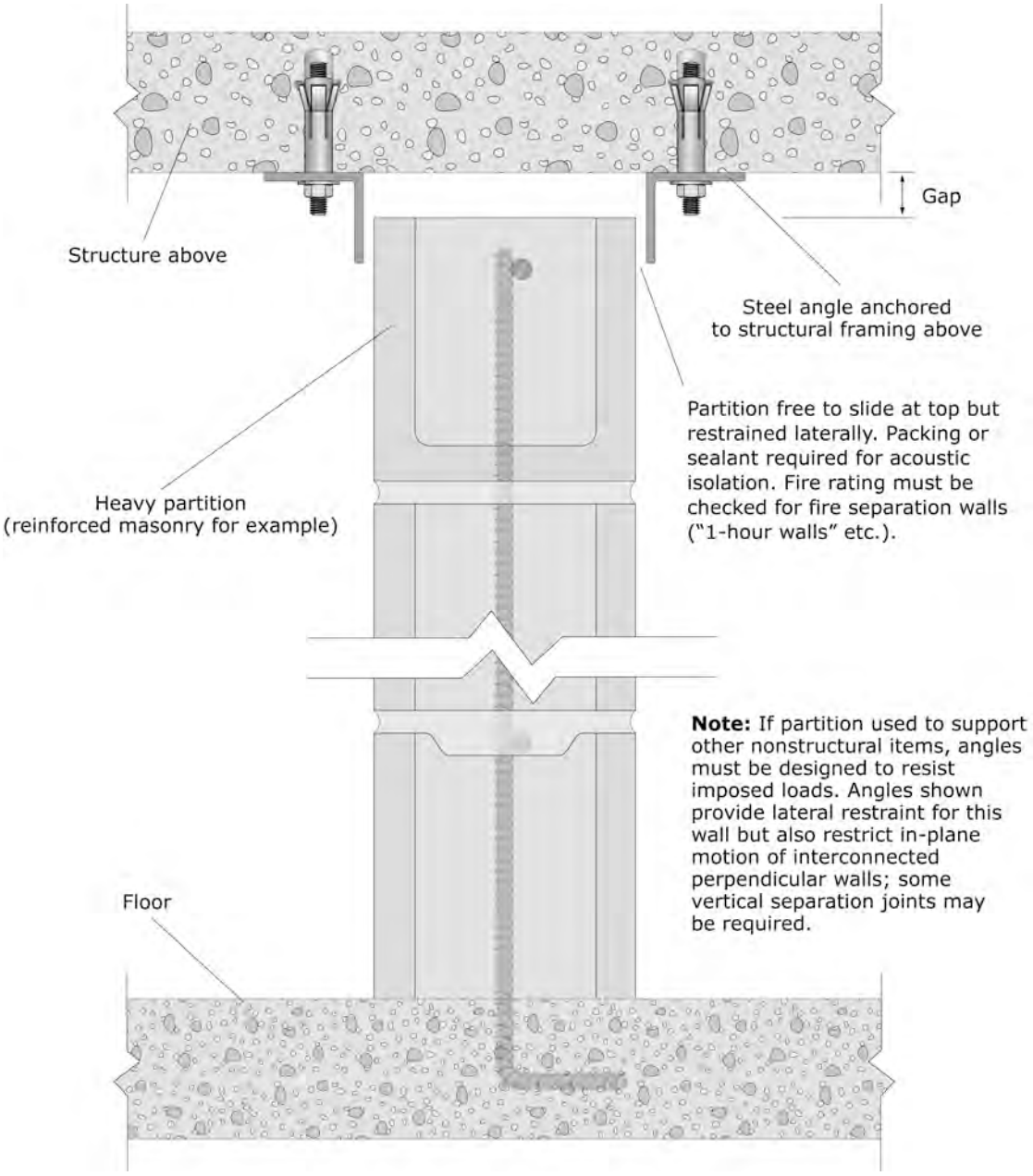


Figure 6.3.2.1-9 Full height heavy partition (ER).

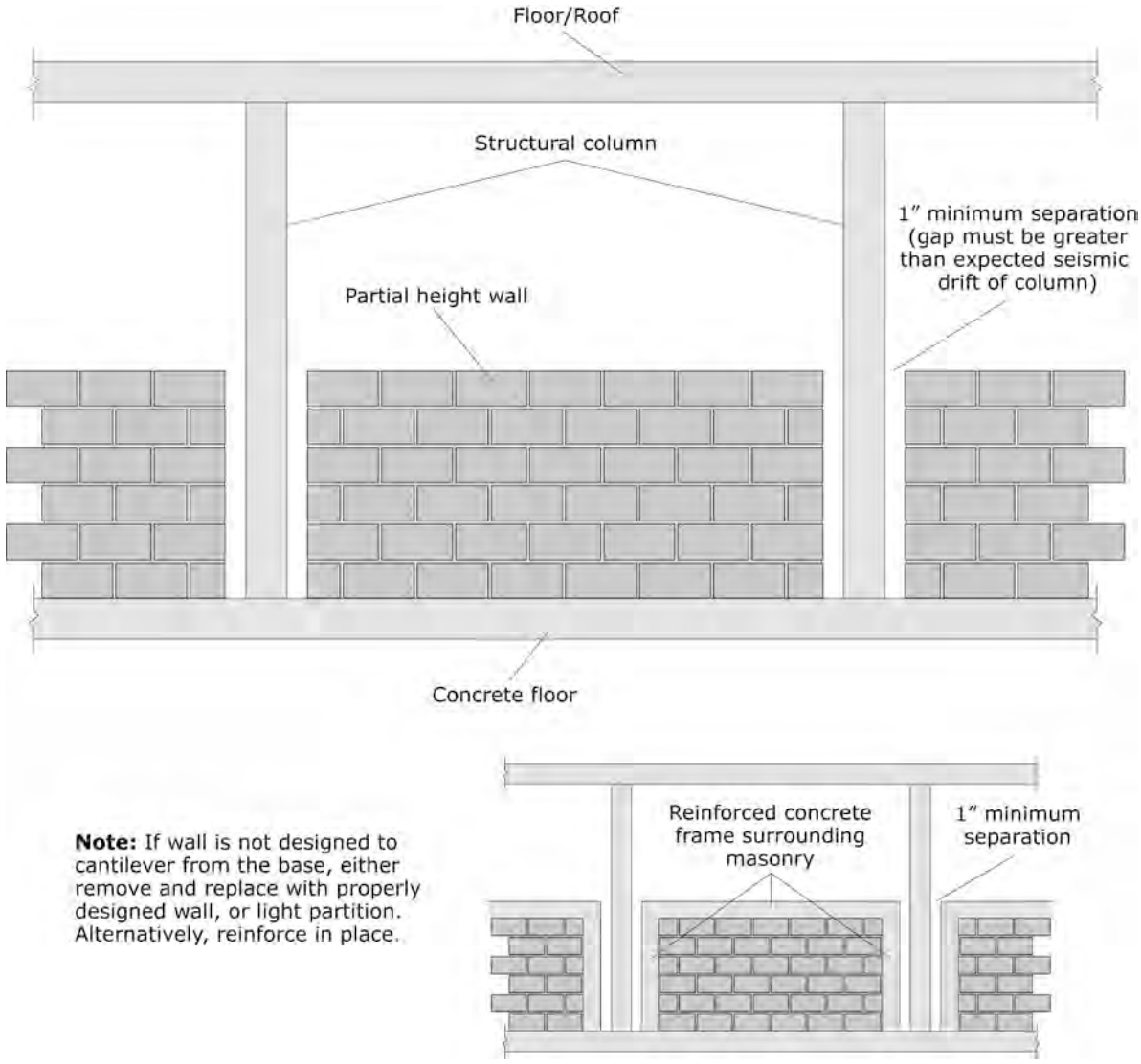


Figure 6.3.2.1-10 Partial height heavy partition (ER).

6.3 Architectural Components

6.3.2 Interior Partitions

6.3.2.2 Interior Partition Walls, Light

Light partitions are those that are built using wood or metal studs with gypsum board or lath and plaster finish. The studs may be full height (extending from floor-to-floor) or partial height, extending to the ceiling but not to the structural framing above. Partitions with partial height studs may be braced by the ceiling, but more commonly are braced with diagonal braces or wires independent of the ceiling, particularly at ceilings of lay-in acoustical tiles. The finish material may also run full height or stop at the ceiling, depending on fire or acoustical separation requirements.

In recent testing of a full scale 5-story building performed at the UC San Diego shake table (see Section 6.1.3), all floors included full height gypsum wall board partition wallboard partitions on metal studs that were subjected to severe earthquake motions and inter-story drifts. The partition walls were installed in accordance with normal installation practices. Severe gypsum wallboard damage and metal stud distress were observed following the strongest shaking but none of the walls collapsed. Additional tests were conducted to examine the potential consequences of fire initiated by earthquakes. Following the shake table testing, one of the floors was subjected to controlled burn and pressure tests to gauge how much the fire resistance of the fire-rated walls had been impaired by earthquake damage. The tests demonstrated that gypsum wallboard partitions may have reduced fire resistance following the earthquake, as compared to the fire resistance before the earthquake. This subject is the focus of ongoing study.

Provisions

BUILDING CODE PROVISIONS

Building code provisions for light interior partition walls limit deflections under out-of-plane loading, specify minimum out-of-plane loads, and have prescriptive bracing requirements when the height or weight of the partition exceed certain limits:

- The minimum out-of plane lateral load for partition walls is the larger of 5 psf or that computed in ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13. When computing the lateral load, the weight of casework, shelving, and wall-mounted items should be considered.

- Deflection limits in *International Building Code* (IBC, 2012) for interior partitions are based on the type of the partition finish. They range from the partition height, L, divided by 120, L/120, for flexible finishes to L/360 for brittle finishes. These deflection limits are checked using the 5 psf minimum load noted above.
- Partitions greater than 6 feet in height must be laterally braced to the structure, independent of any ceiling lateral bracing

Although crucial for controlling damage due to story drift, there are no code requirements governing the detailing at the head of the wall.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies light interior partitions as both acceleration and deformation sensitive.

- Light interior partitions are subject to the requirements of ASCE/SEI 41-06 when the performance level is Immediate Occupancy.
- Acceptance criteria focus on verifying that the partitions have sufficient strength to resist out-of-plane forces, and verifying building drift limits.

Typical Causes of Damage

- In-plane (parallel with the wall) damage can occur to light partitions as a result of deformations of the structure (drift). Full-height partitions in flexible structures may be damaged in this way unless they are isolated from the building deformations. Typical damage consists of cracked or spalled finishes, deformed partition framing, and failed connections. Damage to ceilings may occur at partial height partitions, due to the in-plane stiffness of the partition and the flexibility of the ceiling suspension and bracing.
- Metal studs are often installed with a deflection track at the top that provides lateral support but also accommodates potential movement of the floor above due to changing gravity loading. See Figures 6.3.2.2-3A through C. In order for the deflection track to be effective in allowing vertical movement, neither the stud nor the finish material should be attached to the track. This lack of connection is often in conflict with fire or acoustical approvals of partitions systems. In addition, ASTM C754-11, *Standard Specification for Installation of Steel Framing Members to Receive Screw-Attached Gypsum Panel Products*, covering installation of steel studs requires studs to be attached at jambs and partition intersections. To satisfy this condition, some installers attach such studs with angles with slotted holes to allow for vertical movement and prevent stud buckling. Deflection track details, if not compromised by occasional stud

attachment or finish attachment, will also allow in-plane lateral movement, minimizing damage to the finishes due to structural drift. However, even with no direct attachment to the floor above, sliding along the top track is incompatible with the rigid out-of-plane support of perpendicular partitions at corners. The local corner damage from this incompatible movement is difficult to avoid.

- Out-of-plane (perpendicular to the wall) damage is due to inertial loading on the wall from the floor accelerations (shaking). This loading is proportional to partition weight, so partitions with heavy finishes or hung book or storage shelves are more susceptible. Typically, damage from this loading occurs at the top connection of the partition to the structure or ceiling and may include local connection damage or complete failure leading to overturning of the partition. Such partition failures may create falling hazards, block corridors, and endanger occupants attempting to exit from damaged buildings.
- Partitions are also used to provide lateral support for floor supported storage shelves, equipment or other nonstructural items. This additional loading was often not anticipated in the design of the partition and damage could occur at the equipment connection, in the studs themselves, or at the wall-to-structure connections. The supported item could also be damaged due to unanticipated sliding or overturning.

DAMAGE EXAMPLES



Figure 6.3.2.2-1 Out-of-plane failure of inadequately braced partial height metal stud partitions in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).



Figure 6.3.2.2-2 In-plane damage to wood stud wall spanning floor-to-floor caused by differential movement between the two floors in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).

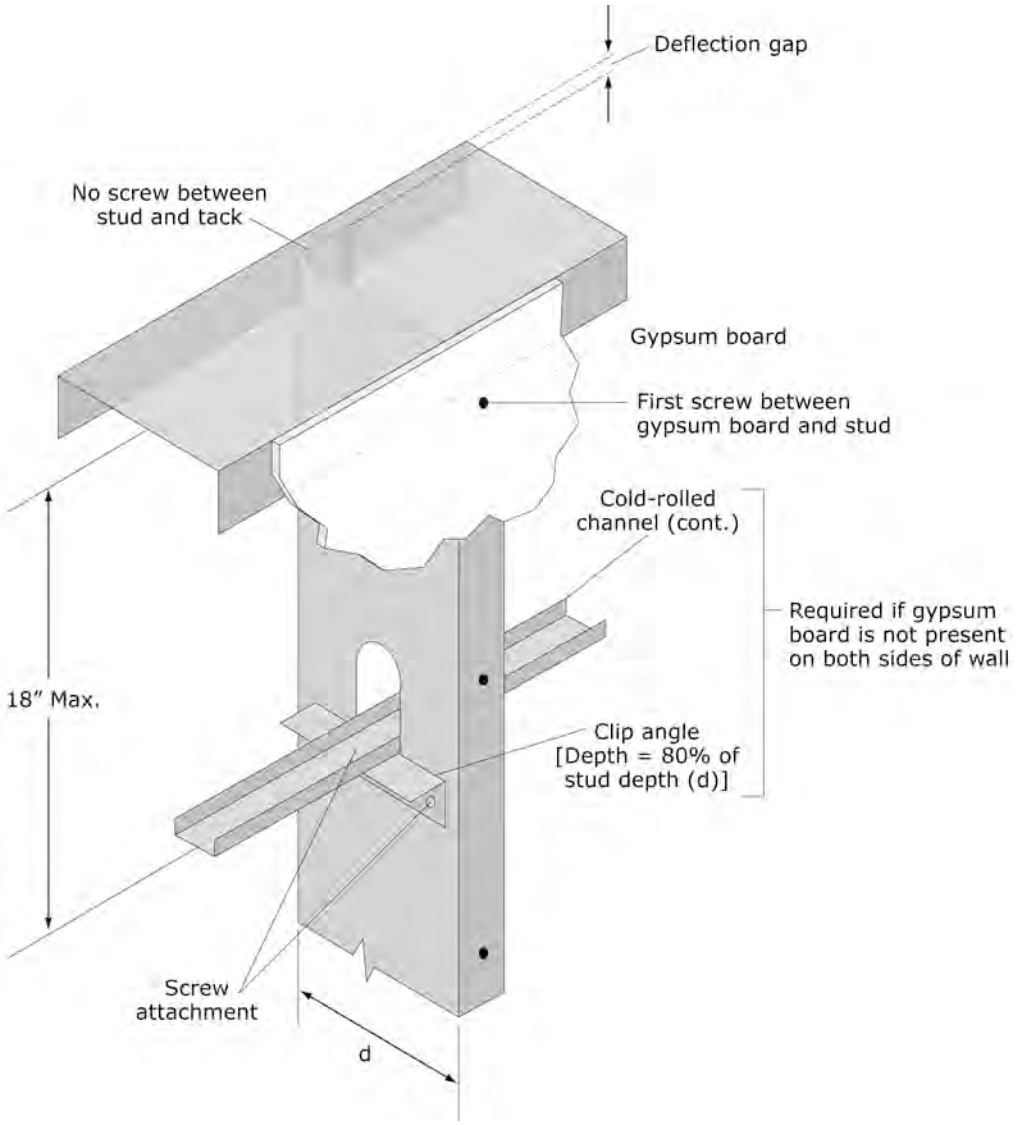


Figure 6.3.2.2-3a Top connection for metal studs with deflection channel.

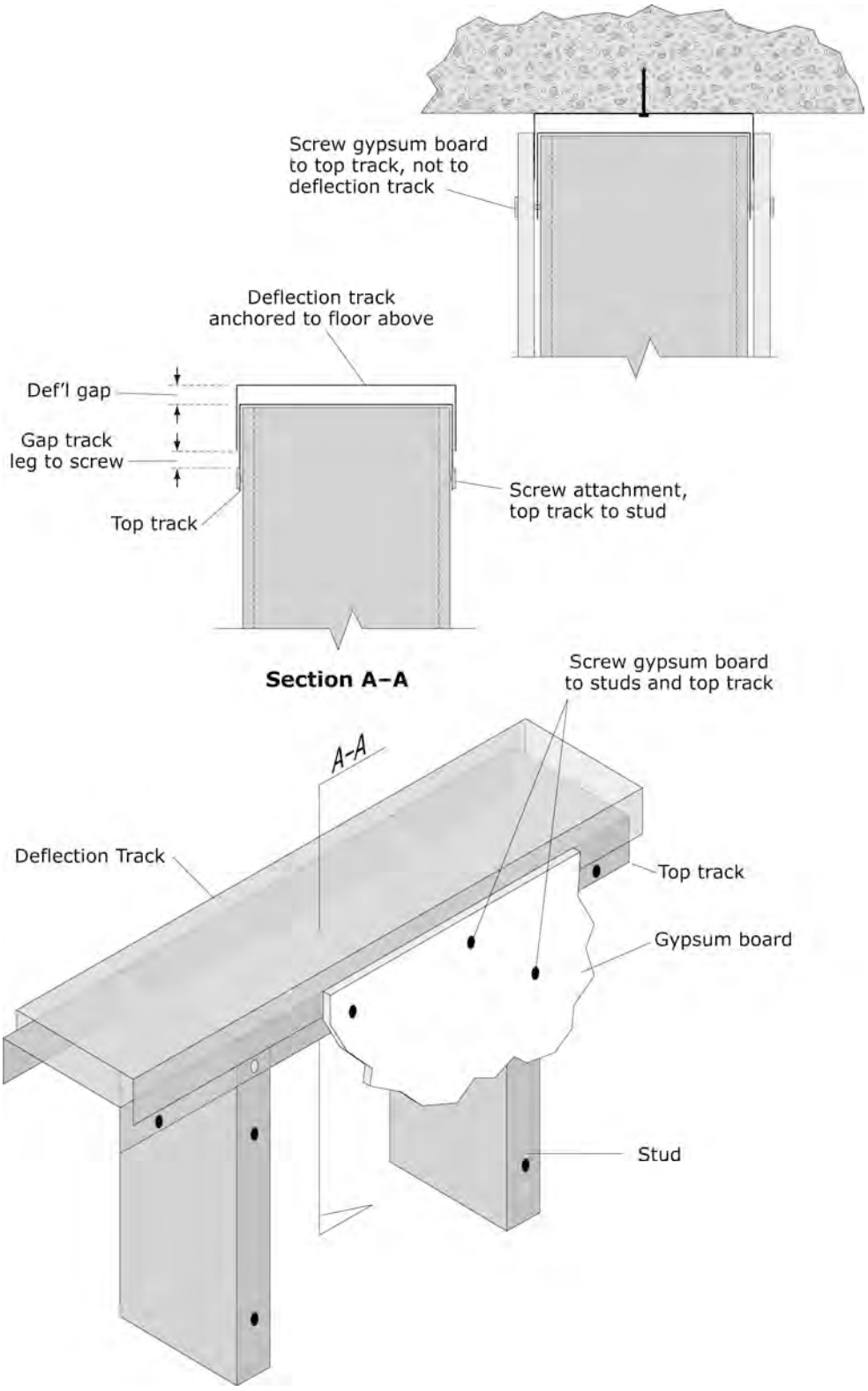


Figure 6.3.2.2-3b Top connection for metal studs with deflection channel with double track. Studs can be attached to insider channel without compromising vertical or lateral movement.

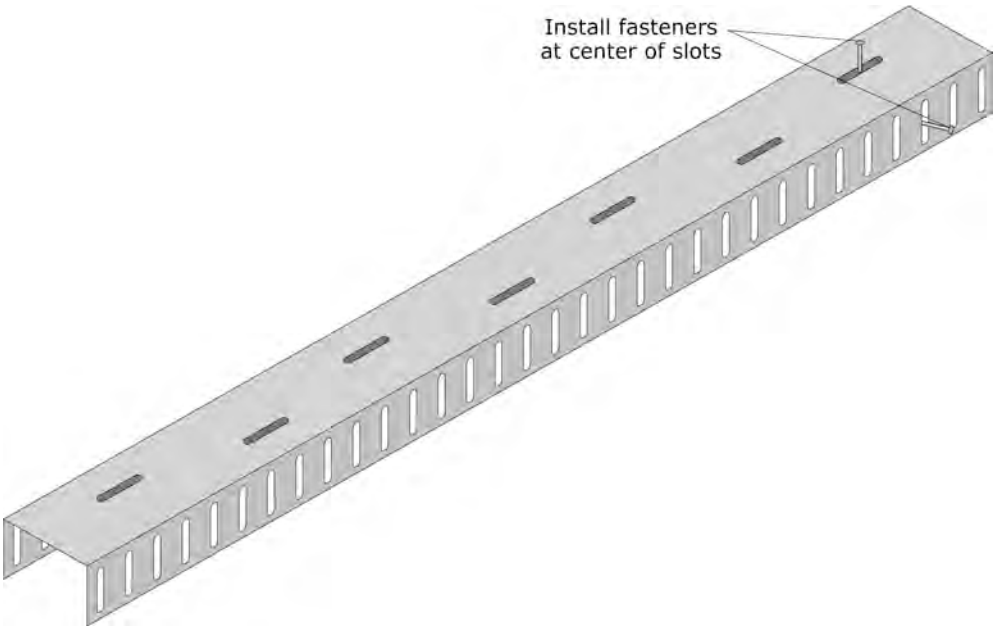


Figure 6.3.2.2-3c Example proprietary top track metal stud connection system. Studs are connected to the track through vertically slotted holes to allow for vertical movement. The connection of the track to the overhead structure through longitudinally slotted holes can accommodate in-plane slip to minimize damage from drift. The longitudinal slip capability can be inadvertently compromised by installing screw connections through the solid web, by overtightening screws through the slots, or by interruptions of the vertical alignment of the track at beams or changes in elevation of the overhead structure. This system does not solve the local damage at partition corners.

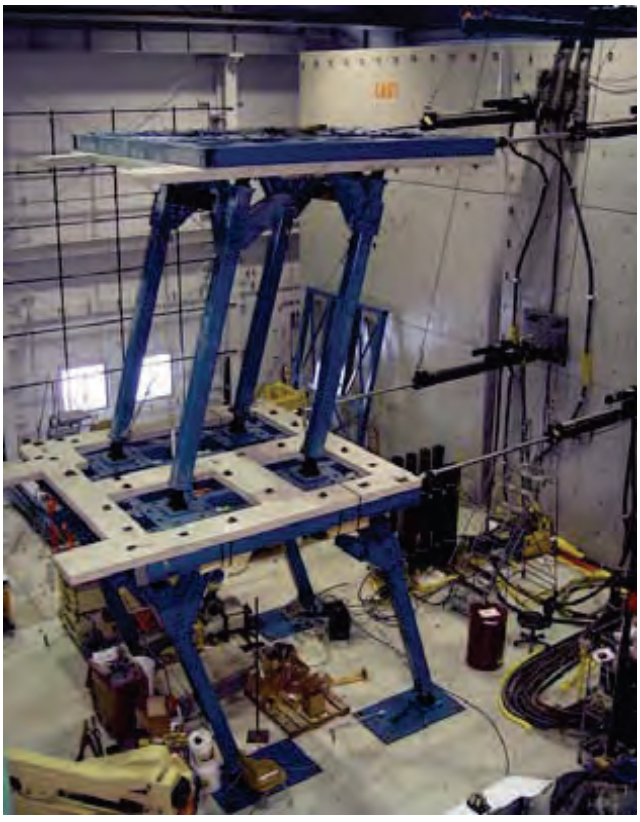
Seismic Mitigation Considerations

- Both laboratory testing and earthquake experience have shown that light interior partitions are vulnerable to damage due to story drift, even in low levels of shaking. The detailing at the head of the partition (the "top track") plays a critical role in determining the nature and severity of earthquake damage.
- For multistory and other engineered buildings, damage to non-load bearing full-height steel stud partitions can be minimized by avoiding connection of stud and finish to the top track. This can be accomplished by using a double track system or slotted tracks. . Note that special details need to be coordinated with requirements to meet fireproofing, sound proofing, weatherproofing, or insulation requirements. More elaborate details would be needed to minimize or eliminate damage at interconnected perpendicular walls since the out-of-plane restraints along one wall may prevent slip on the perpendicular wall. If fire or acoustical requirements allow, partial height partitions are less susceptible to in-plane damage, but should be braced to the overhead structure and not the ceiling.
- In wood framed buildings, partitions on wood studs are often installed with fixed connections top and bottom, although slip connections can also be developed in such cases. In small wood framed buildings gypsum or plaster non bearing partitions often provide additional lateral support against seismic shaking.If partition walls will be used to provide lateral restraint for other nonstructural items, the walls and the lateral connections at the top should be checked for adequacy.
- New or improved restraint systems for steel stud partitions are under development; one such scheme was tested at Stanford University in July 2010 that allows for over 1.5" of displacement in any horizontal direction, which would provide protection against damage at intersection of perpendicular walls. Check the internet for additional restraint options.

MITIGATION EXAMPLES



Figure 6.3.2.2-4 Bracing of partial height stud partition (Photo courtesy of Degenkolb Engineers).



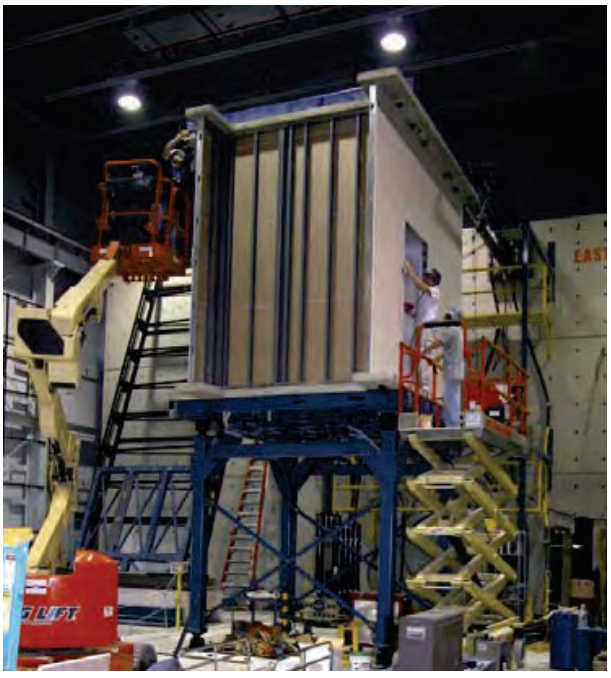


Figure 6.3.2.2-5 Two-story nonstructural component simulator at the University of Buffalo, SUNY shown at left. Preparation for dynamic testing of stud partitions for the NEES Nonstructural Project shown at right. Tests such as these improve understanding of the seismic behavior of nonstructural components (Photos courtesy of University of Buffalo, SUNY).

MITIGATION DETAILS

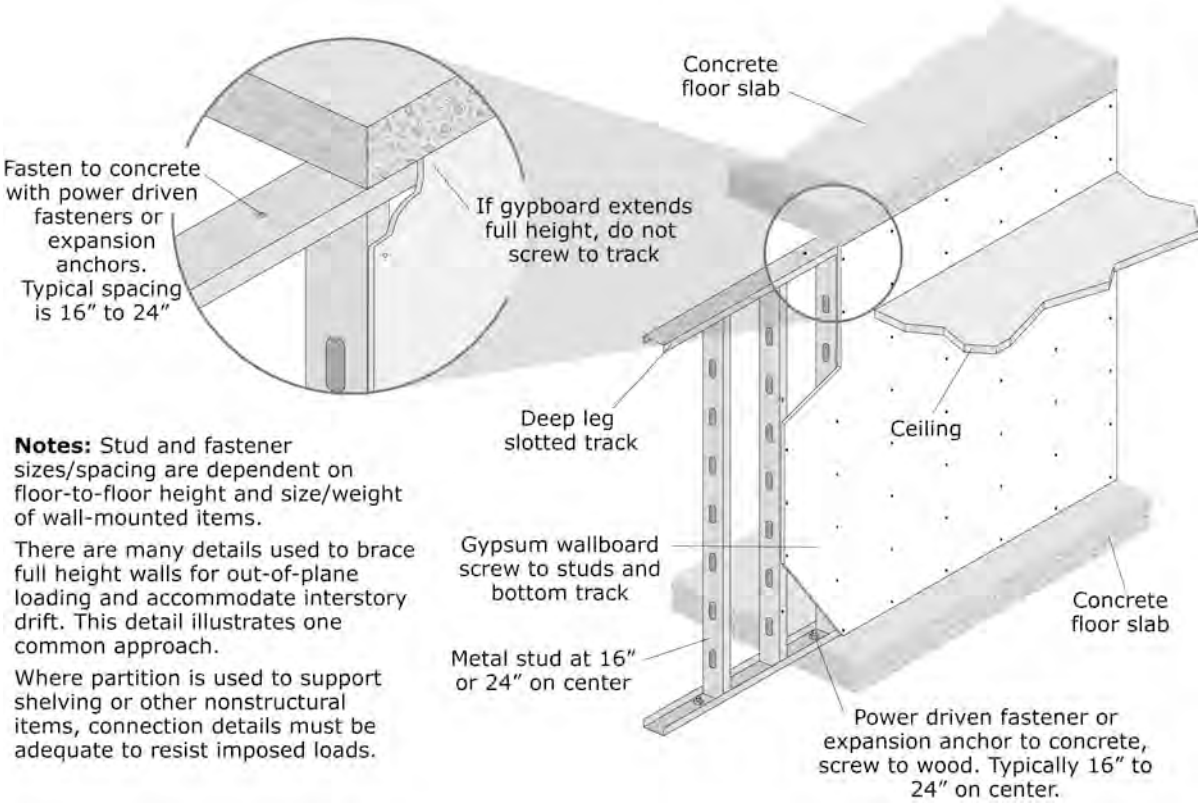


Figure 6.3.2.2-6 Full height nonbearing stud wall (ER).

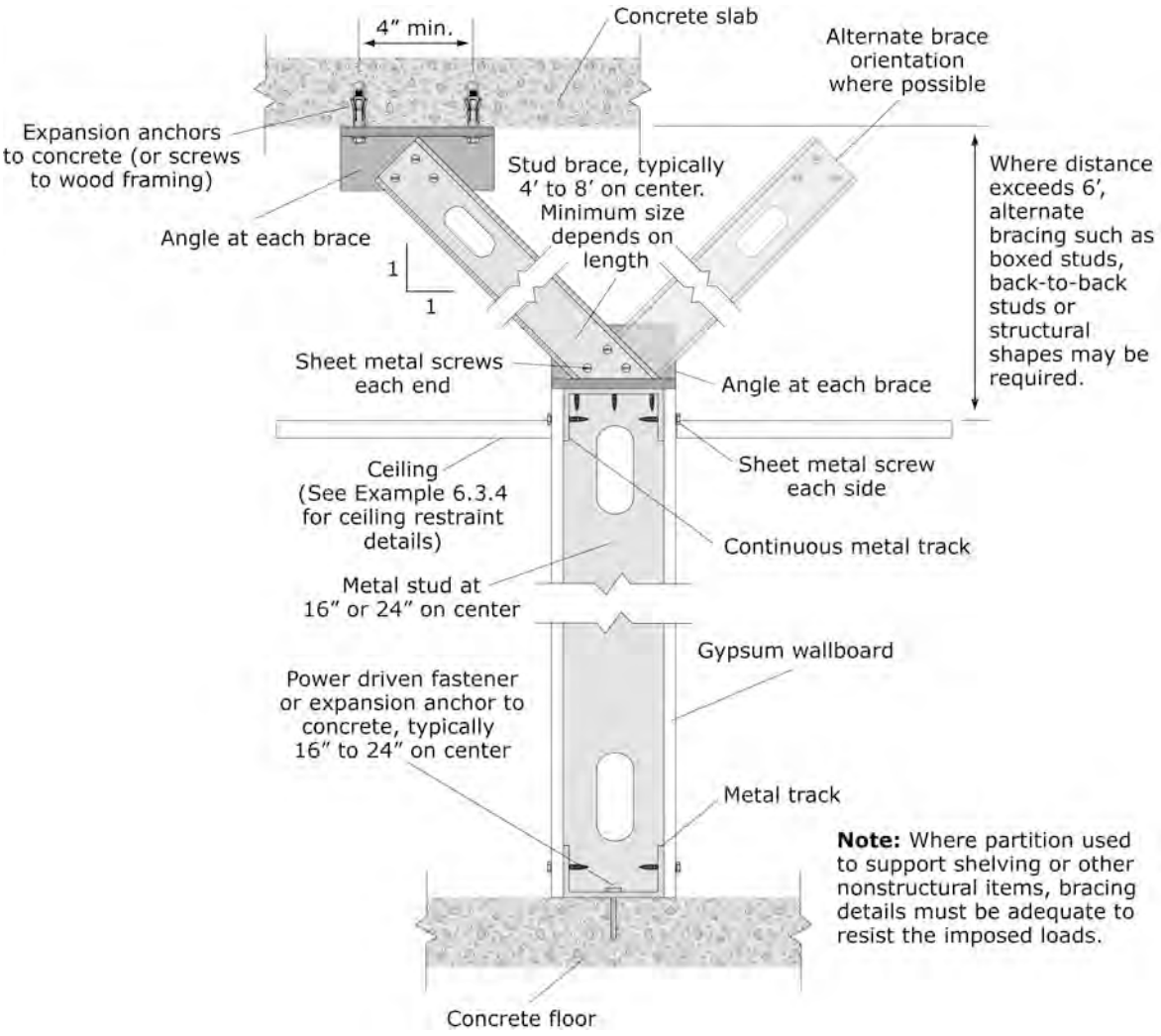


Figure 6.3.2.2-7 Partial height nonbearing stud wall (ER).

6.3 Architectural Components

6.3.2 Interior Partitions

6.3.2.3 Glazed Partitions

Glazed partitions are often used in office corridors or around conference rooms to provide enhanced interior lighting. Glazing may be found in light, heavy, or demountable partitions; glazed partitions may be either full height or partial height. Glazing assemblies may be vulnerable to earthquake damage; glazed partitions must have lateral support but should be isolated from the movement of the surrounding structure.

Provisions

BUILDING CODE PROVISIONS

Glazed partitions are subject to the provisions of Chapter 24 of the 2012 IBC, *International Building Code*, (ICC 2012), and are subject to the same requirements as exterior glazing. Seismic design is governed by ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures (*ASCE, 2010). ASCE/SEI 7-10 focuses on providing a mechanism to accommodate building deformations, or sufficient ductility to accommodate drift without a failure of the glazed partition:

- The building code has specific requirements on the type of glazing that may be used in different areas. Tempered glass is required within 10' above a walking surface under some circumstances; check applicable code requirements. Wired glass with a grid of steel wire embedded in the pane is an option for some situations where fire and impact rating are not also required. ANSI A97.1 *Safety Glazing Materials Used in Buildings* (ANSI, 2004) is the standard that defines different kinds of safety glass.
- The design of glazing assemblies depends on the calculated inter-story drift for the building, and the type of glass. Like exterior glazing assemblies, they are sensitive to both accelerations and deformations and are subject to both in-plane and out-of-plane failures.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies glazed partition systems as both acceleration and deformation sensitive.

- Glazed partition systems are subject to the requirements of ASCE/SEI 41-06 when

  - The performance level is Immediate Occupancy or Life Safety in high, moderate, and low seismicity areas, or
  - The performance level is Hazards Reduced in high, moderate, and low seismicity areas and the glazing is located over areas of public access or egress.
- ASCE/SEI 41-06 does not contain detailed acceptance criteria for glazed partitions. However, the behavior of these systems is very similar to glazed curtain wall systems. A drift analysis should be performed to determine if the glazing can accommodate the expected story drifts, and the anchorage of the glazed partition under seismic loading. The evaluation approach is similar to that used in ASCE/SEI 7-10.

Typical Causes of Damage

- Glazing assemblies may be damaged as a result of either in-plane or out-of-plane loading unless properly detailed. Failure of glazed partitions may create falling hazards, block corridors, and endanger occupants attempting to exit from damaged buildings. Glazing is particularly vulnerable in assemblies where there is insufficient clearance in the glazing pockets or insufficient isolation from the structure to accommodate inter-story drifts.
- Full height glazed partitions in flexible structures may fail unless they are isolated from the building deformations. In addition to broken glass, the mullions, gaskets, or setting block may be damaged. Damage may also include cracked or spalled finishes surrounding the glazing, deformed partition framing, and failed connections. Partial height glazed partitions may damage ceiling framing to which they are attached or can fall out-of-plane unless they are laterally braced to the structure above. Particularly hazardous is glazing used at the top portion of partial height partitions where it can fall from increased height; such glazing is often used to allow light transmission but reduce sound transmission.
- Glazed partitions may be damaged by impact from unanchored furniture or contents or suspended items without appropriate sway bracing.

DAMAGE EXAMPLES



Figure 6.3.2.3-1 Glass shards fallen from the top of partial height office partitions in the reception area during the magnitude-8.8 2010 Chile Earthquake (Photo courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).



Figure 6.3.2.3-2 Damage to glazed doors at the Concepción airport in the 2010 Chile Earthquake. In the top photo the glazing in the sliding glass door shattered; in the lower photo the glass is intact but the door frames are misaligned (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).



Figure 6.3.2.3-3 Failed wood framed glazing assembly in the 2010 Chile earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). The wood framing was held in place by metal or rebar brackets embedded in the masonry wall. The adobe wall on the left of the door collapsed and the brackets on the right side pulled out of the brick masonry wall (lower right). The glazing assembly at the rear entrance of the chapel was anchored overhead to the wood balcony framing and was undamaged.

Seismic Mitigation Considerations

- Architectural Design for Earthquake (Charleson, 2007) provides discussion and graphics pertaining to seismic detailing for glazing and glazed partitions. In addition, the American Architectural Manufacturer's Association (AAMA) has published guidelines for testing glazing assemblies and determining Δfallout. These guidelines may be obtained at www.aamanet.org.
- Glazing may be found in heavy, light, or demountable partitions; glazed partitions may be either full height or partial height. Anchorage details for heavy partitions are shown in Section 6.3.2.1, light partition details are shown in Section 6.3.2.2, and demountable partition details are shown in Section 6.5.5.2. The nonstructural surround must be self-supporting and not deliver loads to the glazing assembly from above or either side; thus, wall elements above the glazed portion may need to be suspended from above or

have an adequate lintel so the weight does not bear on the glazing or mullions. A deep leg slip track could be installed either at the top of the mullion or at the structure above, depending on the structural framing configuration. Note that because glazed partitions must meet the seismic drift limits for glass components, glazed partitions may require additional or different bracing than a similar partition without glazing. Also note that where the partition is properly detailed to be isolated from the seismic inter-story drift of the surrounding structure, the glass-to-frame clearance required around each pane of glazing is reduced. Special care should be given when detailing glass on intersecting planes such as corners and reentrant corners as these locations are particularly vulnerable to damage.

- Safety glazing, such as laminated or tempered glass, may be required in areas adjacent to stairways or subject to human impact; check the applicable code for specific requirements. Use of safety glass will reduce the hazard in the event that some of the glazing breaks in an earthquake.
- All glass assemblies have become common for enclosing lobby areas or atria in large commercial buildings. These typically are suspended from specially designed steel framing and may include details such as glass fins and steel connecting hardware. These assemblies are typically left free to slip at the bottom and must be specially detailed at edges and corners to avoid impact with adjacent panes.
- Glazed partitions should not be used to provide lateral support to other nonstructural components such as book shelves, electrical panels, file cabinets, unless adequate lateral resistance can be shown. In addition, such items should not be located where they can tip, fall, or swing and break the partition glazing.
- The use of glazed partitions should be avoided in emergency exit corridors or stairways; limiting the height and area of partition glazing or using multiple smaller panes of glass may be less hazardous than larger and taller panes.

MITIGATION EXAMPLES



Figure 6.3.2.3-4 Glazed partition supported at base with slip track at top; partition above glazing suspended and braced from above. Glazing subdivided into relatively small panels with ample clearance at mullions (Photo courtesy of Cynthia Perry, BFP Engineers).



Figure 6.3.2.3-5 Specialized glazing details for glass dome using specialty hardware, such as large sealant joints required to accommodate thermal movement and seismic deformations at the California Academy of Sciences, San Francisco, California (Photos courtesy of Cynthia Perry, BFP Engineers).

MITIGATION DETAILS

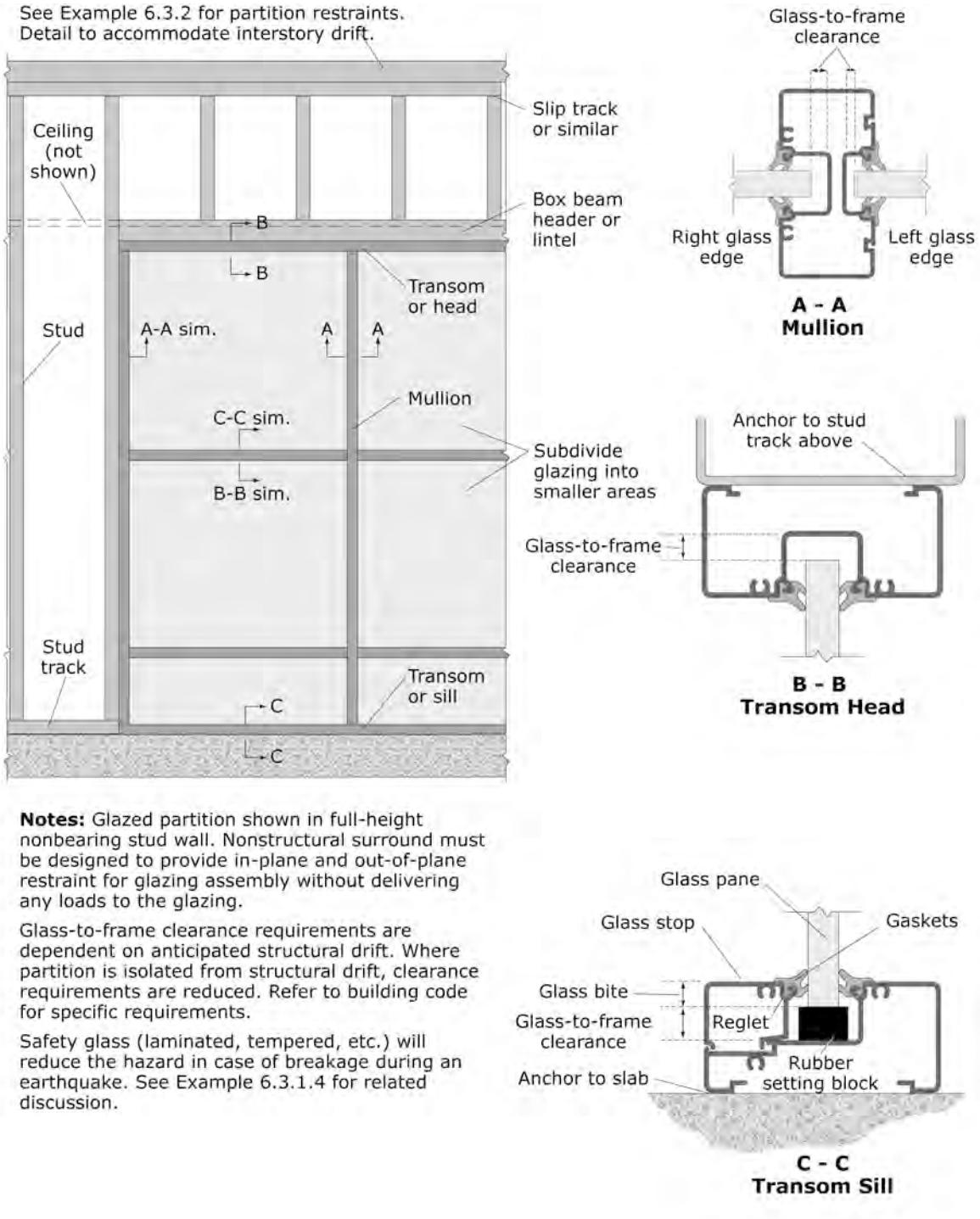


Figure 6.3.2.3-6 Details for full-height glazed partition (ER).

6.3 ARCHITECTURAL COMPONENTS

6.3.3 Interior Veneers

6.3.3.1 Stone, Tile and Masonry Veneer

Interior veneer may be either adhered or anchored; both types are addressed here. Veneer made of thin materials such as ceramic tile, masonry, corian or similar solid surface, and stone can be attached to a backing substrate with adhesive. Heavy veneers such as masonry, stone, or stone slab units weighing more than 20 psf must be anchored to the structure by mechanical means. To avoid becoming a falling hazard, veneers and their connections must be designed to accommodate the anticipated seismic drift. Alternatively, they must be attached to interior partitions which are isolated from the anticipated seismic drift of the structure.

Provisions

BUILDING CODE PROVISIONS

Building code provisions for adhered and anchored veneers are prescriptive, and contain a number of prescriptive requirements and limitations. Design provisions are found in both 2012 IBC, *International Building Code*, (ICC, 2012) and TMS402-11/ACI530/ASCE 5-11, *Building Code Requirements for Masonry Structures* (ACI, 2011). There are limits on the thickness, size, and weight of veneers. In general, the provisions for interior veneer are identical to those for exterior veneers (see Section 6.3.1.1 and 6.3.1.2), with some additional limits on unit size and weight

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies interior veneers as primarily deformation sensitive, but it may also become detached due to out-of-plane acceleration.

- Interior veneer is subject to the requirements of ASCE/SEI 41-06 when:
  - The performance level is Immediate Occupancy,
  - The performance level is Life Safety, except that ceramic tile need not be evaluated, or
  - The performance level is Hazards Reduced and heavy interior veneer is located over areas of public access or egress.

- Acceptance criteria focus on limiting the in-plane deflections of the veneer, and verifying that the anchorage is adequate for seismic loading.

Typical causes of damage

- Adhered veneers are deformation sensitive and may crack or become dislodged due to deformation of the backing substrate. Veneer adhered directly to structural elements may be particularly vulnerable, for example, veneer adhered to a concrete or masonry shear wall may be damaged when the wall deforms. Poorly adhered veneer may come loose due to direct acceleration. Where veneer, such as tile, is used to provide a water barrier, such as in kitchens, restrooms, or showers, the adhesive and backing substrate may be damaged due to water intrusion if the mortar joints are cracked or deteriorated. In this case, whole sections of tile might come loose.
- Anchored veneers and their connections may be damaged by inertial forces and by building distortion, especially when located at corners and openings. Rigid connections may distort or fracture if they do not have sufficient flexibility to accommodate the seismic drift. In addition, veneer units may crack, spall, or become completely dislodged and fall.

DAMAGE EXAMPLES



Figure 6.3.3.1-1 Damage to adhered tile veneer in residential bathroom and kitchen in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Ruben Boroschek & Associates). Tile is adhered to CMU infill partitions.



Figure 6.3.3.1-2 Damage to adhered tile veneer in locker room and kitchen at industrial facility in the 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Tile was adhered to CMU partitions which were built integral with the concrete frame. While only a limited number of tiles were broken, equipment had to be disconnected and many tiles removed to repair cracks in the wall and facilitate the repair of the veneer.

Seismic Mitigation Considerations

- Where interior veneer is attached to nonstructural walls or partitions, these partitions must be designed with adequate in-plane and out-of-plane support but detailed to accommodate the anticipated inter-story drift of the structural frame. Sections 6.3.1.1 and 6.3.1.2 provide additional information about adhered and anchored exterior veneers; the details used for interior veneers are similar, although interior and exterior finishes are typically installed by different trades.
- 2012 IBC contains a number of prescriptive requirements and limitations on the use of veneer. These include height limits, drift limits, deflection limits, limits on the use of combustible structural supports such as wood, mortar bed minimum thickness limits, and minimum tie spacing limits. Check the applicable code requirements when considering seismic mitigation options.
- Care must be taken in detailing corners, openings, edges and joints between structural elements and nonstructural substrates, such as a corner where a concrete masonry infill wall with veneer abuts a concrete column. While joints between individual tiles or stones may be grouted, movement joints may require a flexible sealant and bond breaker. Check manufacturer's recommendations for detailing under these special conditions.
- Adhered veneer placed directly on concrete or masonry shear walls is likely to be damaged during a design level earthquake since the shear wall is designed to deform to resist seismic loading. Cracking or spalling of adhered veneer on a shear wall is a sign that the shear wall has been damaged and may also be in need of repair.
- There are many vendors who supply veneer adhesion or anchoring systems. Some seismic veneer anchor examples for exterior veneers are shown in Section 6.3.1.2, and others can be found online. Figure 6.3.3.1-3 shows two examples of anchoring schemes for thin stone slabs as typically installed by specialty contractors. Both the supporting structure and the anchorage assembly must be designed to accommodate the anticipated inter-story drift.
- Existing veneer anchors should be checked periodically and corroded anchors should be replaced. Tie spacing should be compared with current code requirements to evaluate whether the anchorage is sufficient. Additional anchors may be installed to reduce the falling hazards. Adhered veneer used to provide a water barrier must also be periodically inspected and maintained; if not repaired, water intrusion may cause corrosion or deterioration of the backing substrate or structural supports.
- It may be prudent to remove interior veneer in exit corridors or above exits, especially if larger units are mounted above 10 feet.

MITIGATION DETAILS

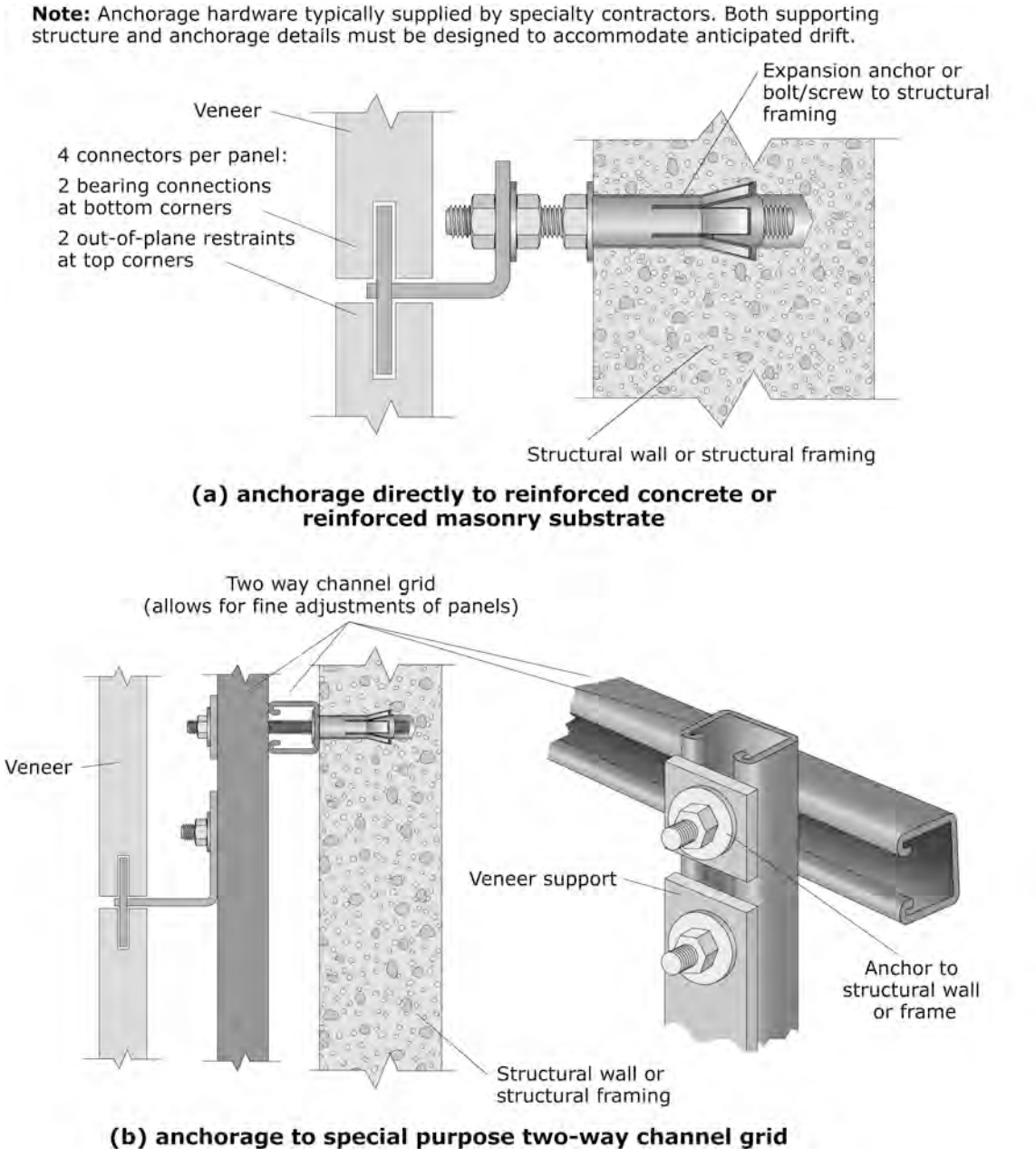


Figure 6.3.3.1-3 Detail for anchored interior veneer (ER).

6.3 Architectural Components

6.3.4 Ceilings

6.3.4.1 Suspended Lay-in Tile Ceiling Systems

Suspended modular ceiling systems are used widely in many types of buildings. These ceilings consist of light gauge metal inverted T-sections in a grid pattern, usually 2' x 2' but sometimes 2' x 4', hung from the structure with wires. The ceiling panels are most commonly designed for acoustics and are lightweight, typically weighing 1 psf or less. However, the same suspension system is often used for metal or other custom designed panels, sometimes resulting in a total system weight of up to 4 psf. Suspended lay-in tile ceiling systems typically support lighting and air diffusers, and have penetrations for sprinkler heads. Diagonal bracing wires, when present, extend from the hanger wire locations to the structure above to reduce swaying of the ceiling. Modern ceilings also have a "compression post" at each bracing location to prevent uplift of the ceiling.

Provisions

BUILDING CODE PROVISIONS

Suspended acoustic ceiling systems are subject to the requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13, Nonstructural Components. Two options for establishing compliance are available:

- Suspended acoustic ceiling systems may be designed as an integral system, considering the mass and flexibility of elements including the ceiling, lights, HVAC air diffusers, and sprinklers.
- Suspended acoustic ceiling systems may be installed in accordance with the prescriptive requirements of ASTME E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010), as modified by ASCE/SEI 7-10, Chapter 13.

RETROFIT STANDARD PROVISIONS

ASCE/SOU 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies ceilings into one of four types. Suspended acoustic ceiling systems are classified as "Category d", an integrated ceiling that includes lighting fixtures and mechanical items (air diffusers). Compliance with the requirements of the standard is necessary when:

- The performance level is Immediate Occupancy.
- The performance level is Life Safety in high, moderate, or low seismicity areas and the weight of the ceiling panels exceeds 2 psf.

Note that even if the ceiling system is exempt, light fixtures and air diffusers in the ceiling system may still be subject to support and bracing requirements.

Suspended acoustic ceiling systems are classified as both force and deformation controlled. Evaluation and rehabilitation of these ceilings is performed using prescriptive requirements such as ASTM E580, as modified by ASCE/SEI 7-10, Chapter 13.

Typical Causes of Damage

- The panels are supported by the metal Tee grid, but the metal Tee grid is stabilized by the panels. If one or the other system is damaged, the entire ceiling could become unstable and collapse as shown in Figure 6.3.4.1-1 through 6.3.4.1-3. Such general instability often starts at the perimeter of the ceiling, particularly where there is no wire hanger on the first span of Tees next to the wall. If the Tees fall off the wall angles without additional wire support, tiles will fall, the perimeter Tees become unstable, and the ceiling system will have uncontrolled sway, usually leading to collapse. Bracing will somewhat control the sway in this case but if the perimeter of the ceiling starts to fall apart, braces are only partly effective.
- Any differential movement of the ceiling relative to structural elements, such as structural columns or walls, partitions, sprinklers heads, or fixed lighting may locally damage the ceiling. Similarly, movement of unrestrained piping, mechanical ducts, or lighting in a tightly braced ceiling can also damage the ceiling.
- Recent laboratory tests (University of Buffalo, NEES Nonstructural Grand Challenge) have shown that in ceilings with a 50 foot dimension, the tees in between braced lines (12 feet spacing) were not sufficiently restrained by the braces and pulled away from the perimeter walls. Added braces, or staggering braces on different tee lines, may avoid this failure mode.
- Where lights, diffusers and other services within the ceiling do not have independent safety wires, these items can fall and create a hazard for occupants.
- Conflicts between ceilings and sprinkler heads are a common occurrence causing damage to both the ceiling and sprinkler heads, potentially setting off the sprinkler system or causing local leaks..
- Ceiling failures may result in building evacuations and loss of functionality until the ceiling and utilities are repaired. In a hospital setting or clean lab, the failure of the

ceiling system may introduce dust and debris, including asbestos, into the room below compromising its functionality. In the case of asbestos contamination, this may involve costly removal before functionality can be restored.

DAMAGE EXAMPLES



Figure 6.3.4.1-1 Failure of suspended ceiling system including lights, air diffusers, and insulation in control room of an industrial plant in the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of BFP Engineers).



Figure 6.3.4.1-2 Failure of suspended ceiling system including lights and air diffusers in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).



Figure 6.3.4.1-3 Generalized failure of ceiling grid, tiles, lights, and diffusers at the Los Angeles Hospital in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Bill Holmes, Rutherford & Chekene).



Figure 6.3.4.1-4 Fallen ceiling tiles at Talca Hospital in the 2010 Chile Earthquake, in spite of the use of clips as shown in detail at right. Most ceilings observed in Chile did not have seismic detailing (Photos courtesy of Bill Holmes, Rutherford & Chekene).



Figure 6.3.4.1-5 Damage to suspended metal panel ceiling system and fire sprinklers at Concepción airport, primarily at far end and around column obstructions in the 2010 Chile Earthquake (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates). The metal panel was strong enough to fail the sprinkler head shown at lower left.

Seismic Mitigation Considerations

- Standard practice for the seismic design of suspended acoustic lay-in tile ceilings is described in ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASCE, 2010), which is referenced in ASCE 7-10 Section 13.5.6. This standard supersedes several previous Ceilings and Interior Systems Construction Association (CISCA) standards.
- For ceilings in Seismic Design Category C, the objective of these standards is to provide an unrestrained ceiling that will accommodate the movement of the structure during a seismic event. This is achieved by specifying the strength of grid connectors, frequency of hangers, perimeter closure angles, edge clearances, etc.
- For ceilings in Seismic Design Category D, E, and F, the objective of these standards is to provide a restrained ceiling with connection to the perimeter wall and with rigid or non-rigid bracing assemblies. This is achieved by specifying the strength of grid elements, grid connections, frequency of hangers and lateral bracing assemblies, 2" minimum perimeter closure angles, minimum edge clearances, etc. For Seismic Design Category D, E & F, lateral bracing assemblies are required for all ceiling areas greater than 1000 sq. ft. There are several exemptions as follows:
    - Seismic detailing is not required for suspended ceilings less than or equal to 144 sq. feet that are surrounded by walls or soffits that are laterally braced to the structure (this exemption applies to heavy or light suspended ceiling systems).
    - For ceilings in Seismic Design Category C weighing less than 2.5 psf, special seismic perimeter closure details are required to provide an unrestrained ceiling; bracing assemblies are not required.
    - Ceilings weighing above 2.5 psf in Seismic Design Category C and ceilings in Seismic Design Categories D, E, and F are detailed to provide a restrained ceiling; nevertheless, ASTM E580 does not require bracing assemblies unless the ceiling area is larger than 1000 sq. ft. However, recent shake table testing indicates that long lengths of unbraced Tees cannot deliver the tributary seismic load to the fixed walls. Based on previous testing, it is estimated unbraced tees of greater than 30 feet should be avoided.
- For Seismic Design Category D, E, and F, these details typically include requirements for perimeter closure that provides fixity along two adjacent sides and allows ¾" of slip on the opposite sides as well as periodic bracing assemblies in ceilings larger than 1000 sq. ft. ASTM E580 includes requirements for the strength of connections between grid elements, minimum size (2") for the closure angle, requirements for seismic separation

joints for ceilings larger than 2500 sq. ft., requirements for the support of lighting and mechanical services, and other requirements. See also Figures 6.3.4.1-8, 9, and 10.

- Where lights and diffusers and supported by the ceiling grid, either an intermediate duty or heavy duty grid must be used and supplementary framing and hanger wires may be required to provide direct support for such items. For instance, ASTM E580 requires heavy duty main runners with a load carrying capacity of 16 lb/ft for Seismic Design Category D, E and F. If cross runners with a load carrying capacity less than 16 lbs/ft are specified, and the corner of any light fixture is supported on two adjacent sides by these intermediate duty cross runners, then a supplementary hanger wire must be attached to the grid within 3" of each such corner. ASTM E580 includes several figures showing examples where these supplementary wires are required. These supplementary hanger wires are not required where heavy duty cross runners are specified. See Examples 6.4.6.2 and 6.4.9 for additional requirements for ail diffusers and lights, respectively.
- Seismic bracing assemblies for suspended ceilings typically include a vertical compression strut and diagonally splayed wire braces as shown in Figure 6.3.4.1-9. Rigid bracing assemblies, such as those shown to brace overhead piping in Section 6.4.3 may also be used.
- ASTM E580 includes other requirements for clear openings for sprinkler heads, seismic separation joints, ceiling penetrations, and consideration of consequential damage and seismic interaction effects.
- The Division of the State Architect sets forth special ceiling standards for California schools in DSA IR 25-5 (California Department of General Services, 2009c),. This reference is a useful tool for designing in areas of potentially severe seismic shaking. In California, schools require ceiling bracing assemblies at a spacing of not more than 12 feet in each direction; essential services buildings require bracing assemblies at a spacing of not more than 8 ft. by 12 ft. on center. DSA requirements differ slightly from those in ASTM E580; check the applicable jurisdiction for specific requirements.
- Ceiling details in Figures 6.3.4.1-7, 8, 9 and 10 are for Seismic Design Category D, E and F where the total ceiling weight does not exceed 4 psf or Seismic Design Category C where the total ceiling weight is between 2.5-4 psf. These details and diagrams are adapted from CA DSA IR 25-5 and ASTM E580. These figures are shown with heavy duty main runners and cross runners as required by DSA IR 25-5. Check the applicable jurisdiction; in some cases, ceilings heavier than 4 psf, or those with a plenum larger than a certain threshold, may require engineering. See references for additional information, updates, or for connection details and special conditions not shown.

- There are shake table tests of ceilings which show that systems perform better when the tile almost nearly fills the available space and has ample overlap on the runners. These systems also have fewer tiles drop in tests than systems with smaller tiles.
- ASCE/SEI 7-10 Section 13.5.6.3 includes a discussion of "integral construction" where the grid, panels, lights, piping, and other overhead services are shop assembled in modules and bracing is provided for the whole assembly. These are included as an alternative to the details shown here. Check the internet for proprietary systems or systems pre-approved for use in your jurisdiction.
- Safety wires are required for lights and mechanical services in suspended acoustic tile ceilings to prevent them from falling. Refer to Sections 6.4.9 and 6.4.6.2 for additional information. As noted above, supplementary hanger wires for the ceiling grid may also be required. The weight of supported items should never exceed the carrying capacity of the ceiling grid. Special details are required for heavy lighting or heavy mechanical items; these should be supported directly from the structure above and not depend on the ceiling grid for vertical or lateral support. For such fixed items, perimeter closure details may be required for the ceiling to prevent impact with the ceiling system.
- Although not required by code, some manufacturers offer slide-on metal fabrications to clip the panels to the runnersfor enhanced stability. The main problem with such clips is that they defeat the purpose of an accessible ceiling space. In the case shown in Figure 6.3.4.1-4, the clips were installed but extreme shaking and ceiling movement at the walls still caused panels to fall.

MITIGATION EXAMPLES



Figure 6.3.4.1-6 Compression struts and diagonal splayed wires are used to limit the movement of suspended acoustic tile ceilings. Per ASTM E580, this type of bracing assembly is required for ceiling areas larger than 1000 sq. ft. in Seismic Design Category D,E, and F (Photo courtesy of Maryann Phipps, Estructure).

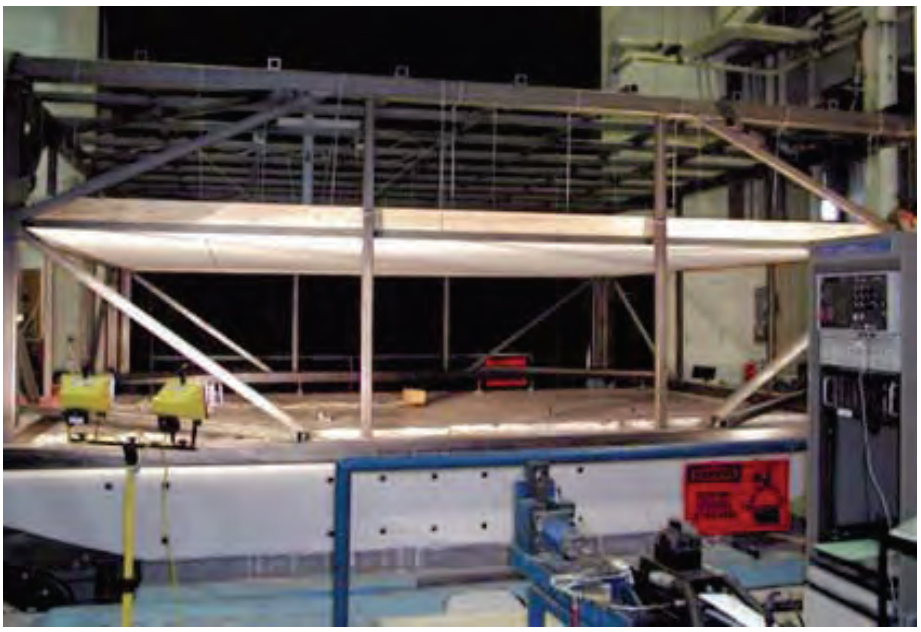


Figure 6.3.4.1-7 Shake table testing of a proprietary suspended acoustic lay-in tile ceiling at MCEER (Photo courtesy of University of Buffalo, SUNY). Additional testing of these systems will help improve our understanding of their failure modes and help inform the design of more resilient systems.

MITIGATION DETAILS

Ceiling details in Figures 6.3.4.1-8, 9, 10 and 11 are for Seismic Design Category D, E and F where the total ceiling weight does not exceed 4 psf or Seismic Design Category C where the total ceiling weight is between 2.5-4 psf. These are adapted from DSA IR 25-5 and ASTM E580. These figures are shown with heavy duty main runners and heavy duty cross runners as required by DSA IR 25-5; see discussion in text regarding the requirement in ASTM E580 for supplementary hanger wires at light fixtures supported by intermediate duty cross runners. Check the applicable jurisdiction; in some cases, ceilings heavier than 4psf, or those with a plenum larger than a certain threshold, may require engineering. See sources for additional information, updates, or for connection details and special conditions not shown.

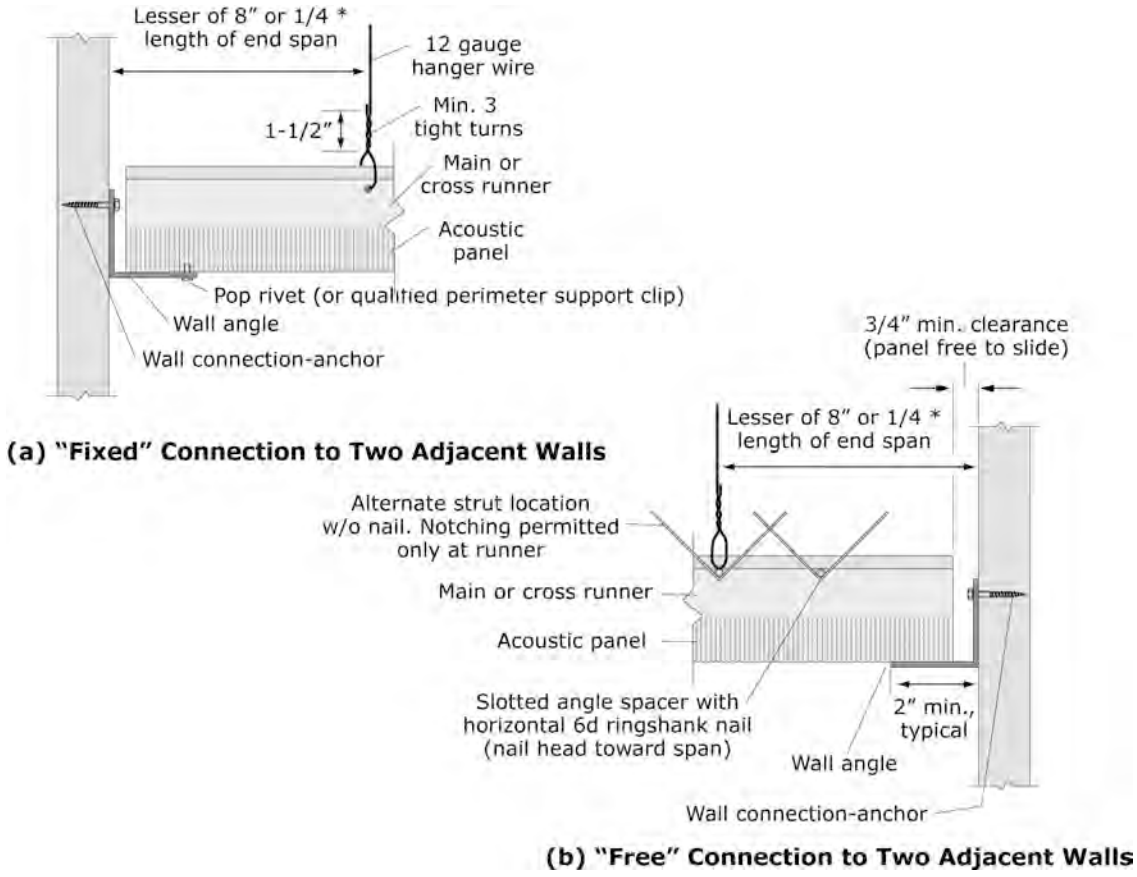
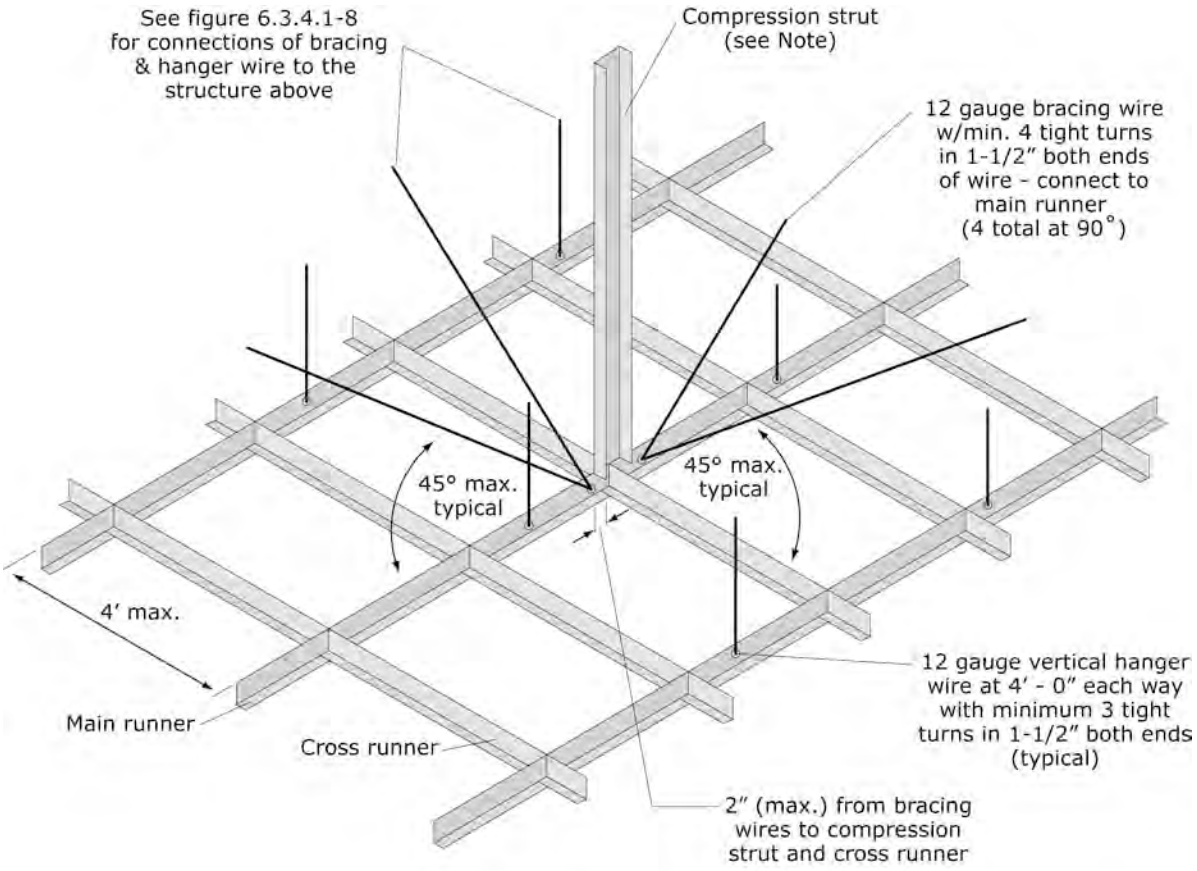


Figure 6.3.4.1-8 Suspension system for acoustic lay-in panel ceilings – edge conditions (PR).



Note: Compression strut shall not replace hanger wire. Compression strut consists of a steel section attached to main runner with 2 - #12 sheet metal screws and to structure with 2 - #12 screws to wood or 1/4" min. expansion anchor to structure. Size of strut is dependent on distance between ceiling and structure ($l/r \leq 200$). A 1" diameter conduit can be used for up to 6', a 1-5/8" X 1-1/4" metal stud can be used for up to 10'

Per DSA IR 25-5, ceiling areas less than 144 sq. ft, or fire rated ceilings less than 96 sq. ft., surrounded by walls braced to the structure above do not require lateral bracing assemblies when they are attached to two adjacent walls. (ASTM E580 does not require lateral bracing assemblies for ceilings less than 1000 sq. ft.; see text.)

Figure 6.3.4.1-9 Suspension system for acoustic lay-in panel ceilings – lateral bracing assembly (PR).

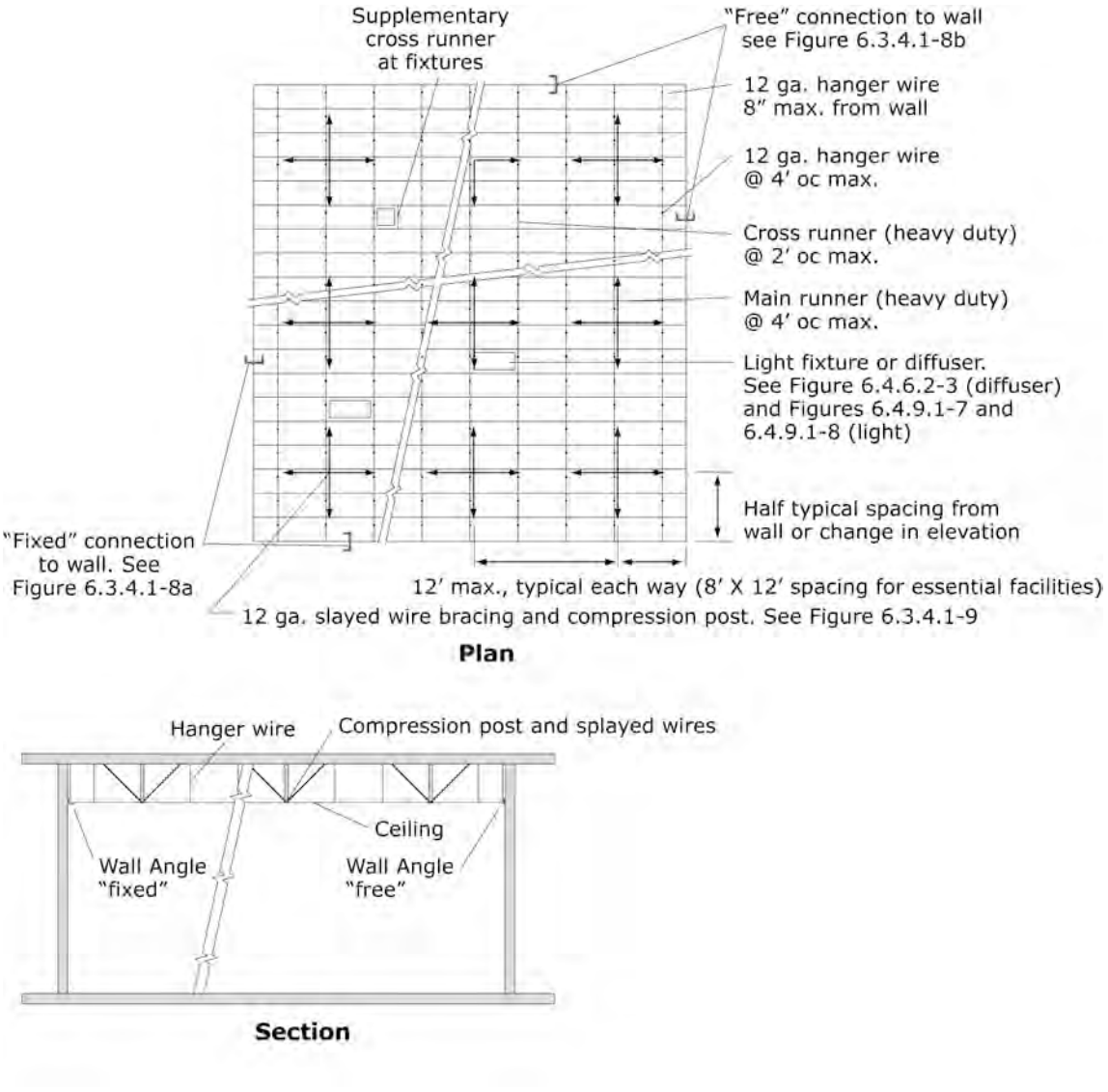


Figure 6.3.4.1-10 Suspension system for acoustic lay-in panel ceiling – general layout. Although installation standards suggest alignment of brace locations, intermediate tees (particularly with a 12 foot brace spacing), may not be sufficiently restrained in large ceilings (greater than 30 foot dimension). In order to follow the current standard and alleviate this problem, braces must be added in between the 12 foot spacing. Another solution, not in complete compliance with the standard, would include staggering brace locations so more tee lines are braced (PR).

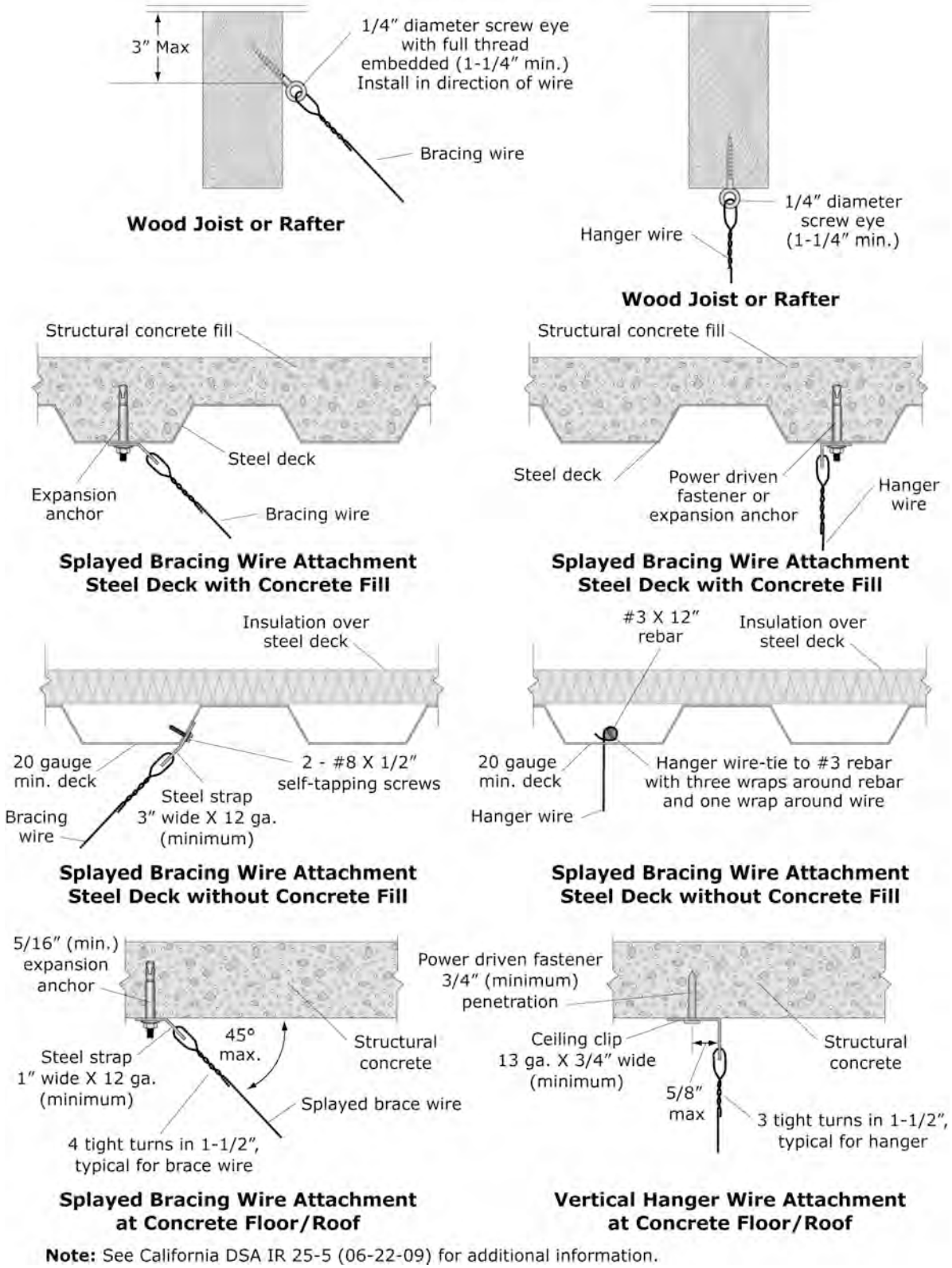


Figure 6.3.4.1-11 Suspension system for lay acoustic lay-in panel ceiling – overhead attachment details (PR).

6.3 Architectural Components

6.3.4 Ceilings

6.3.4.2 Ceilings applied Directly to Structure

Ceiling finishes such as gypsum board, interior lath and plaster, or exterior stucco soffits may be applied directly to structural elements such as wood ceiling joists, beam soffits, or the underside of structural slabs. These overhead finish materials may pose a falling hazard if the finish materials and any backing substrate are not anchored to the structure with sufficiently strong positive attachments.

Provisions

BUILDING CODE PROVISIONS

Ceilings applied directly to the structure are considered force controlled, and the principal objective of the code provisions is to prevent ceilings from falling.

- Ceiling assemblies of gypsum board and plaster are covered by Chapter 25 of the 2012 IBC, *International Building Code* (ICC, 2012). These are prescriptive requirements, including requirements for horizontal gypsum board diaphragm ceilings.
- Seismic loads for ceilings are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures (*ASCE, 2010), Chapter 13.

RETROFIT STANDARD PROVISIONS

- ASCE 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) contains specific requirements for ceilings that are surface applied or furred with materials that are applied directly to wood joists, concrete slabs, or steel decking. Compliance with the anchorage provisions of the standard is required when:
    - The performance level is Immediate Occupancy.
    - The performance level is Life Safety and the plaster ceiling is over 10 sq. ft. in area and attached to metal or wood lath.
    - The performance level is Hazards Reduced and the ceiling is located in areas of public occupancy or egress. Such ceilings shall meet the Life Safety Nonstructural Performance Level.
- There are no prescriptive rehabilitation approaches for surface applied ceilings. Lateral forces are computed using ASCE 41-06 Section 11.7.4.

Typical Causes of Damage

- Vintage lath and plaster ceilings may fall if the wood or metal lath is not adequately secured to the structure above or if the plaster has separated from the lath. Even well secured ceilings may exhibit x-cracking in buildings with flexible diaphragms or cracking around the edges where the ceiling and walls meet or at locations with seismic joints that have not been properly detailed. These ceilings may be particularly vulnerable if they have deteriorated due to roof or plumbing leaks.
- Stucco soffits on exterior surfaces, such as the underside of balconies or canopies, may fall if the wood or metal lath or finish materials are not adequately secured to the structure above or if the attachments have corroded or the components have deteriorated due to long term exposure or leakage from the roofing or decking above. Stucco soffits on cantilevered balconies or canopies may be particularly vulnerable as they often experience higher vertical accelerations than other structures.
- Large expanses of ceiling attached directly beneath flexible diaphragms may be damaged unless the ceiling is properly detailed with two adjacent sides attached and the opposite sides free and is subdivided into smaller areas (<2500 sq ft) with seismic expansion strips. Damage may occur around the perimeter, at changes in elevation, or at corners, columns, or other obstructions.

DAMAGE EXAMPLES



Figure 6.3.4.2-1 Damage to metal lath and plaster ceiling applied to the underside of the concrete slab in 10-story residential building in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). The damage occurred due to pounding at the interface between two wings of the structure.



Figure 6.3.4.2-2 Damage to stucco soffit of historic church in the 2010 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Stucco applied directly to the underside of the slab above without furring; portion at left has fallen, portion at right delaminated.



Figure 6.3.4.2-3 Damage to soffit paneling and wood framing at hotel in the 2010 Chile Earthquake; panels and wood framing show signs of prior water damage and deterioration. Note also damage to storefront glazing and glass doors (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

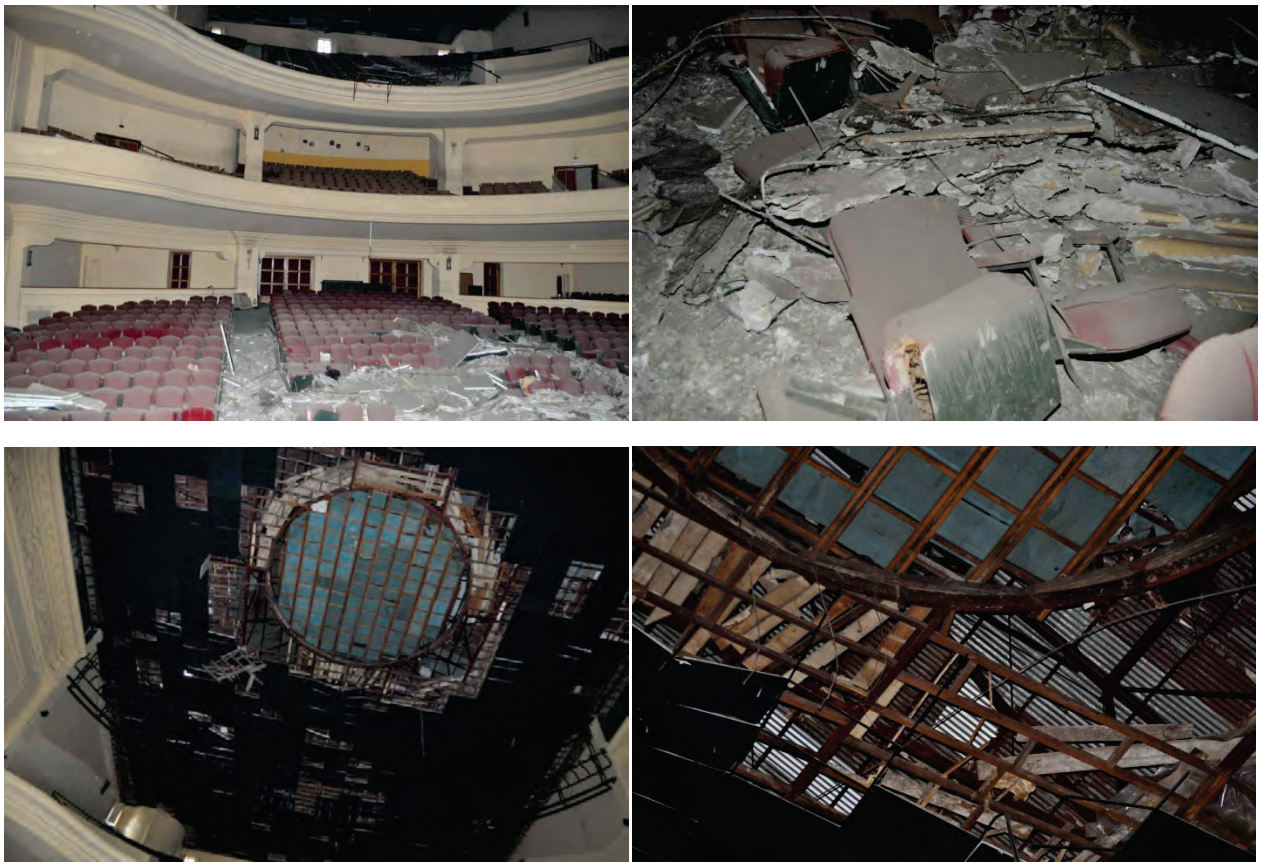


Figure 6.3.4.2-4 Damage to theater ceiling where foam panels and grid came down over orchestra seating and in upper balcony at the Municipal Theater Valparaiso in the 2010 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). A circular section of metal lath and plaster collapsed completely. It appears the metal lath may have only been attached around the perimeter to wood furring added in the plane of the steel framing; circular area of wired glass is in a plane above the level of the wood furring. Black panels are lightweight foam supported by a grid attached directly to the wood furring.



Figure 6.3.4.2-5 Extensive failure of ceiling in the main terminal of the Santiago airport in the 2010 Chile Earthquake. Metal panels with lights and diffusers hung from furring on short metal tabs; these remained in place but detail at lower left shows they also sustained some damage. Furring channels still in place throughout ceiling but majority of lightweight ceiling panels and much of the cross furring came down as shown at lower right photo of exterior soffit with same system (Photos courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).

Seismic Mitigation Considerations

- Provide positive connections from the gypsum board, plaster or stucco finish materials to the furring and from the furring to the structure above. Protect these connections from water damage or corrosion. Check local codes for specific requirements or exemptions; in many cases these ceilings do not require special seismic detailing as long as the installation meets current industry standards.
- It may be prudent to reduce the standard connector spacing on stucco soffits or finishes mounted beneath cantilevered balconies or canopies which may experience large vertical accelerations during an earthquake. Note that finishes with exterior exposure such as soffits also need to be designed for wind.
- Gypsum board ceilings are frequently used to meet requirements for fire-rating or sound proofing or both. Rated systems may include combinations of metal decking, wood subflooring, wood or metal joists, insulation, resilient furring strips, and one or several layers of gypsum board. While rated systems are typically proprietary, care must be taken to insure that appropriate fasteners are used for each successive layer and that they are installed with adequate penetration into the joists or furring strips. These multi-layer systems get increasingly heavy and also have increased in-plane stiffness. In some instances, care must be taken with the perimeter details to provide seismic expansion joints and to allow relative movement with the walls but maintain the fire-rating. Availability of certified systems with seismic detailing wherever sound or fire proofing is required should be checked and these systems must be installed exactly as specified and as tested otherwise the certification is not valid.
- Vintage lath and plaster ceilings still exist in many older structures. These ceilings should be in good condition with the lath securely fastened to the structure and the plaster secured to the lath. The most reliable way to upgrade these ceilings would be to remove and replace with a code compliant ceiling system. Where it is important to match other vintage finishes, screw attached metal lath with a new plaster finish can be used. As an alternative to replacement, screwing 1x2 wood strips at 16 in centers into the joists from below may serve as a safety net (See Figure 6.3.4.2-9). Some ornate theatre ceilings have been encapsulated from below with netting to reduce the falling hazard; such netting and all its attachments must be designed to contain any falling debris.

MITIGATION EXAMPLES







Figure 6.3.4.2-6 Mitigation examples with 1-1/2″ hat channels at 16″ on centers screwed in place with #12 self drilling screws and furring strips ready to receive gypsum board (Photo courtesy of Excalibur Steel). No special seismic details are required for this type of ceiling where the gypsum board is well secured directly to furring strips.



Figure 6.3.4.2-7 View of typical wood lath and plaster ceiling from the 1920's from above (Photo courtesy of Cynthia Perry, BFP Engineers). The wood lath is well nailed to the underside of the ceiling joists. This type of ceiling typically remains intact during an earthquake but may require crack repair and painting. Where the plaster has delaminated from the lath due to age or water leakage, wood strips could be installed from below as in Figure 6.3.4.2-8.

MITIGATION DETAILS

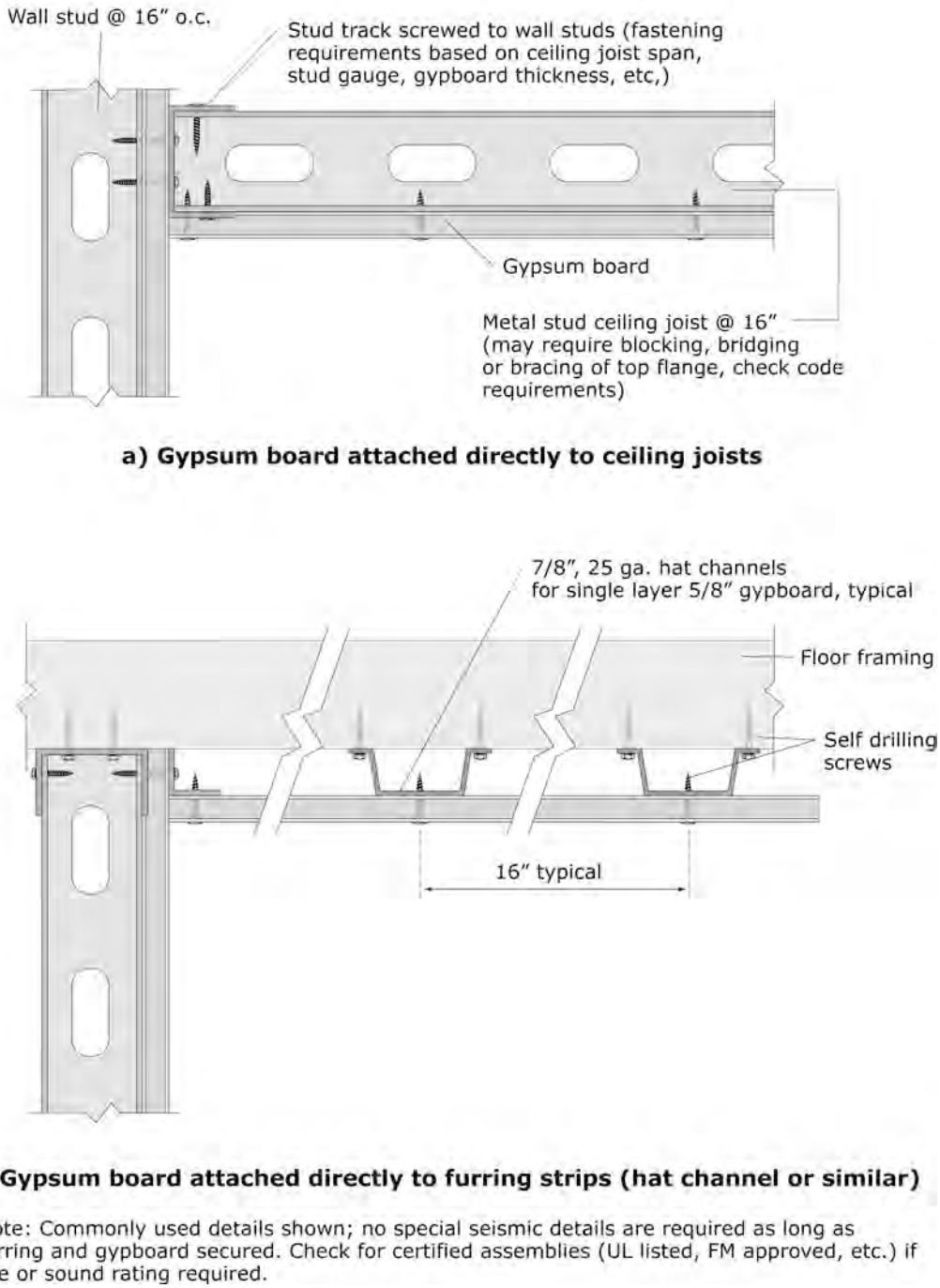


Figure 6.3.4.2-8 Gypsum board ceiling applied directly to structure (NE).

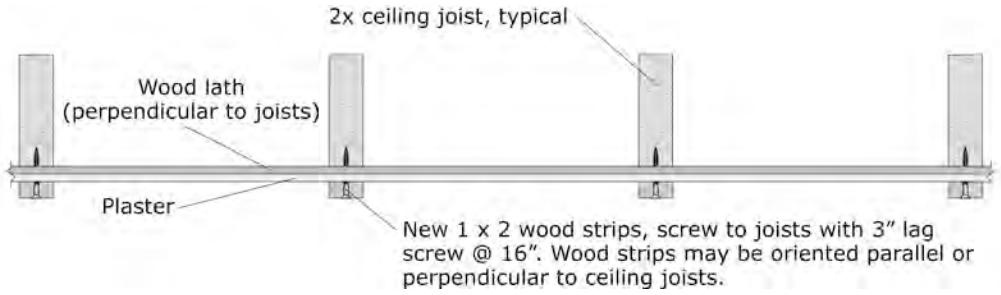


Figure 6.3.4.2-9 Retrofit detail for existing lath and plaster (NE).

6.3 Architectural Components

6.3.4 Ceilings

6.3.4.3 Suspended Heavy Ceilings

This category covers several different types of overhead ceilings suspended from above including dropped furred gypsum board ceilings and suspended lath and plaster ceilings. Suspended ceilings with wood or metal panels would also fit into this category. These systems typically have finish material attached to a two-way furring grid which is suspended from above. In order to reduce damage and prevent falling hazards the finish material must be well secured to the furring grid. Damage can be reduced if the ceiling is attached to the walls along two adjacent sides but separated from the walls along the opposite two sides and the furring grid is laterally braced to the structure above.

Provisions

BUILDING CODE PROVISIONS

Suspended heavy ceiling systems are subject to the force requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13, Nonstructural Components. Ceiling assemblies of gypsum board and plaster are also subject to the requirements of the 2012 IBC, *International Building Code*, (ICC, 2012).

- Section 13.5.6 of ASCE/SEI 7-10 contains requirements for special seismic perimeter details and lateral bracing assemblies for suspended ceilings but includes several significant exemptions from these requirements as follows.
    - Seismic detailing is not required for suspended ceilings less than or equal to 144 square feet that are surrounded by walls or soffits that are laterally braced to the structure (this exemption applies to heavy or light suspended ceiling systems).
    - Seismic detailing is not required for suspended ceilings constructed of screw- or nail-attached gypsum board on one level (constructed in a single plane) that are surrounded by and connected to walls or soffits that are laterally braced to the structure above. Note that this exemption does not apply to plaster ceilings or to gypsum board ceilings on multiple levels (constructed in more than one ceiling plane elevation).

- Chapter 25 of the 2012 IBC contains general provisions for horizontal assemblies of gypsum board and plaster, including prescriptive requirements for installation. There are, however, no provisions for lateral design of suspended ceilings.
- The Division of the State Architect sets forth ceiling standards for California schools in DSA-IR 25-3 *Drywall Ceiling Suspension, Conventional Construction – One Layer* (California Department of General Services, 2005b). This document provides general guidance for design and detailing of heavy suspended ceilings.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies ceilings into one of four types. Suspended ceiling systems are classified into one of two categories:

- Category b, short-dropped gypsum board sections (less than 2-ft drop) attached to wood or metal furring supported by carrier members.
- Category c, dropped gypsum board sections greater than 2 and suspended metal lath and plaster.

These ceiling systems are considered force and deformation sensitive. Compliance with the requirements of the standard is necessary when:

- The performance level is Immediate Occupancy.
- The performance level is Life Safety or Hazards Reduced in high or moderate seismicity areas.

If the performance level is Hazards Reduced and the ceiling is located in areas of public occupancy or egress, the ceiling must meet the Life Safety performance level.

Note that even if the ceiling system is exempt, light fixtures and air diffusers in the ceiling system may still be subject to support and bracing requirements.

Typical Causes of Damage

- Suspended heavy ceilings may be damaged both by direct acceleration and by deformation. Direct acceleration may cause connectors to become loose or deform, and differential movement of the ceiling relative to structural elements such as columns or walls or nonstructural elements such as partitions, lights, diffusers, or sprinklers may also damage the ceiling.
- As these systems are heavier than acoustic tile ceilings, the consequences of failure may be more hazardous for occupants since both the finish material and the furring grid may

fall. Ceiling failures are often costly because the space underneath may be unusable while the ceiling is repaired or replaced.

- Ceiling finishes may crack unless adequately isolated from the motion of the surrounding structural and nonstructural elements. Crack repair in gypsum board and plaster ceilings is a common expense following earthquakes.

DAMAGE EXAMPLES



Figure 6.3.4.3-1 Damage to ornate wire lath and plaster ceiling in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Wire lath is attached to arches or to wood furring suspended from the roof framing.



Figure 6.3.4.3-2a Complete collapse of a large suspended gypsum board ceiling over a swimming facility in Japan (Photo courtesy of Shojiro Motoyui, Tokyo Institute of Technology). This type of failure has been replicated on the E-defense shake table and occurs when the U-shaped clip holding the cross furring (M-bar) to the main runners (channel) opens into a V-shape and drops the furring grid. This type of failure is not common in the U.S.

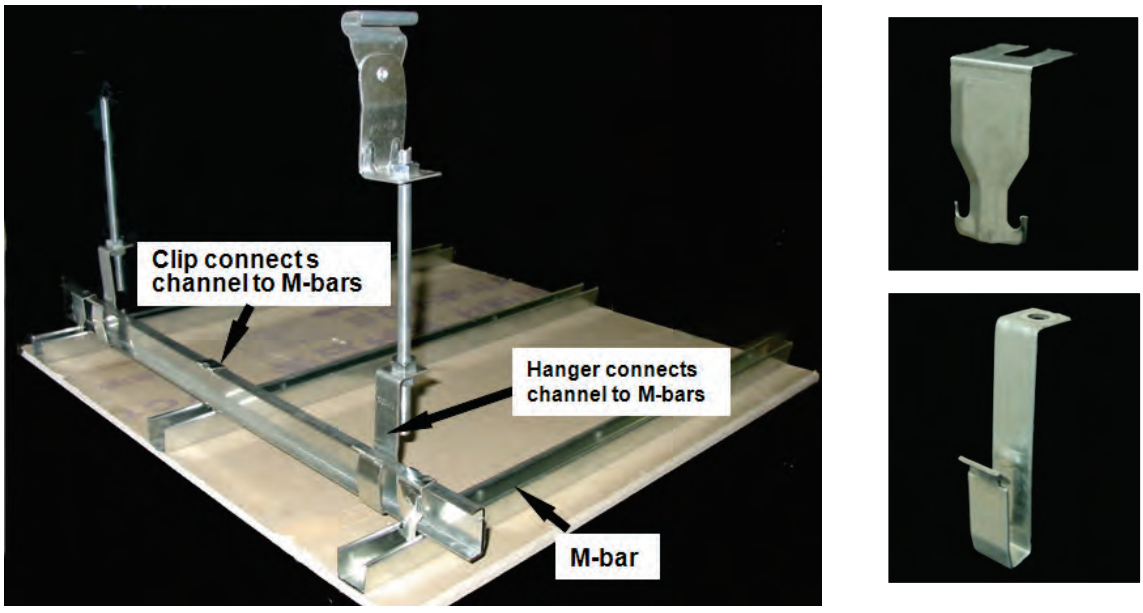


Figure 6.3.4.3-2b Schematic view of Japanese drywall ceiling grid. These ceilings are also typically installed with lateral bracing and 200mm edge clearance. Clip shown at lower right opens when the M-bar slides back and forth relative to the main runner, particularly those located near a diagonal brace. This type of clip is not common in the U.S (Source: "Dynamic characteristics of Japanese style of ceiling," Motoyui, S., Satoh, Y., and Kawanishi, T. *Proceedings 7CUEE & 5ICEE*, March 2010).



Figure 6.3.4.3-3 Collapse of exterior soffit at Jefferson Elementary School in Calexico in the 2010 Baja California Earthquake; approximately 1200 sq ft of soffit collapsed at this school built in the 1960's (Photo courtesy of Baja Earthquake Reconnaissance Team, Earthquake Engineering Research Institute (EERI), published in the EERI July 2010 Newsletter).

Seismic Mitigation Considerations

- Special seismic detailing may be required for heavy ceilings such as plaster, wood or metal panels, or for gypsum board ceilings at multiple levels. For these cases, details are typically configured similar to those used for acoustic ceilings with more frequent bracing and robust members and connections to account for the increased weight. Seismic bracing for suspended heavy ceilings typically includes a vertical compression strut and diagonally splayed wire braces as shown in Figure 6.3.4.3-7. Rigid bracing (strut or cold-formed steel) is sometimes used in lieu of splayed wire bracing and compression posts. Special perimeter details typically include 2" wide perimeter closure angles, fixed attachments on two adjacent walls and clearance of at least ¾" from the two opposite walls as shown in Figure 6.3.4.3-5.
- Details shown in Figures 6.3.4.3-5, 6.3.4.3-6, and 6.3.4.3-7 are based on requirements for schools in California. The Division of the State Architect sets forth ceiling standards for California schools in DSA-IR 25-3 Drywall Ceiling Suspension, Conventional Construction – One Layer (California Department of General Services, 2005b). This standard refers to DSA-IR 25-5 Metal Suspension Systems for Lay-in Panel Ceilings (California Department of General Services, 2009c) for specific details regarding the bracing assembly. These references are useful tools for designing in areas of potentially

severe seismic shaking or in jurisdictions where bracing is required. In California, ceiling bracing assemblies at a spacing of not more than 12 feet in each direction are required in schools and bracing assemblies at a spacing of not more than 8 ft by 12 ft on center, as shown in Figure 6.3.4.3-5, are required in essential services buildings.

- This section provides prescriptive details for suspended gypsum board ceilings where the grid is composed of channel sections for the main runners with hat channels wired below as the cross furring. Check with manufacturers for alternative proprietary systems that use T-bars for both the main and cross runners.
- Vintage lath and plaster ceilings are typically hung with wood hangers and runners without consideration of seismic design forces. Diagonal 45 degree splay bracing wires can be added at select wood hanger locations (for instance, 4 ft by 6 ft) to brace these ceilings. Some jurisdictions, such as the Salt Lake City School District, require that vintage lath and plaster ceilings be removed and replaced with compliant ceiling systems. Where historic preservation considerations require and the local codes permit, replacement plaster ceilings may be constructed with screw-attached metal lath and dedicated bracing. As a lower cost alternative to replacement in wood framed construction, the seismic risk posed by a plaster ceiling can be reduced by screwing 1x2 wood strips at 16" centers into wood joists from below (oriented perpendicular to the joists) to serve as a safety net. Some ornate theatre ceilings have been effectively encapsulated from below with netting to reduce the falling hazard; such netting and all its attachments must be designed to contain any falling debris.
- Ceiling anchorage needs to be coordinated with the anchorage for lighting, air diffusers, and sprinkler lines. All recessed or drop-in light fixtures and diffusers must be supported directly by main runners or by supplemental framing with positive attachment to main runners. In order to minimize their potential falling hazard, lights, diffusers and similar items are required to be independently supported by the structure, typically with a minimum of two wires, as discussed in Sections 6.4.6.2 and 6.4.9.3. In some locations and occupancies, penetrations for sprinkler heads in ceilings braced with splayed wire bracing are required to have a 2 inch oversized opening to allow for free movement of 1 inch in all horizontal directions. Check local code requirements.
- Mechanical connectors between the component parts of the ceiling assembly must be chosen carefully to avoid failures. Catastrophic failures of ceiling systems in Japan have been replicated during shake table testing because the U-shaped mechanical clip used to hang the cross furring from the main runner can open during an earthquake, dropping the cross furring and drywall as shown in Figures 6.3.4.3-2.

MITIGATION EXAMPLES



Figure 6.3.4.3-4 Details of suspended and braced plaster ceiling,. Rigid bracing and compression posts (highlighted) are provided at 6 ft by 8 ft on center. Note cross furring saddle tied to black channel (main runner) from below; supplementary framing for lights runs parallel to cross furring and saddle tied to main runner from above (Photo courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

Per ASCE 7-10, suspended ceilings constructed of screw- or nail-attached gypsum board on one level that are surrounded by and connected to walls or soffits that are laterally braced to the structure above are exempt from any special seismic design requirements.

The exemption above does not apply to suspended plaster ceilings, other heavy ceilings or to gypsum board ceilings at more than one level or that are not adequately supported by surrounding walls; these may require bracing assemblies and special edge details such as those shown here. Check applicable code requirements. Details in Figures 6.3.4.3-6, 7, and 8 are adapted from California DSA IR 25-3 (revised 7-21-05) that provides prescriptive details for a single layer of suspended gypsum board; check with DSA for additional details and the latest requirements (http://www.dsa.dgs.ca.gov/Pubs/IRManual.htm). These details are shown with standard steel shapes; proprietary T-bar systems are also available.

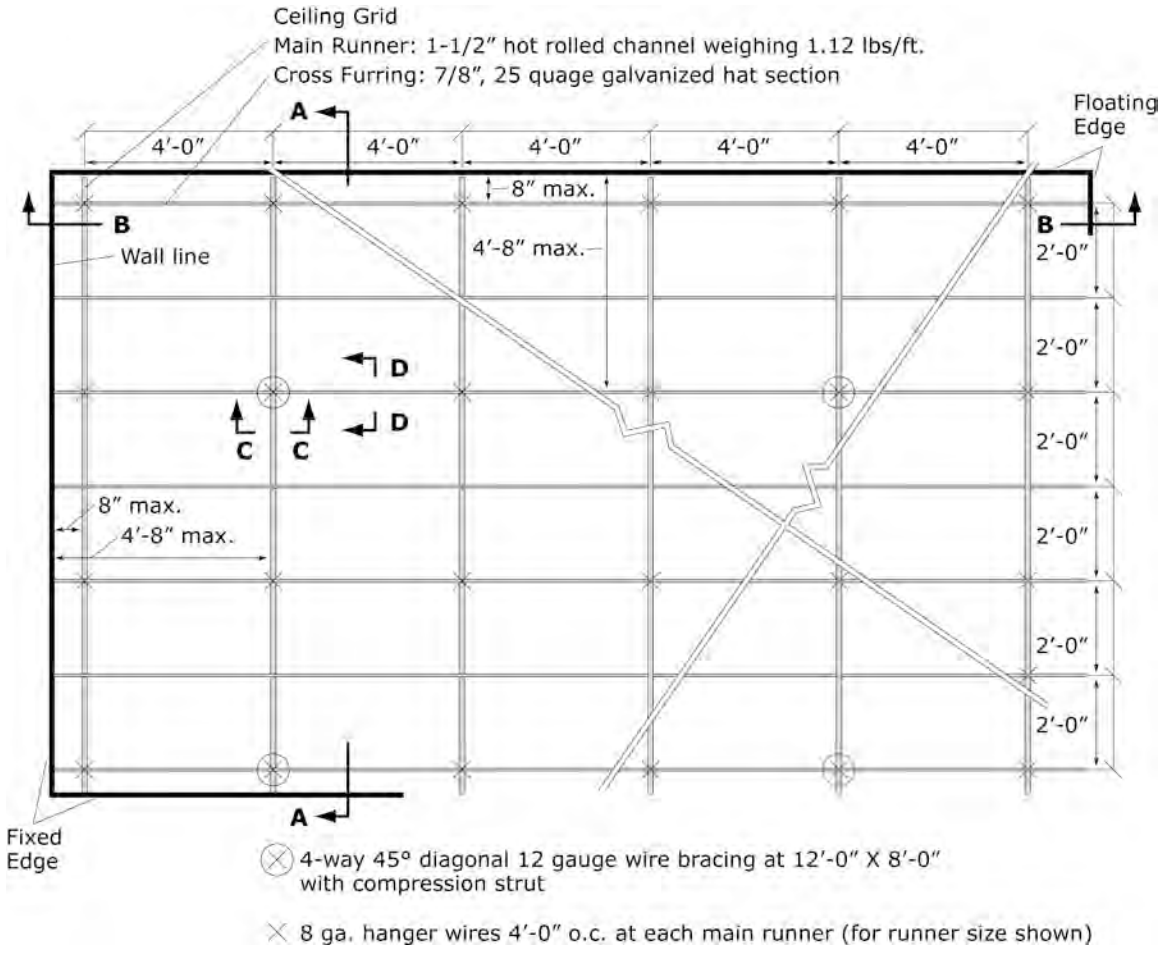


Figure 6.3.4.3-5 Diagrammatic view of suspended heavy ceiling grid and lateral bracing (PR).

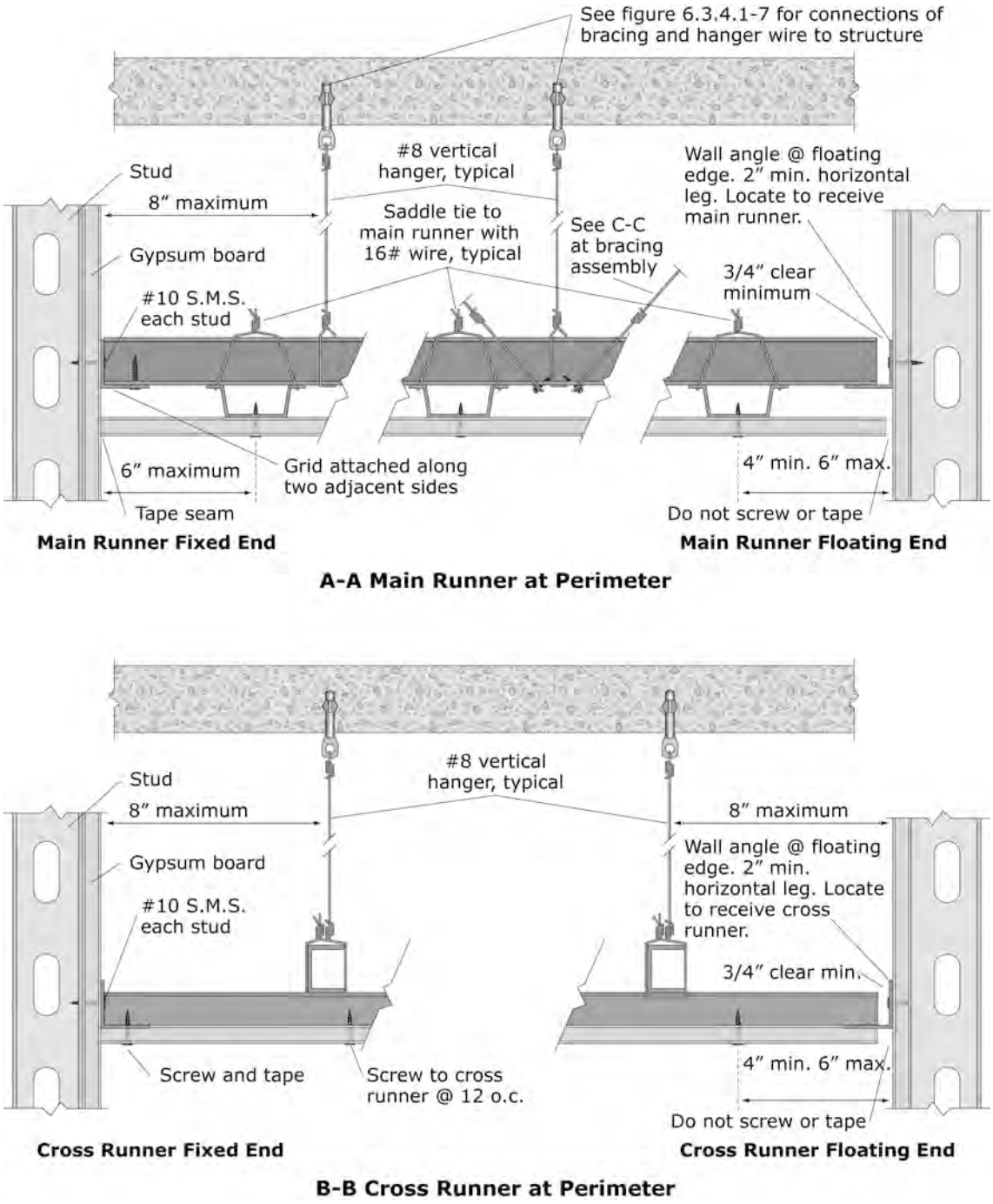
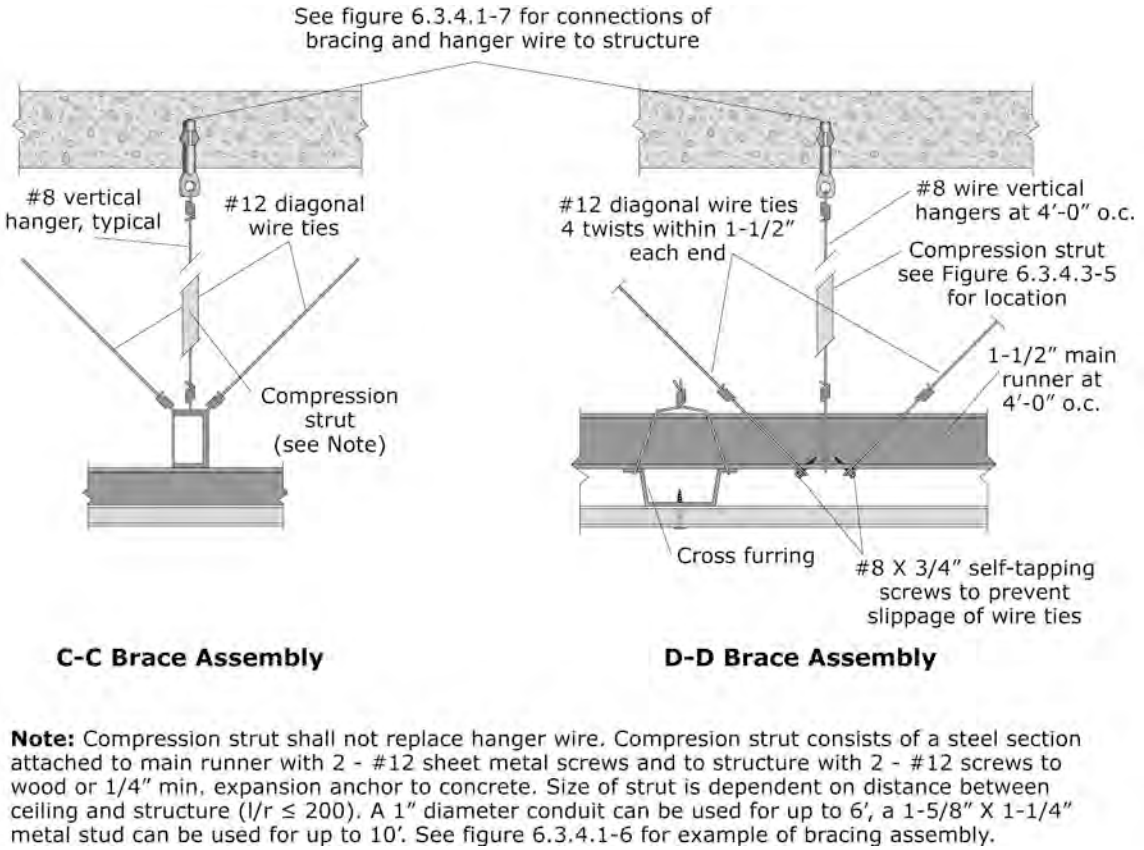


Figure 6.3.4.3-6 Perimeter details for suspended gypsum board ceiling (PR).



Note: Compression strut shall not replace hanger wire. Compresion strut consists of a steel section attached to main runner with 2 - #12 sheet metal screws and to structure with 2 - #12 screws to wood or 1/4" min. expansion anchor to concrete. Size of strut is dependent on distance between ceiling and structure (l/r ≤ 200). A 1" diameter conduit can be used for up to 6', a 1-5/8" X 1-1/4" metal stud can be used for up to 10'. See figure 6.3.4.1-6 for example of bracing assembly.

Figure 6.3.4.3-7 Details for lateral bracing assembly for suspended gypsum board ceiling (PR).

6.3 Architectural Components

6.3.5 Parapets and Appendages

6.3.5.1 Unreinforced Masonry Parapets

Unreinforced masonry (URM) parapets, cornices and appendages pose a significant falling hazard and have caused numerous injuries and required costly repairs in past earthquakes. While the function of parapets is "nonstructural," i.e., to prevent fire spread, create a safety railing or conceal roof-mounted equipment, they are a structural concern that requires engineering expertise to address.

Provisions

BUILDING CODE PROVISIONS

Parapets are subject to the force requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13, Nonstructural Components. In general, unreinforced masonry construction is not permitted in areas of moderate and high seismicity (Seismic Design Categories B and higher).

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies unreinforced masonry parapets as force-controlled. Compliance with the requirements of the standard is required for all performance levels in areas of high, moderate and low seismicity. If the performance level is Hazards Reduced and the unreinforced masonry parapet is located in areas of public occupancy or egress, it must meet the Life Safety performance level. If the unreinforced masonry parapet is not over 4 feet in height, it may be retrofitted using prescriptive design concepts.

Typical Causes of Damage

- Heavy unbraced parapets typically fail out-of-plane at the roofline and may take part of the building wall with it as they fall. Even small pieces of masonry falling several stories may cause serious bodily injury.
- Appendages may crack or spall; connections may be damaged. Pounding between adjacent buildings often results in damage to brittle masonry parapets, cornices, and appendages.
- Failed parapets may fall either inwards or outward. When parapets collapse inward they can damage the roof and have the potential to fall through light roof construction

posing a safety hazard to occupants below. If they collapse outward they can fall to the street or onto the roof of an adjacent property.

DAMAGE EXAMPLES



Figure 6.3.5.1-1 URM parapet fell and smashed two cars in the 1992 magnitude-7.2 Petrolia Earthquake. A parapet at same location in Ferndale, California failed in 1906 and killed two cows (NGDC, 2009).



Figure 6.3.5.1-2 Unreinforced masonry parapet failures along Beach Street, Watsonville in the 1989 magnitude-6.9 Loma Prieta Earthquake (NGDC, 2009).



Figure 6.3.5.1-3 Damage to roof framing caused by failure of overhanging brick masonry during the 1962 magnitude-5.8 Cache Valley, Utah earthquake (Photo courtesy of PEER Steinbrugge Collection, No. S828).

Seismic Mitigation Considerations

- Some jurisdictions have parapet ordinances requiring seismic bracing for URM parapets along a public right of way; check the local jurisdiction for requirements.
- Parapet and roof conditions may vary widely. An engineered design accounting for specific as-built construction details is needed to provide reliable earthquake performance. Flashing and weatherproofing must be provided for any roof-mounted connections.
- The reliability of bolts in unreinforced masonry is heavily dependent on the quality of masonry and the amount of overburden (weight above the anchor). With poor quality masonry or little overburden, oversized plate washers or a continuous plate may be needed on the outside face of the wall to enhance the effectiveness of the anchorage.
- Connection details for terra cotta cornices and appendages are similar to those for anchored veneer. See Section 6.3.1.2 and check the internet for various types of masonry, stone and veneer anchors.

MITIGATION EXAMPLES



Figure 6.3.5.1-4 Bracing of URM parapet (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.3.5.1-5 Bracing of unreinforced masonry parapet (Photo courtesy of Degenkolb Engineers).



Figure 6.3.5.1-6 Close-up of parapet bracing (Photo courtesy of Degenkolb Engineers).

MITIGATION DETAILS

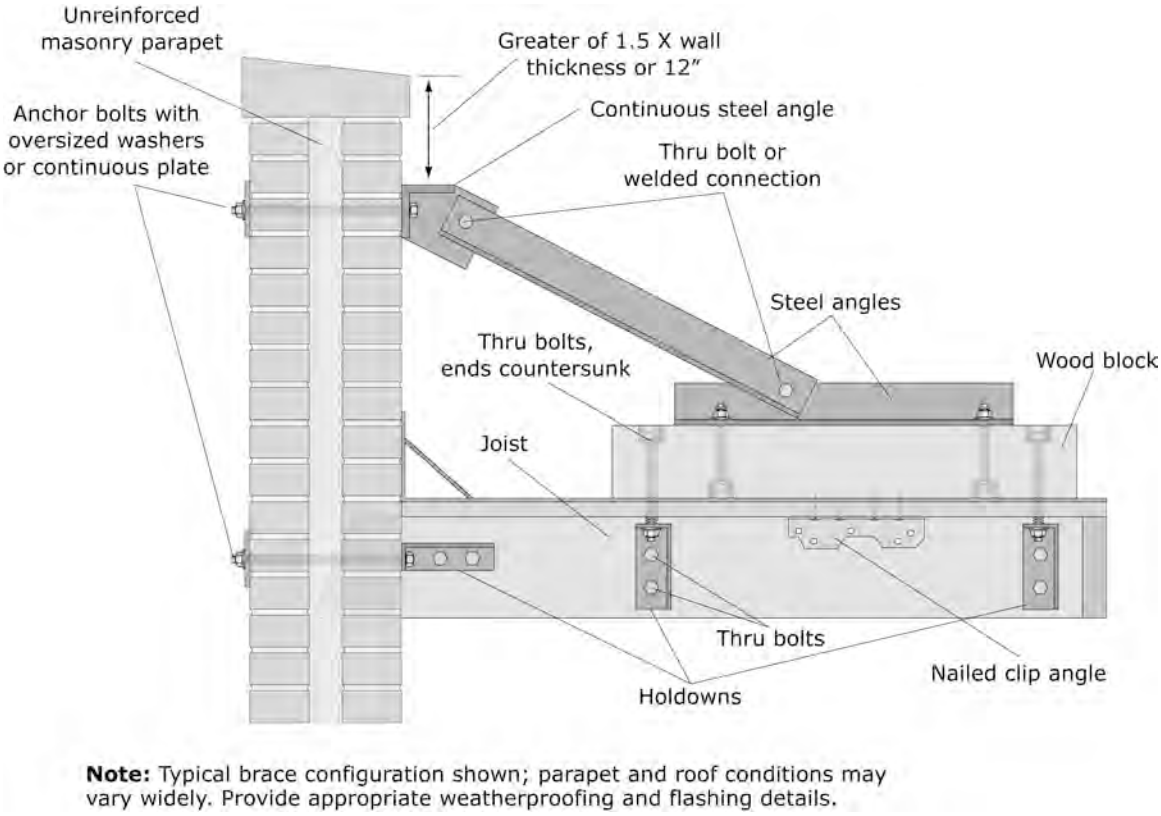


Figure 6.3.5.1-7 Unreinforced masonry parapet (ER).

6.3 Architectural Components

6.3.6 Canopies, Marquees, and Signs

6.3.6.1 Canopies, Marquees, and Signs

Cantilevered appendages of any type may pose a significant falling hazard when located above an entrance or along a sidewalk or street.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010) classifies canopies, marquees, and signs as "Appendages and Ornamentations." Both the anchorage of the component and the structure of the component itself must be designed for gravity, wind, and seismic loads. Special consideration of the vertical response of components that cantilever from the structure is necessary. ASCE/SEI 7-10 specifies a vertical force component that is applied concurrently with the lateral design force for design.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies canopies, marquees, and signs as force-controlled. Compliance with the requirements of the standard is required for all performance levels in areas of high, moderate, and low seismicity. Free-standing marquees are subject to the requirements of ASCE/SEI 41-06. Canvas or fabric covered projections are not subject to the rehabilitation requirements. If the performance level is Hazards Reduced and the component is located in areas of public occupancy or egress, it must meet the Life Safety performance level.

Typical Causes of Damage

- Unbraced cantilevered items may bounce or swing; connection hardware may be undersized or corroded; items may collapse and fall.

DAMAGE EXAMPLES



Figure 6.3.6.1-1 Failure of commercial sign in the 1979 Imperial Valley, California earthquake (Photo courtesy of Robert Reitherman).



Figure 6.3.6.1-2 Reinforced concrete appendage dangling from connection on one side; impact damaged the curtain wall and created a serious hazard above the entrance of the Corte de Apelaciones de Talca in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- Anchorage detail shown is for a cantilevered canopy, sign, or marquee that is oriented horizontally; the vertical braces protect the item from vertical accelerations and prevent bouncing.
- Seismic protection of building appendages requires a reliable connection from the appendage to structural framing members. Heavy canopies, marquees, or signs may require installation of supplemental framing to deliver seismic demands to primary structural framing elements.

MITIGATION DETAILS

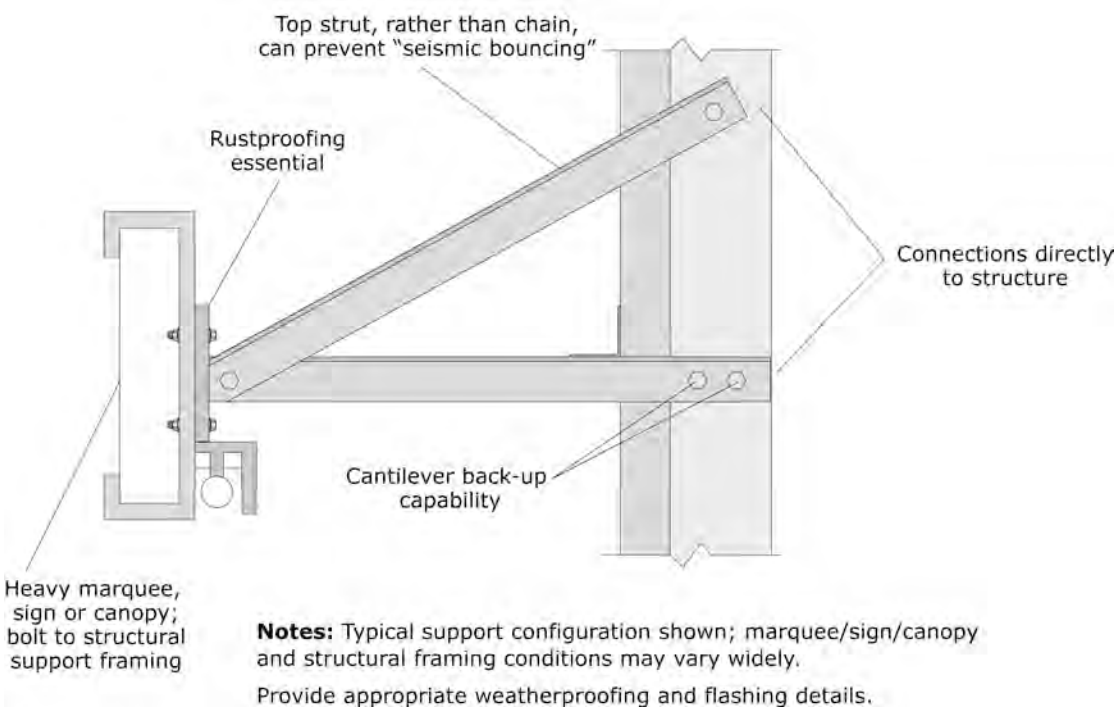


Figure 6.3.6.1-3 Canopy, marquee, or sign support (ER).

6.3 Architectural Components

6.3.7 Chimneys and Stacks

6.3.7.1 Unreinforced Masonry Chimney

Unreinforced masonry (URM) chimneys are extremely vulnerable to earthquake damage; their behavior has long been used as an indicator of seismic intensity as in the Modified Mercalli Intensity (MMI) scale.

Provisions

BUILDING CODE PROVISIONS

Masonry chimneys are subject to the force requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13, Nonstructural Components. In addition, masonry fireplaces are subject to the prescriptive requirements of 2012 IBC, *International Building Code*, (ICC 2012), Chapter 21. The 2012 IBC provisions focus on seismic reinforcing and anchorage of masonry fireplaces. In general, unreinforced masonry chimney construction is not permitted in areas of moderate and high seismicity (Seismic Design Categories C and higher).

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies unreinforced masonry chimneys as force-controlled. Compliance with the requirements of the standard is required for all performance levels in areas of high and moderate seismicity. If the performance level is Hazards Reduced and the unreinforced masonry chimney is located in areas of public occupancy or egress, it must meet the Life Safety performance level. Residential unreinforced masonry chimneys may be retrofitted using prescriptive design concepts.

Typical Causes of Damage

- Unreinforced masonry chimneys may crack, spall, separate from the structure, or collapse. They may fall through the roof structure and injure occupants or fall to the ground.
- Chimneys may suffer damage even at relatively low levels of ground shaking.

DAMAGE EXAMPLES



Figure 6.3.7.1-1 Chimney collapsed and fell through the roof; approximately 2,600 chimneys were destroyed in the 1992 Big Bear City, California earthquake (NGDC, 2009).



Figure 6.3.7.1-2 Residential metal flue in wood frame chimney that failed in the 2003 magnitude-6.5 San Simeon earthquake. The house fell off its cripple wall, pushing over the chimney (Photo courtesy of Michael Mahoney).



Figure 6.3.7.1-3 Chimney collapse (Photo courtesy of Earthquake Engineering Research Institute).

Seismic Mitigation Considerations

- The most reliable mitigation measure is to remove a URM chimney and replace it with a metal flue inside a framed enclosure or to remove the chimney and firebox entirely.
- If the chimney is not being used, reducing its height to not more than 1 to 2 feet above the roofline will limit the potential for damage.
- Chimney and roof configurations vary widely. If a URM chimney is to be braced in place, an engineered design is needed to account for specific as-built construction details.
- To protect against a chimney falling in toward the roof and posing a safety hazard below, the roof can be locally strengthened with plywood.
- Large historically important chimneys need special consideration; these could be reinforced using a "center core" technology to improve their performance; this method involves core drilling the masonry and filling the cores with reinforcing and grout.
- Fire code requirements and local ordinances must be considered when considering strategies for reducing the risk of unreinforced masonry chimneys.
- The City of Seattle developed guidelines for *Alteration and Repair of Unreinforced Masonry Chimneys* following the 2001 Nisqually Earthquake; these can be found at http://www.seattle.gov/dclu/codes/dr/DR2004-5.pdf and include details for straps at the roof and floor lines, bracing above the roofline, and partial replacement above the roofline. Similarly, the Los Angeles Department of Building and Safety developed prescriptive measures for *Reconstruction and Replacement of Earthquake Damaged Masonry Chimneys*, available at http://ladbs.org/LADBSWeb/LADBS_Forms/InformationBulletins/IB-P-BC2008-070EQDamagedChimney.pdf.

MITIGATION EXAMPLES



Figure 6.3.7.1-4 Braced chimney (FEMA, 2004).

MITIGATION DETAILS

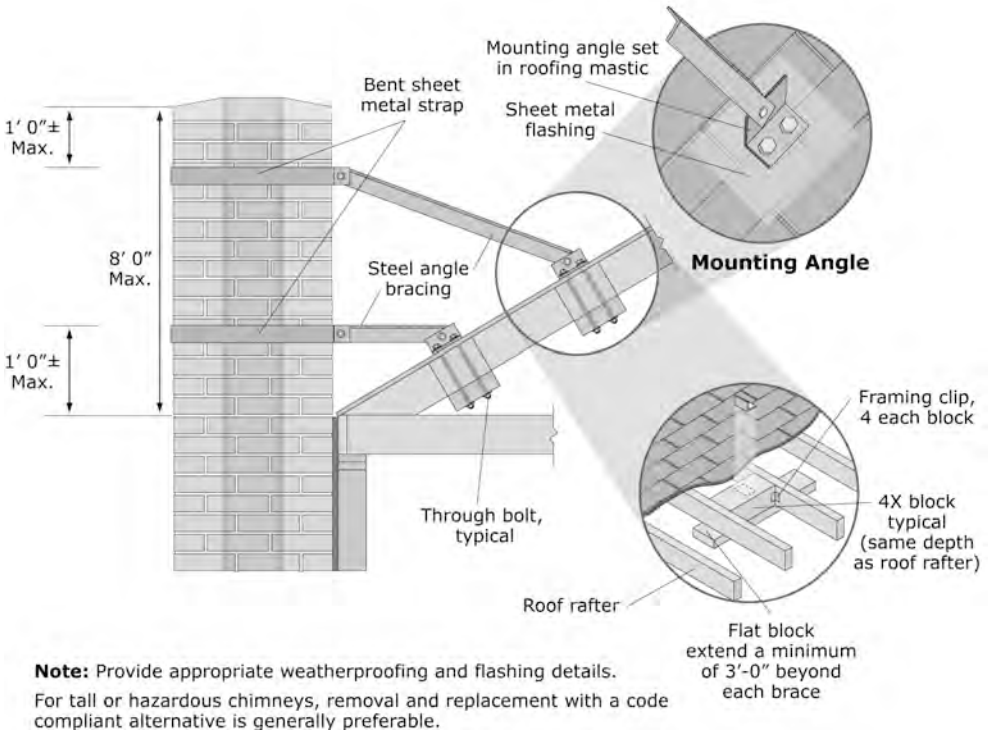


Figure 6.3.7.1-5 Unreinforced masonry chimney bracing (ER).

6.3 Architectural Components

6.3.8 Stairways

6.3.8.1 Stairways

This includes stairs between floors, which may be independent of the structure, or integral with it. Stairs are needed for exiting following an earthquake and hence protecting them from damage and keeping them clear should be a high priority. Protecting a stair from damage is a structural concern that requires engineering expertise to address.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings* (ASCE, 2010), Section 13.1.3.1 specifies that systems required for life-safety purposes after an earthquake, including exit stairways, be classified as designated seismic systems and designed using a component importance factor, I_p, of 1.5. Designated seismic systems may require engineering calculations, special inspection, etc. Stairways must be designed to accommodate story drift, while having sufficient strength to resist inertial loads.

- The minimum lateral loads and seismic relative displacements on stairways are determined using ASCE/SEI 7-10, Chapter 13.
- Where the actual design drifts of the structure for displacement analysis are not known, the allowable story drifts of ASCE/SEI 7-10, Chapter 12 may be used.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies stairs and stair enclosures as either acceleration or deformation sensitive, depending on the predominant behavior. Components of stairs that are attached to adjacent floors or the floor framing are considered deformation sensitive. All other stair components are considered acceleration sensitive.

- Stairs are subject to the requirements of ASCE/SEI 41-06 when the performance level is Immediate Occupancy, or in regions of high and moderate seismicity when the performance level is Life Safety.
- The evaluation must consider the stairs and their connection to the supports, supporting and adjacent walls, windows, and other elements of the stair shaft system.

- Acceptance criteria focus on verifying that the stairs have sufficient strength to resist out-of-plane forces, and the ability to accommodate the expected relative displacements.

Typical Causes of Damage

- Stairs are primarily damaged by interstory drift, i.e., differential movement of the adjacent floors, because the stairs must accommodate the differential movement. Stair damage is more likely to occur in flexible buildings with larger interstory drift and less likely to occur in stiffer buildings.
    - When stairs are rigidly attached to both floor levels, the stair structure will try to act like a diagonal brace and could be damaged as shown in Figure 6.3.8.1-3.
    - When one end or both ends of the stair have slip or sliding connections, the design differential movement could be exceeded causing failure of the connection and perhaps collapse of the stair as shown in Figures 6.3.8.1-4 and 6.3.8.1-5.
    - Steel and concrete stairs are vulnerable to inter-story drifts if not specially detailed for seismic resistance. Recent shake table testing of a full scale 5-story building at University of California, San Diego (project website is located at http://bncs.ucsd.edu/) revealed that standard prefabricated steel stairs can be badly damaged or even collapse at inter-drift levels less than expected in a Design Earthquake in flexible buildings.
- Damage to stairs will also vary depending on the material of construction, as follows:
    - Damage has been observed most often in stairs with concrete stringer assemblies, which, if not specifically detailed for movement, will naturally have very rigid connections. Concrete stairs are typically not detailed for ductility, so large tension or compression demands can lead to severe damage.
    - Single run stairs with steel stringers as shown in Figure 6.3.8.1-1, not detailed with slip connections, will provide stiff resistance to drift which could cause buckling of the stringers or failure of the connections.
    - Typical commercial steel exit stairways, often purchased on a “design-build” basis, are generally not provided with drift allowance on the basis that, with normal landing configurations, sufficient flexibility is provided. However, recent testing at the University of California, San Diego), has shown that these stairs can suffer dangerous damage if not specifically detailed for slip, or provided with ductile connection details.

- Wooden stairs are generally in smaller, stiff buildings and have inherent flexibility in connections. Damage to wooden stairs has not been common, although configurations which provide direct bracing between floors (e.g., a straight run from ground to first floor)should be provided with a slip connection.

- The walls surrounding a stairway may be damaged during an earthquake causing debris to fall into the stairwell and rendering the stairs unusable. Brittle materials such as brick, hollow clay tile, or glass are particularly vulnerable and may create falling and debris hazards in stair enclosures as shown in Figure 6.3.8.1-2.

DAMAGE EXAMPLES



Figure 6.3.8.1-1 Stairway damaged by drift in the 1994 magnitude-6.7 Northridge, California earthquake (Photo courtesy of Wiss, Jenney, Elstner Associates).



Figure 6.3.8.1-2 View of stairway in the Banco Central Building, Managua, Nicaragua after the 1972 magnitude-6.2 Managua Earthquake. Most of the stairs were covered with debris that resulted from the failure of the hollow tile partitions surrounding the stairs. This photograph highlights the need to not only prevent direct damage to stairway framing and connections, but also to protect against damage to surrounding walls (Photo courtesy of PEER Godden Collection, No. J94).



Figure 6.3.8.1-3 Stairs damaged up the full height of this apartment building in Viña del Mar in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Santiago Pujol, Purdue University). The stairs were rigidly attached at adjacent floors and behaved like diagonal braces although they were neither designed nor detailed to function as structural braces.



Figure 6.3.8.1-4 Stair support condition at Forsyth-Barr Building in Christchurch, New Zealand. Precast stair runs have completely pulled off supports and collapsed into stairwell (Photo courtesy of Des Bull, Holmes Consulting Group).



Figure 6.3.8.1-5 One story precast stair units stacked up at base of stairwell after falling off the sliding end supports and collapsing into stairwell (Photo courtesy of Des Bull, Holmes Consulting Group).

Seismic Mitigation Considerations

- Precast connection details in Christchurch, New Zealand often featured sliding joints in "pockets" that allowed only limited movement that tended to put the stair in compression. After stairs were compressed and shortened in one direction, the bearing length was reduced for sliding in the other direction. See Figure 6.3.8.1-6. Sliding joints on stairs can also cause collapse if the bearing length is simply too small. Guidelines in New Zealand recommend providing safe movement for 1.5 x the maximum expected drift.
- In order to prevent stairs from behaving like diagonal struts between adjacent floors, the stairs should be detailed with a fixed connection at one floor and a sliding connection at the other that allows movement parallel to the direction of the stair. Movement allowance must be adequate for the maximum possible drift, or connections provided with a fail-safe mechanism to prevent gravity failure. See Figures 6.3.8.1-7 (steel) and 6.3.8.1-8 (wood).
- Sliding "gang plank" connections or connections with slotted holes can also be used to isolate the stair from one of the attached floors and prevent damage due to interstory drift. The connection must be designed to accommodate the anticipated drift.
- If stair enclosures are built using brittle materials such as unreinforced masonry, hollow clay tile, glass block, or skylights, it is recommended that they be encapsulated or replaced to prevent falling hazards and debris in the stairwell. Provide bracing and anchorage for pipes, lighting, emergency lighting or ducts to prevent falling hazards and debris in the stairwell. Maintaining safe exits is a critical element of earthquake safety.

MITIGATION DETAILS

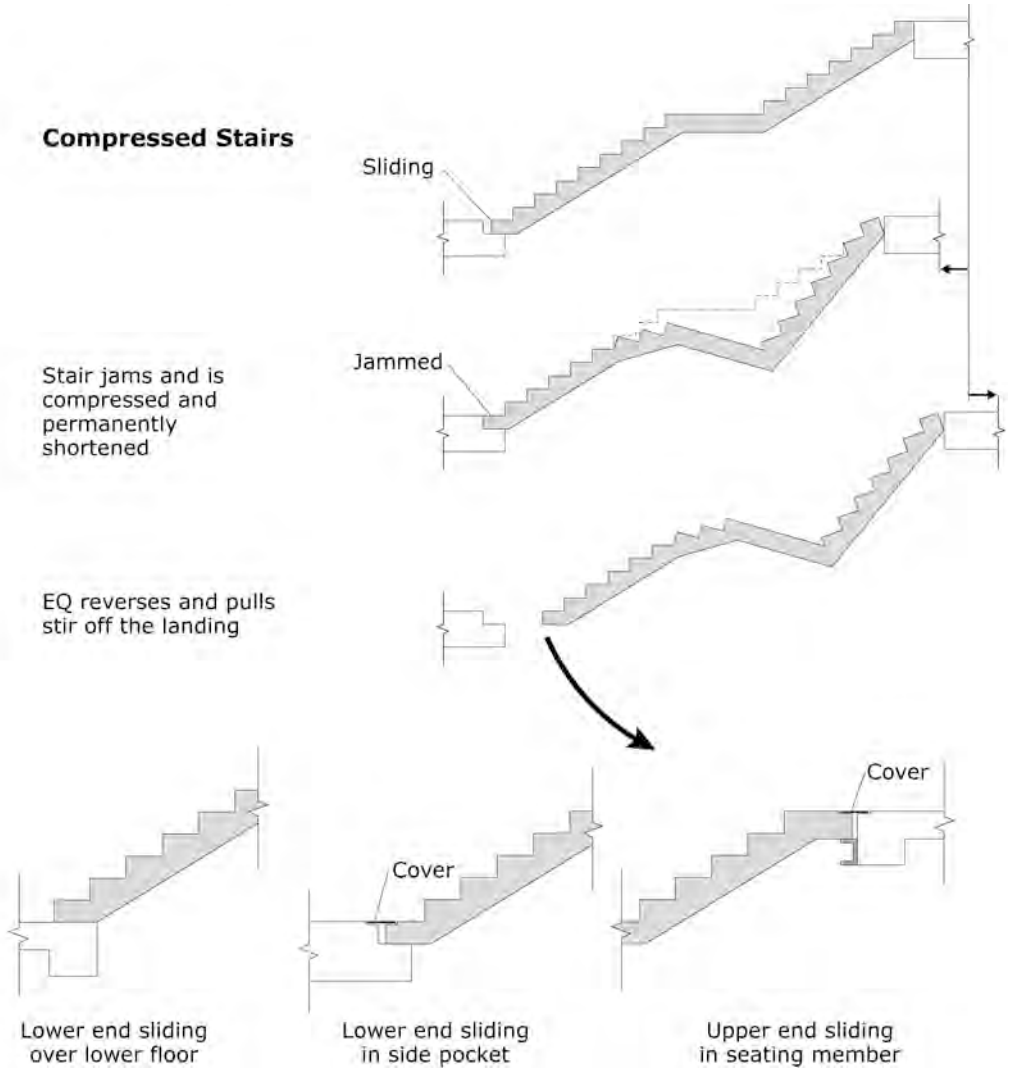


Figure 6.3.8.1-6 Figure showing how inadequate sliding surface can compress and then drop precast stair sections.

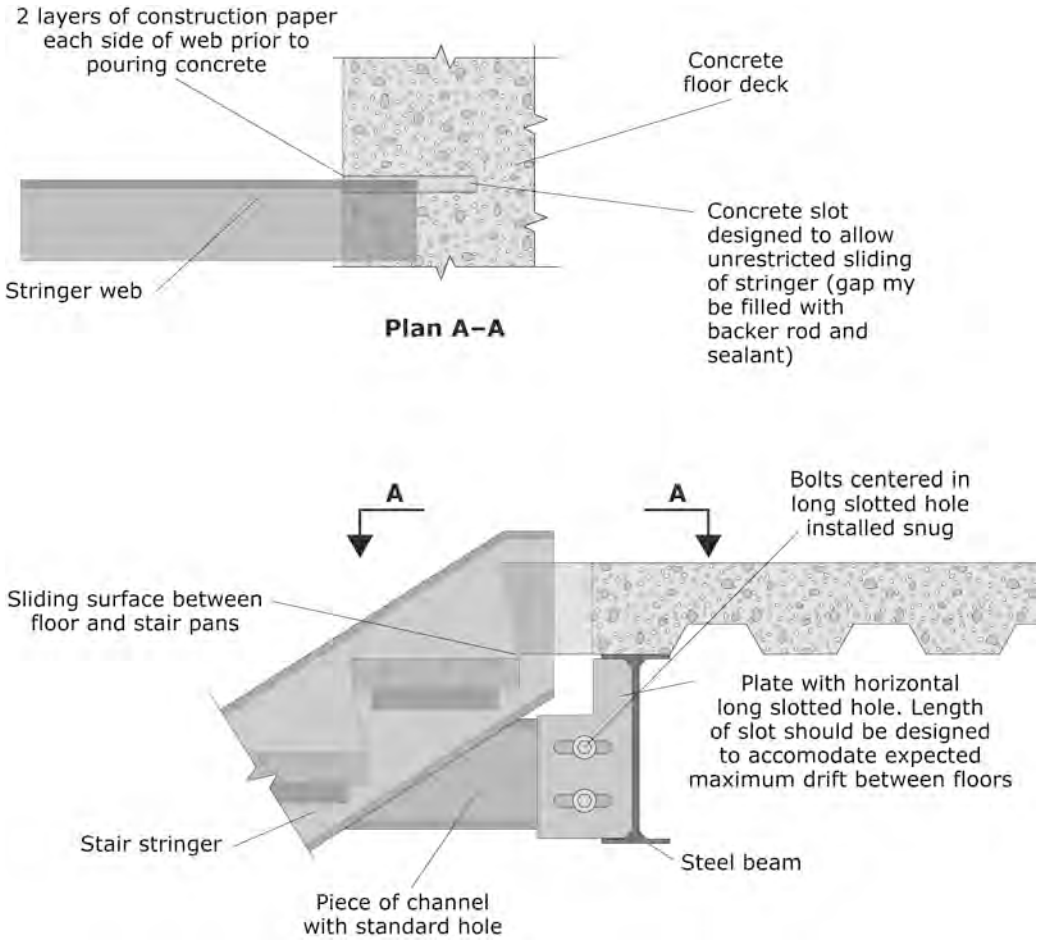


Figure 6.3.8.1-7 Example slip connection for steel stair stringer (ER).

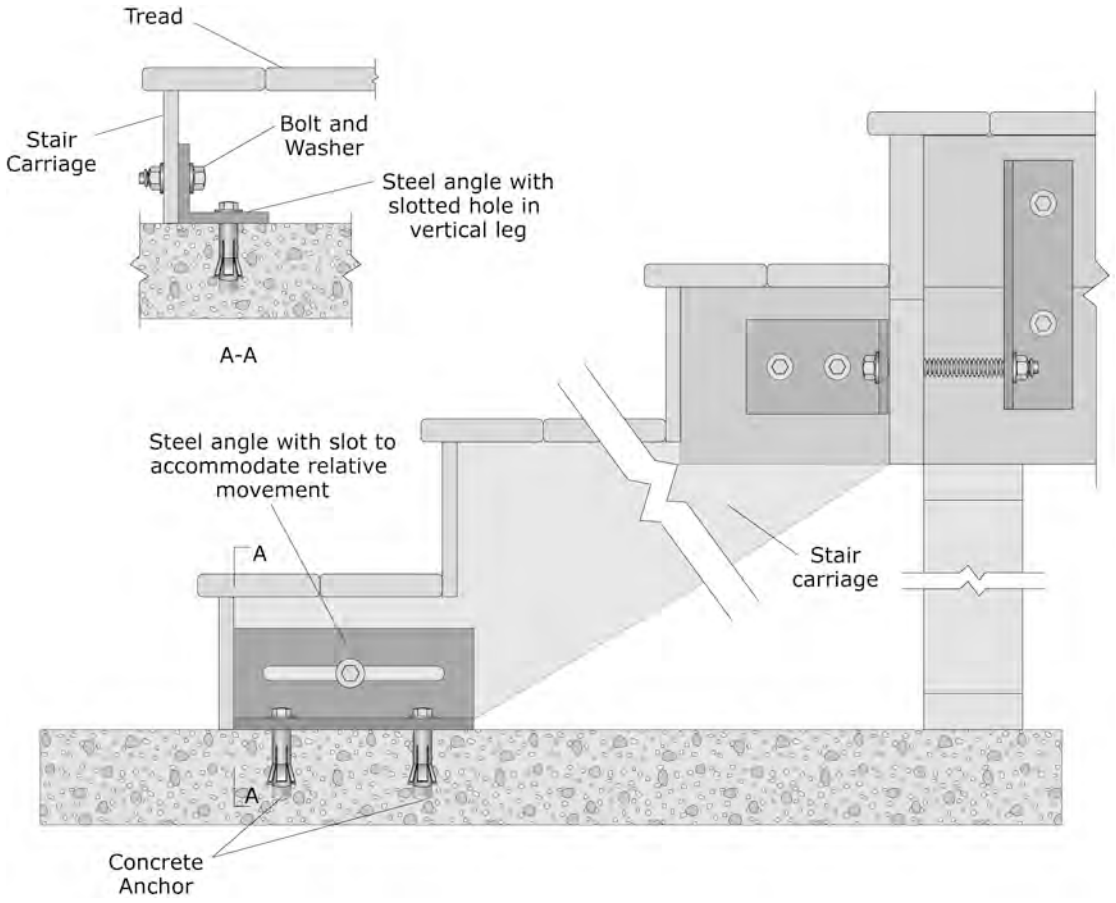


Figure 6.3.8.1-8 Example slip connection for wood stair with single run between floors (ER).

6.3 Architectural Components

6.3.9 Freestanding Walls or Fences

6.3.9.1 Freestanding Masonry Wall or Fence

This category covers freestanding (cantilevered) walls and fences built of either reinforced or unreinforced masonry. Freestanding fences of 6 feet or less are often not covered by code provisions; nevertheless, unreinforced or poorly reinforced masonry walls or fences or those with inadequate foundations are vulnerable to earthquake damage.

Typical Causes of Damage

- Unreinforced masonry elements perform poorly in earthquakes; unreinforced or under-reinforced masonry walls and fences frequently fail out-of-plane and may collapse completely. Walls with inadequate foundations may also fail out-of-plane and tip over.
- Falling masonry walls and fences may injure people and property and block pedestrian walkways, driveways, loading docks, streets and access for emergency vehicles during an emergency.
- When these fences serve as a security perimeter, their failure may result in a security breach following an earthquake resulting in additional property damage due to trespassing or looting.
- The 1994 Northridge Earthquake damaged many miles of poorly constructed concrete masonry unit (CMU) fences and caused collapse of walls with inadequate or absent reinforcing and foundations in Northridge and Sylmar, California, covering sidewalks with debris, as shown in Figure 6.3.9.1-1. After the 2010 Haiti Earthquake, the debris were apparent from aerial photos of the affected areas.

DAMAGE EXAMPLES



Figure 6.3.9.1-1 Collapse of freestanding CMU walls covering much of the sidewalk in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Robert Reitherman). The rubble reveals that the wall was unreinforced.



Figure 6.3.9.1-2 Freestanding masonry fences with inadequate reinforcement collapsed covering both sides of this street in Port-au-Prince in the 2010 magnitude-7 Haiti Earthquake (Photo courtesy of Yves Montoban). Many miles of such fencing collapsed in the 2010 Haiti Earthquake.



Figure 6.3.9.1-3 Damage to reinforced masonry boundary fence at industrial facility in Southern Peru; out-of-plane movement at construction joint in wall without sufficient reinforcing for the level of shaking experienced at this location in the 2001magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Additional boundary steel or reinforced concrete boundary columns located either side of construction joints would improve the performance of this type of fence.



Figure 6.3.9.1-4 Photo at top shows complete collapse of poorly detailed confined masonry fence in foreground; partial collapse of poorly detailed confined masonry fence in distance at left; no damage to well detailed confined masonry fence in distance at right in the 2010 Haiti Earthquake. Close-up view of well-detailed confined masonry fence in bottom photo with concrete columns and bond beam at top (Photos courtesy of Eduardo Fierro, BFP Engineers). Fences in foreground and at right formed the security perimeter at an electric power plant in Port-au-Prince.

Seismic Mitigation Considerations

- Freestanding walls or fences built of concrete masonry units (CMU), brick or stone need to be engineered and constructed to cantilever from the base with appropriate foundations, adequate reinforcing, good quality mortar, and good workmanship.

Seismic loading at the base of tall cantilever walls can be substantial in a major earthquake. Such walls could be constructed using standard seismic detailing for reinforced masonry such as the details shown in Figure 6.3.9.1-6 and 7. Engineered reinforced concrete walls would clearly be another, although more costly, alternative.

- The State of California has published several guidelines that relate to the construction of such fences; see DSA IR 21-1 *Masonry Wall – Non Structural*, DSA IR 21-2 *Concrete Masonry High Lift Grouting Method*, DSA IR 21-3 *Clay Brick Masonry High Lift Grouting Method*, and DSA IR 21-4 *Masonry: Concrete Masonry Unit Standards* (California Department of General Services, 2007a, 2009b, 1999, and 2007b). DSA IR 21-1 describes minimum requirements for a garden wall or screen wall to be used at California schools or essential facilities. Other jurisdictions may have standard details for highway sound walls or short retaining walls that could be adapted for use. Some jurisdictions or homeowner associations may also have zoning restrictions or similar that limit the height, setbacks, or materials used for fencing; check the local jurisdiction. The details shown in Figure 6.3.9.1-5 were adapted from details provided online by the City of San Diego, California for reinforced CMU fences up to 6 feet in height.
- While design and construction of unreinforced masonry walls or fences typically do not come under the purview of the building code, there are many hazardous masonry walls or fences in existence. These could be demolished and replaced with a reinforced masonry fence, wood fence, or cyclone fence. As an alternative, the performance of unreinforced masonry walls with adequate foundations could be substantially improved by using retrofit details for confined masonry. Even though the use of confined masonry is rare in the U.S., it is common in other parts of the world. This system utilizes reinforced concrete boundary members on all four sides of each unreinforced masonry wall panel with a panel size limited to roughly 3 meters in length. The Confined Masonry Network (http://www.confinedmasonry.org/) provides information and details on this subject.
- The International Building Code exempts fences from a building permit if the fence is not over 6 feet in height. The code also states that work must still comply with building code requirements even when a permit is not required.
- Fence heights may also be regulated by the zoning laws of the city. For specific information about the zoning regulations for your fence on your lot, contact the development services and zoning departments for requirements.

MITIGATION DETAILS

1. ALL MATERIAL AND WORKMANSHIP SHALL CONFORM TO THE REQUIREMENTS OF THE AUTHORITY HAVING JURISDICTION.

2. CONCRETE SHALL ATTAIN A COMPRESSIVE STRENGTH OF 2,500PSI MINIMUM AT 28 DAYS.

3. CONCRETE BLOCK UNITS SHALL BE MEDIUM OR NORMAL WEIGHT UNITS CONFORMING TO ASTM C90 (LATEST REVISION).

4. MORTAR SHALL BE TYPE S CONFORMING TO ASTM C270 WITH A COMPRESSIVE STRENGTH OF 1,800PSI MINIMUM AT 28 DAYS.

5. GROUT SHALL CONFORM TO ASTM C476 AND BE COMPOSED OF THE FOLLOWING RATIO BY VOLUME: 1 PART PORTLAND CEMENT, 3-PARTS SAND, 2-PARTS PEA GRAVEL, AND SUFFICIENT WATER FOR POURING WITHOUT SEGREGATION OF GROUT CONSTITUENTS (MIN. COMPRESSIVE STRENGTH OF 2,000PSI AT 28 DAYS).

6. ALL REINFORCING STEEL SHALL COMPLY WITH ASTM A615, GRADE 60. VERTICAL STEEL SHALL BE CENTERED IN THE CONCRETE BLOCK CELL IN WHICH IT IS LOCATED, U.O.N.

7. WALL JOINT REINFORCING STEEL SHALL BE DUR-O-WAL WIRE CONFORMING TO ASTM A82 AND ASTM A641 – STANDARD, MILL GALVANIZED MINIMUM LAP SPLICE OF JOINT REINFORCEMENT SHALL BE 12 INCHES.

8. CELLS CONTAINING REINFORCING STEEL SHALL BE SOLID GROUTED.

9. ALL HORIZONTAL WALL REINFORCING BARS SHALL BE PLACED IN BOND BEAM UNITS. ALL JOINT REINFORCING SHALL BE PLACED IN THE MORTARED BED JOINT.

10. ALL GROUT SHALL BE CONSOLIDATED BY VIBRATING IMMEDIATELY. RECONSOLIDATE GROUT AFTER INITIAL WATER LOSS BUT BEFORE PLASTICITY IS LOST TO INSURE ADEQUATE CONSOLIDATION.

11. CONCRETE BLOCK UNITS ARE TO BE STAGGERED (COMMON BOND) AND ARE TO HAVE THE VERTICAL CONTINUITY OF THE CELLS UNOBSTRUCTED.

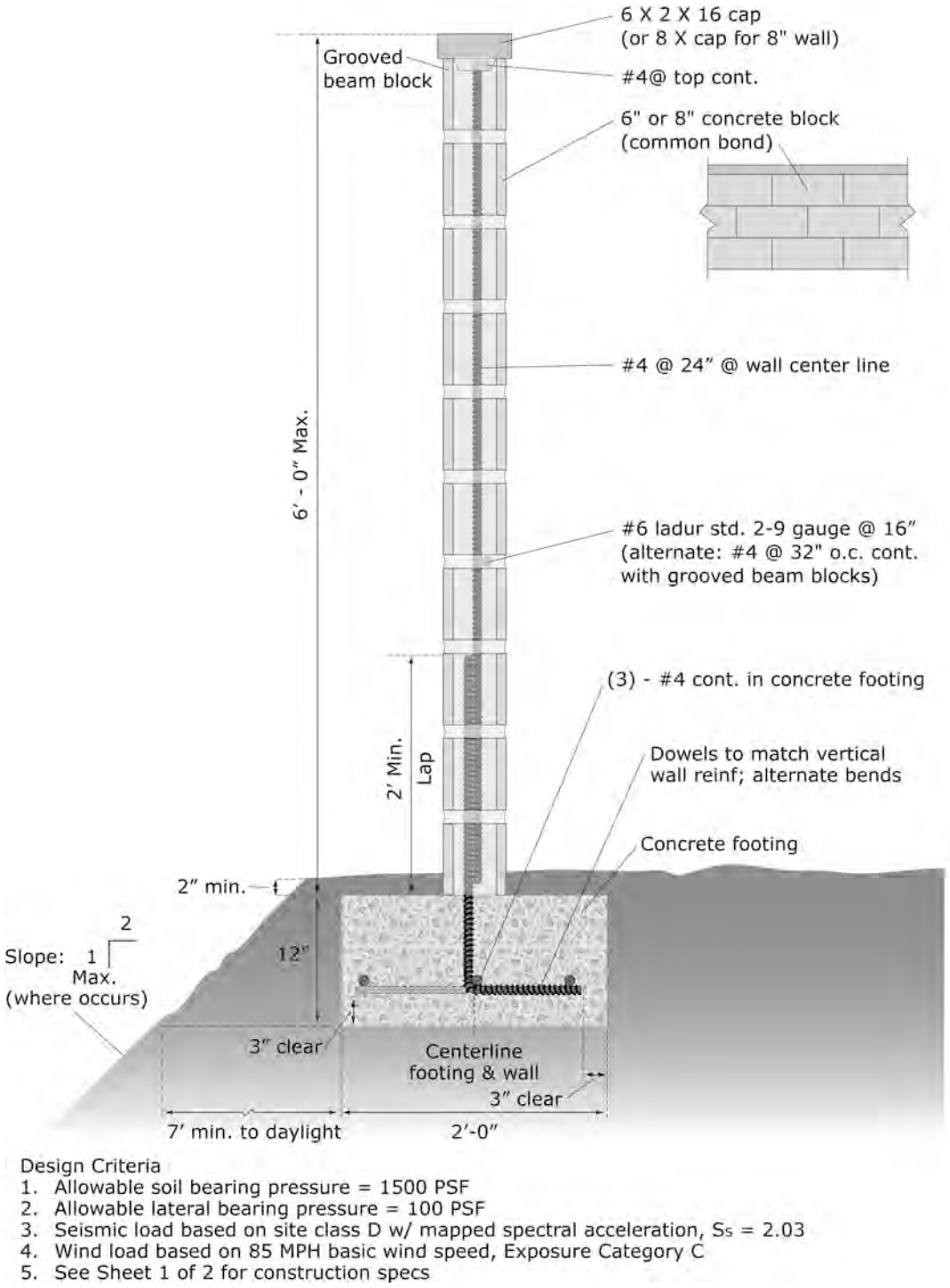
12. ALL FOOTINGS MUST EXTEND INTO FIRM UNDISTURBED NATURAL SOIL OR SOIL WHICH HAS BEEN COMPACTED TO AT LEAST 90 PERCENT MAXIMUM DENSITY.

13. THESE WALLS SHALL NOT BE CONSTRUCTED ON EXPANSIVE SOIL (EXPANSION INDEX GREATER THAN 20), LIQUEFIABLE SOILS OR OTHER QUESTIONABLE SOILS, UNLESS THE SOIL HAS BEEN SPECIALLY PREPARED IN ACCORDANCE WITH RECOMMENDATIONS OF A CIVIL OR GEOTECHNICAL ENGINEER.

14. PROVIDE VERTICAL CONTROL JOINTS AT 25'-0" ON CENTER MAXIMUM.

15. FENCE WALL DESIGN INCLUDES ½" OF PLASTER (OR VENEER) ON EACH SID OF THE WALL. NO FINISHES WITH A TOTAL WEIGHT GREATER THAN 13PSF (SUMMATION OF BOTH SIDES OF WALL) ARE ALLOWED.

Figure 6.3.9.1-5 6ft maximum height concrete masonry unit (CMU) wall (PR) [1 of 2].



Design Criteria
1. Allowable soil bearing pressure = 1500 PSF
2. Allowable lateral bearing pressure = 100 PSF
3. Seismic load based on site class D w/ mapped spectral acceleration, S_S = 2.03
4. Wind load based on 85 MPH basic wind speed, Exposure Category C
5. See Sheet 1 of 2 for construction specs

Figure 6.3.9.1-5 6ft maximum height concrete masonry unit (CMU) wall (PR) [2 of 2].

6.4 Mechanical, Electrical, and Plumbing Components

In the following sections, the seismic performance of individual mechanical components will be discussed. However, it is critical to remember that mechanical components act and interact together as systems. While each component is examined individually, the performance of that component and the system as a whole depends on the performance of many individual components. Depending on the performance objectives of the structure, these interactions may be inconsequential, or should be studied in greater depth. For example, the following would be considered for a rooftop fire water tank, mounted close the edge of the building overlooking a busy sidewalk:

- If the performance objective is limited to protect the occupants of the sidewalk from the tank falling on them, the seismic evaluation may focus on the adequacy of the tank legs, bracing, and anchorage to the roof structure.
- If the performance objective is to prevent the contents of the tank from flooding the floor below, then the evaluation must not only consider the anchorage of the tank but the connections and bracing of the rooftop piping associated with the tank.
- If the performance objective is to provide a reliable fire suppression system that may function after an earthquake, the tank must be considered as part of a complete system that includes fire sprinkler risers, mains, branches and sprinkler drops. The possibility of interactions between the fire protection piping and adjacent structural or nonstructural elements, such as sprinkler heads and hard ceilings, should also be considered.

Having a clear view of the performance objectives will guide the selection of the proper degree of investigation and the mitigation measures needed.

6.4.1 Mechanical Equipment

6.4.1.1 Boilers, Furnaces, Pumps, and Chillers

This category includes equipment such as boilers, furnaces, humidifiers, pumps, chillers and similar that are anchored to a concrete floor or housekeeping pad. These items are either rigidly anchored or have vibration isolation.

In recent shake table testing of a full scale 5story building performed at UC San Diego (see Section 6.1.3), a vibration isolated cooling tower and a self-contained air handling unit, were subjected to severe earthquake motions. The cooling tower and air handling unit were both anchored to the roof of the building per code requirements. Both units were energized and the time of the testing and both were undamaged after all the testing was concluded. There was, however, one issue. As the shaking level increased, water in the cooling tower sloshed and spilled resulting in loss of water. After each test, the cooling tower was refilled with water. At the largest shaking level, the cooling tower lost half of its water capacity because of spillage. This loss of water would affect the cooling tower's ability to maintain its full cooling capability until the water capacity was restored.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for boilers, furnaces, pumps, and chillers are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13. The principal objective of the code provisions is to prevent the component from sliding or overturning.

- ASCE/SEI 7-10 requires anchorage design for all equipment in Seismic Design Categories D, E, and F if the equipment weighs over 400 pounds, or if the item weighs over 20 pounds and is mounted over 4 feet above the floor. Lighter items may be exempt if the component Importance Factor, I_p, is 1.0.
- Items that are exempt from the anchorage design requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. They must also be provided with flexible connections between the equipment and associated pipes, ducts, or conduits unless alternate measures are used to protect the connection.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies boilers, furnaces, pumps, and chillers as force controlled. These components are subject to the provisions of the standard when the performance level is Immediate Occupancy, or Life Safety in high, moderate and low seismicity areas, if:

- The item weighs more than 400 pounds,
- The item is unanchored, weighs over 100 pounds and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 when design loads are applied.
- The item weighs over 20 pounds and is mounted over 4 feet above the floor.
- The equipment is a boiler or furnace.

Acceptance criteria for boilers, furnaces, pumps, and chillers focuses on providing adequate anchorage.

Typical Causes of Damage

- The primary concern is that equipment may slide, tilt or overturn. Anchorage should be made to a structural element with sufficient capacity to resist the anchorage forces, such as a concrete slab or housekeeping pad. Heavy equipment may be anchored to an unanchored or poorly reinforced housekeeping pad and the pad may shift or break.
- Movement of equipment may cause loss of connections to fuel and exhaust lines, relief valves, electrical lines, piping, or ductwork. Fluids such as fuel or refrigerant may leak.
- Even when the equipment is adequately anchored, distribution systems (pipe, conduit, or ducts) connected to the equipment may fail if they experience large movements relative to the equipment. For example, ¾- and 1-inch diameter copper piping (exempt from seismic bracing requirements due their small diameter) has failed where they connect to braced equipment. Providing flexible connections between the equipment and distribution systems will help protect against such failures.
- Function and operability of equipment may be compromised; this is especially critical for hospitals and other essential facilities that must maintain post-earthquake operations.

DAMAGE EXAMPLES

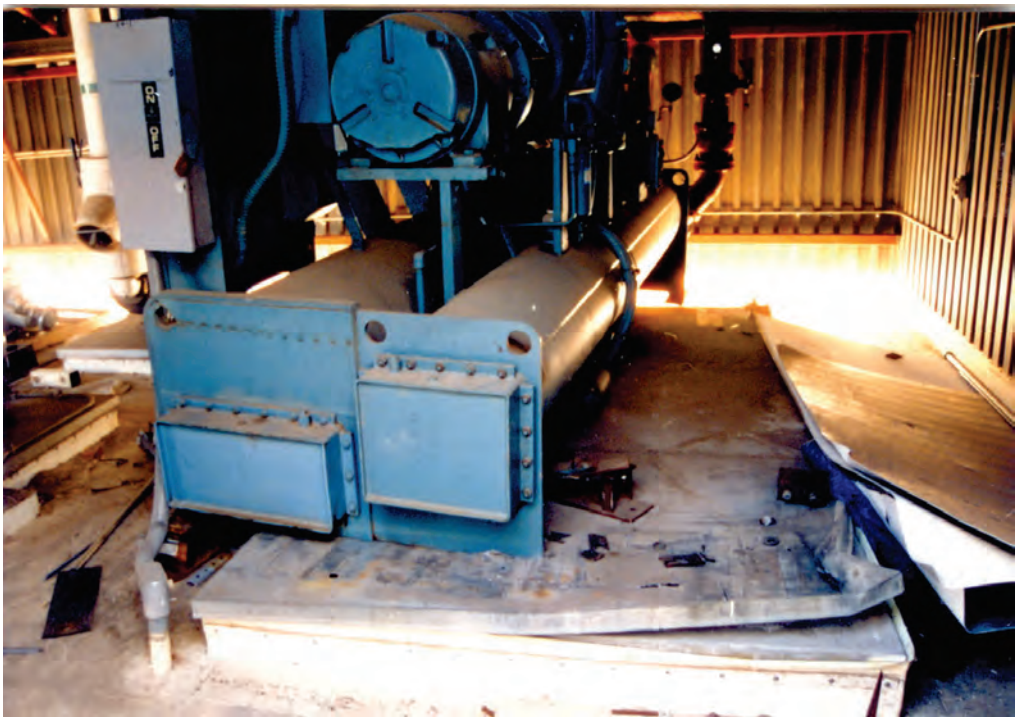


Figure 6.4.1.1-1 Failed chiller mounts due to insufficient uplift resistance in the 1994 magnitude-6.7 Northridge Earthquake ((Photo courtesy of Wiss, Jenney, Elstner Associates).



Figure 6.4.1.1-2 Pumps with rigid anchorage to housekeeping pad in the 2010 magnitude-8.8 Chile Earthquake; housekeeping pad not anchored to base slab and slid horizontally several inches (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- The details shown depict rigid anchorage of mechanical equipment to a concrete slab or housekeeping pad. Verify that the slab and/or housekeeping pad are adequate to resist the imposed loads. Rigidly mounted equipment should have flexible connections for the distribution systems, such as fuel lines and piping where relative motion or displacements due to story drift are likely to occur between the component and the distribution systems. Where flexible connections are used for larger diameter piping, it may be necessary to evaluate the forces imposed on the equipment nozzles when the flexible connections displace. For pressurized systems, “flexible” connections such as braided pipe or hose have significant lateral stiffness, and may overload the nozzle on the equipment, causing it to fail. Piping loops are also an acceptable way of providing a flexible connection, provided that nozzles are not overloading by the piping reactions.
- For equipment with vibration isolation, restraints ("snubbers") or seismic isolators are required; see Section 6.4.1.3 for equipment with vibration isolation. Snubbers should not be rigidly connected to the equipment, but instead allow for a small amount of ordinary vibration movement while preventing large seismic movements. However, the “air gap”, or distance between the snubber and the component should be limited to less than 0.25 inches, to avoid significant dynamic amplification when the component contacts the snubber. The snubbers should have an elastomeric or resilient surface to lessen the impact effects during strong shaking. Where isolators with integral seismic restraint are used, the isolator should be selected and sized to resist the anticipated seismic shear and uplift and connections to the equipment and supporting structure should be specifically designed to resist these forces.
- HVAC equipment or other items required for use in a hospital or essential facility would be classified as designated seismic systems and may require engineering calculations, equipment certification and special inspections. Check with the jurisdiction for specific requirements.
- To see additional examples for specific equipment and different anchorage conditions, refer to FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) and FEMA 414 *Incremental Seismic Restraints for Duct and Pipe* (2004).

MITIGATION EXAMPLES



Figure 6.4.1.1-3 Added lateral capacity provided for skid-mounted equipment added following the 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

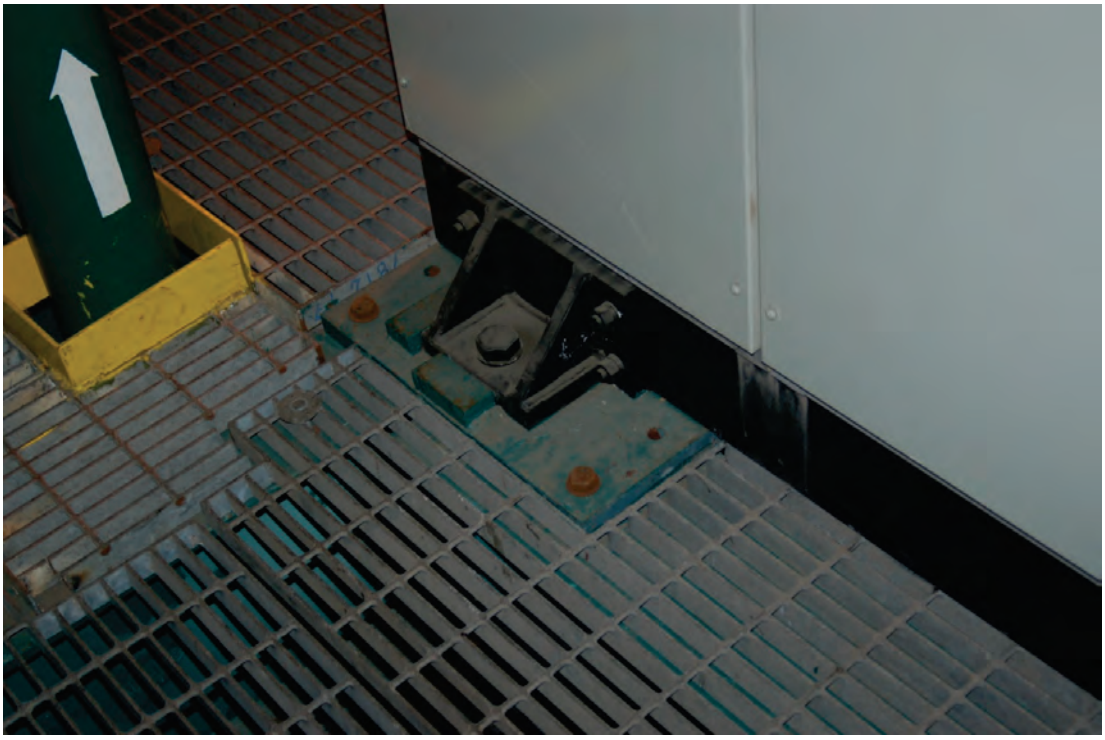


Figure 6.4.1.1-4 Bolted connection to steel skid with added shear lugs (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.1.1-5 Alternate detail for skid mounted equipment (Photo courtesy of Eduardo Fierro, BFP Engineers).

MITIGATION DETAILS

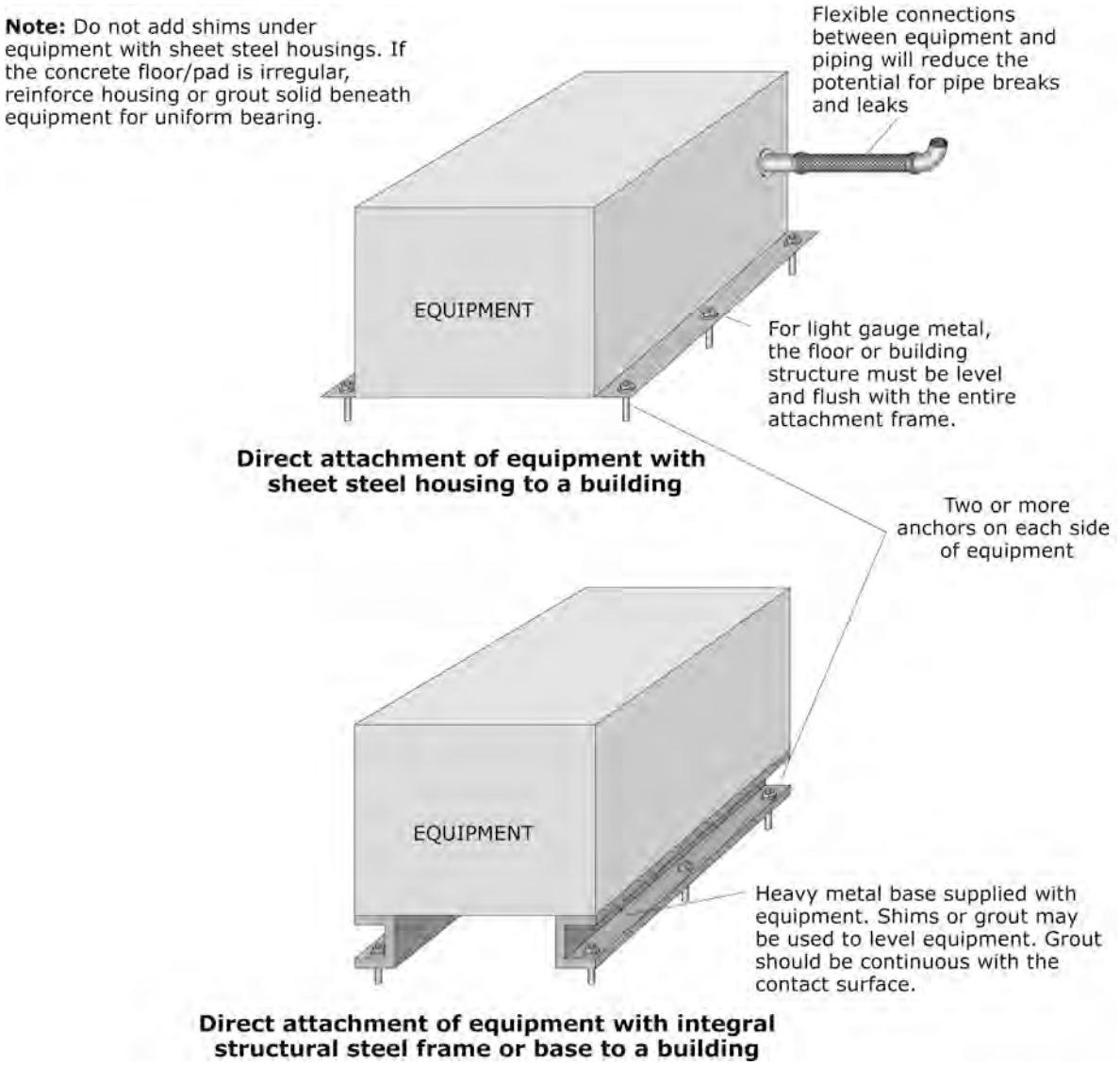


Figure 6.4.1.1-6 Floor-mounted equipment – anchored through integral base (ER).

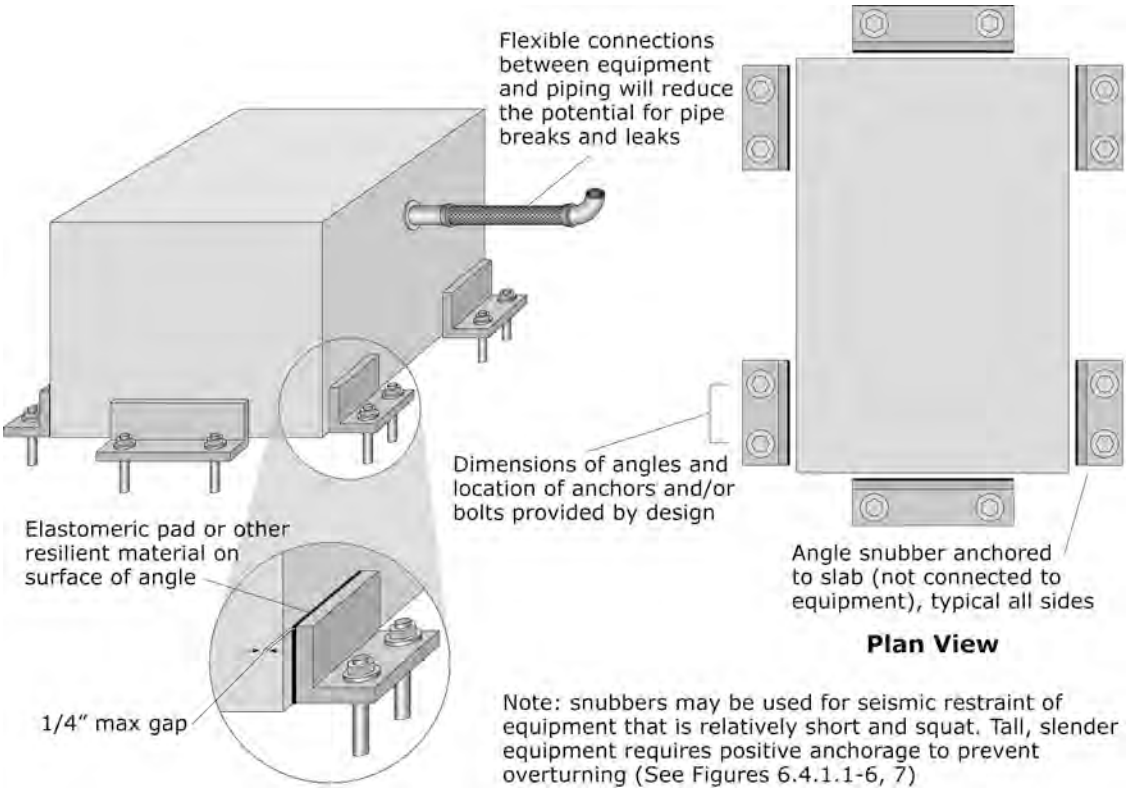


Figure 6.4.1.1-7 Floor-mounted equipment – restrained with snubbers.

6.4 Mechanical, Electrical, and Plumbing Components

6.4.1 Mechanical Equipment

6.4.1.2 General Manufacturing and Process Machinery

This category covers a wide range of equipment of various shapes and sizes. It includes isolated pieces of equipment as well as manufacturing lines that consist of numerous components requiring precise alignment. Mechanical components may be constructed of deformable materials and attachments or rigid components and attachments; they may be floor-, wall-, or roof-mounted.

Provisions

BUILDING CODE PROVISIONS

General manufacturing and process machinery may be subject to the requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13, Nonstructural Components, or Chapter 15, Nonbuilding Structures. Components housed in or supported by a building are typically assumed to be nonstructural components and are covered by Chapter 13. Larger or significant components not enclosed or supported by a building are considered Nonbuilding Structures and are covered by Chapter 15. For example, the components in Figures 6.4.1.2-1 and 6.4.1.2-2 would be classified as Nonbuilding Structures. The distinction between the nonstructural components and Nonbuilding Structures is sometimes difficult to determine. When uncertainty exists, one approach is to use the larger of the seismic demands determined by either method.

The principal objective of the requirements in ASCE/SEI 7-10 is to prevent the component from sliding or overturning. However, depending on the nature of the machinery, it may also be sensitive to building displacements if the system is connected to multiple levels of the same structure, or is connected to adjacent structures.

Requirements for general manufacturing and process machinery classified as Nonbuilding Structures:

- ASCE/SEI 7-10 Chapter 15 classifies Nonbuilding Structures into two broad groups, those that are similar to buildings and those that are not similar to buildings.
- Nonbuilding Structures similar to buildings may be designed or strengthened using the same general approach as those used for buildings. The most significant difference is

that in areas of high seismicity, a broader range of structural systems are permitted for Nonbuilding Structures, although higher design forces are required.

- ASCE 7-10 Chapter 15 provides extensive provisions for Nonbuilding Structures not similar to buildings, including tanks, vessels, silos, and cooling towers.

Requirements for general manufacturing and process machinery classified as nonstructural components:

- ASCE/SEI 7-10 requires anchorage for all equipment in Seismic Design Categories D, E, and F for all equipment weighing over 400 pounds, and items weighing over 20 pounds that are mounted over 4 feet above the floor. Lighter items may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. They must also be provided with flexible connections between the equipment and associated pipes, ducts, or conduits or alternate means for protecting the connections.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies general manufacturing and process machinery as force controlled. For general manufacturing and process machinery that can be classified as a nonstructural component, ASCE/SEI 41-06 requires compliance with the anchorage provisions of the standard when:

- The performance level is Immediate Occupancy
- The performance level is Life Safety in high seismicity areas, if
    - The item is gas-fired.
    - The item is part of an emergency power system,
    - The items weighs more than 400 pounds and is 6 feet or more in height,
    - The item is unanchored, weighs over 100 pounds, is 6 feet or more in height, and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 against overturning when design loads are applied.
    - The item weighs over 20 pounds and is mounted over 4 feet above the floor.

For general manufacturing and process machinery classified as a nonbuilding structure, the provisions of ASCE/SEI 41-06 are not directly applicable. However, the procedures of the document may be extrapolated to apply to many Nonbuilding Structures similar to structures such as pipe racks and structural towers that support tanks, vessels and bins.

Typical Causes of Damage

- Unanchored or poorly restrained equipment can slide, tilt, overturn, or fall. Poorly reinforced housekeeping pads may slide or fail.
- Components may be damaged by shaking or pounding, or may be crushed by other fallen components. Failure of large nonstructural components may result in damage to structural elements due to impact or falling.
- Items crossing seismic joints, attached to adjacent floors, penetrating structural elements, or connections between flexible and rigid components may be particularly vulnerable.
- Machinery may cease to function due to misalignment or internal damage.
- Contents, fluids, or hazardous materials may slosh, mix, or spill.
- Connections of fuel lines, electrical lines, optical cable, piping, or ductwork may be damaged; runs of piping, ducts, or cable may be damaged.
- Loss of function of manufacturing equipment can cause significant business interruption losses.

DAMAGE EXAMPLES



Figure 6.4.1.2-1 Damage to conveyors and equipment at a cement plant in the 2010 magnitude-7 Haiti Earthquake (Photos courtesy of Eduardo Fierro, BFP Engineers).



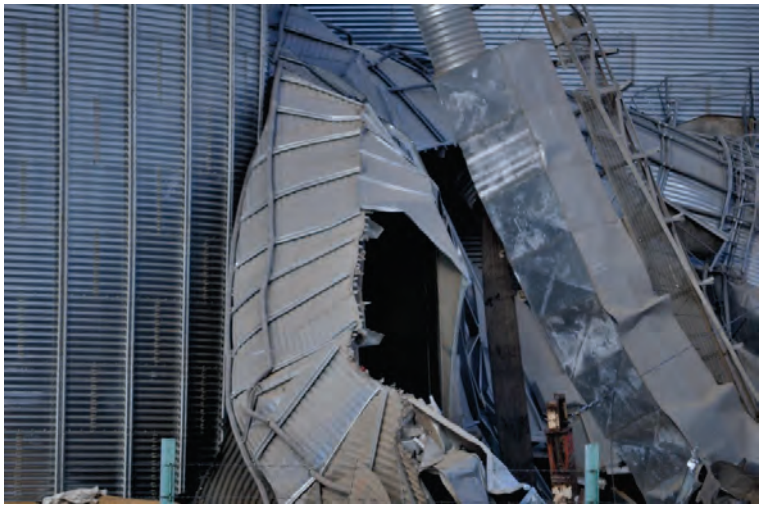




Figure 6.4.1.2-2 Damage to silos, conveyors and equipment at a grain operation in the 2010 magnitude-8.8 Chile Earthquake (Photos courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- In addition to requirements in ASCE/SEI 7-10 *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), anchorage design for equipment may be governed by specialty codes and standards such as ASME, ASHRAE, IEEE, API.
- See Sections 6.4.1.1 and 6.4.1.3 for sample details for floor-mounted equipment and see FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002), FEMA 413 *Installing Seismic Restraints for Electrical Equipment* (2004) and FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for example details for MEP equipment, piping and ductwork. Many of the attachment details in these documents could be adapted for use with other types of equipment.
- Some equipment has been shake table tested and is rated for seismic loading by their vendors; inquire about seismic load ratings and seismic anchorage details when any new equipment is purchased.
- For vulnerable items that require a long lead time to replace, it may be prudent to stock replacement parts or equipment in order to reduce an outage following an earthquake.
- Special attention is required for control rooms and emergency generators to ensure that a facility may be shut down safely after an earthquake.
- Flexible connections should be provided for fuel lines and piping where they connect to rigidly mounted equipment.
- Design of seismic bracing and anchorage for complex manufacturing systems is a significant engineering challenge and should be handled by design professionals with specific expertise in this area. Nonstructural bracing should be checked regularly to ensure that the anchorage has not been compromised. It may be prudent to have a standing agreement with a design professional familiar with the facility to perform postearthquake inspections in order to facilitate speedy repairs and reduce the outage time.

6.4 Mechanical, Electrical, and Plumbing Components

6.4.1 Mechanical Equipment

6.4.1.3 HVAC Equipment with Vibration Isolation

This includes HVAC equipment, typically of sheet metal construction, that is floor- mounted with vibration isolators to prevent the transmission of mechanical vibrations into the building.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for HVAC equipment with vibration isolation are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13. The principal objective is to prevent the component from sliding or overturning.

- ASCE/SEI 7-10 requires anchorage for all equipment in Seismic Design Categories D, E, and F for all equipment weighing over 400 pounds, and items weighing over 20 pounds that are mounted over 4 feet above the floor. Lighter items may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Exempt components must be provided with flexible connections between the equipment and associated pipes, ducts, or conduits.
- The seismic design force for vibration isolated equipment is doubled if the "air gap" (the distance between the equipment support frame and the restraint) is greater than 0.25 inches.

RETROFIT STANDARD PROVISIONS

In ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007), HVAC equipment with vibration isolation is classified as force controlled. ASCE/SEI 41-06 requires compliance with the anchorage provisions of the standard when:

- The performance level is Immediate Occupancy
- The performance level is Life Safety in high seismicity areas, if
    - The item is gas-fired.
    - The item is part of an emergency power system,
    - The items weighs more than 400 pounds and is 6 feet or more in height,

- The item is unanchored, weighs over 100 pounds, is 6 feet or more in height, and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 against overturning when design loads are applied.
- The item weighs over 20 pounds and is mounted over 4 feet above the floor.

Typical Causes of Damage

- Vibration isolated equipment is particularly vulnerable to earthquake damage unless some type of snubbers, bumpers, or vendor-supplied restraints are used. Open and housed springs do not have adequate capacity to resist shear and uplift.
- Vibration isolators tend to amplify seismic response of the equipment This requires the supporting frames or slabs to have adequate capacity to resist higher forces (Figure 6.4.1.3-3).
- Items can slide, tilt, overturn, or fall.
- Internal components may be damaged by shaking.
- Connections of fuel lines, electrical lines or ductwork may be damaged; machinery may cease to function due to misalignment, failure of the isolators, or internal damage.

DAMAGE EXAMPLES

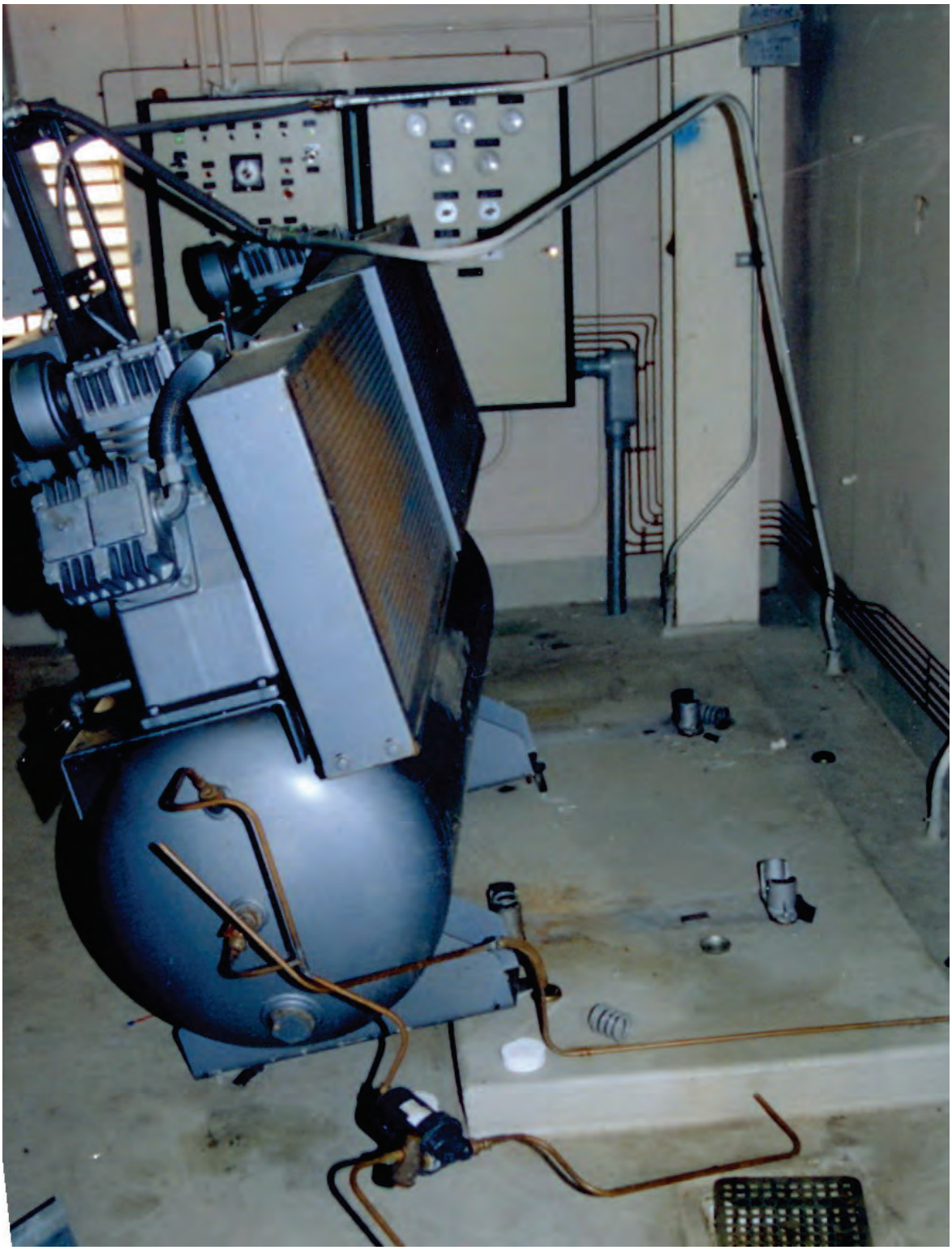


Figure 6.4.1.3-1 Failure of compressor mounted on vibration isolators in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Jenney, Elstner Associates).



Figure 6.4.1.3-2 Failure of pump mounted on three vibration isolators and damage at wall penetration (Photo courtesy of Mason Industries).



Figure 6.4.1.3-3 Failure of an entire support assembly including vibration isolators (Photo courtesy of Mason Industries).



Figure 6.4.1.3-4 Rooftop equipment on isolators collapsed onto skid (Photo courtesy of Mason Industries).

Seismic Mitigation Considerations

- Although the code exempts small components on vibration isolators from design requirements, they should be carefully evaluated, since vibration isolators tend to amplify the seismic response.
- Two methods are used for anchoring floor-mounted equipment on vibration isolators:
    1. Open springs used in conjunction with snubbers or bumpers.

2. Restrained springs with rated capacity to resist the anticipated seismic shear and uplift.

- Rated housed springs with vertical travel limits should be used for seismic restraint applications.
- The "air gap", or distance between the snubber and the component should be limited to less than 0.25 inches, to avoid significant dynamic amplification when the component contacts the snubber.
- Metal-to-metal contact between snubbers and the supporting frame or between the isolator housing and the mounting bolt to the unit should be avoided. The snubbers should have an elastomeric or resilient surface to lessen the impact effects during strong shaking. For housed springs, an elastomeric grommet will prevent hard surface impact.
- Flexible connections must be provided for fuel lines and piping.
- Refer to FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) and FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for additional information and details.
- HVAC equipment or other items required for use in a hospital or essential facility would be classified as designated seismic systems and may require engineering calculations, equipment certification and special inspections. Check with the jurisdiction for specific requirements.

MITIGATION EXAMPLES



Figure 6.4.1.3-5 Restrained springs used to support heavy equipment (Photo courtesy of Mason Industries).

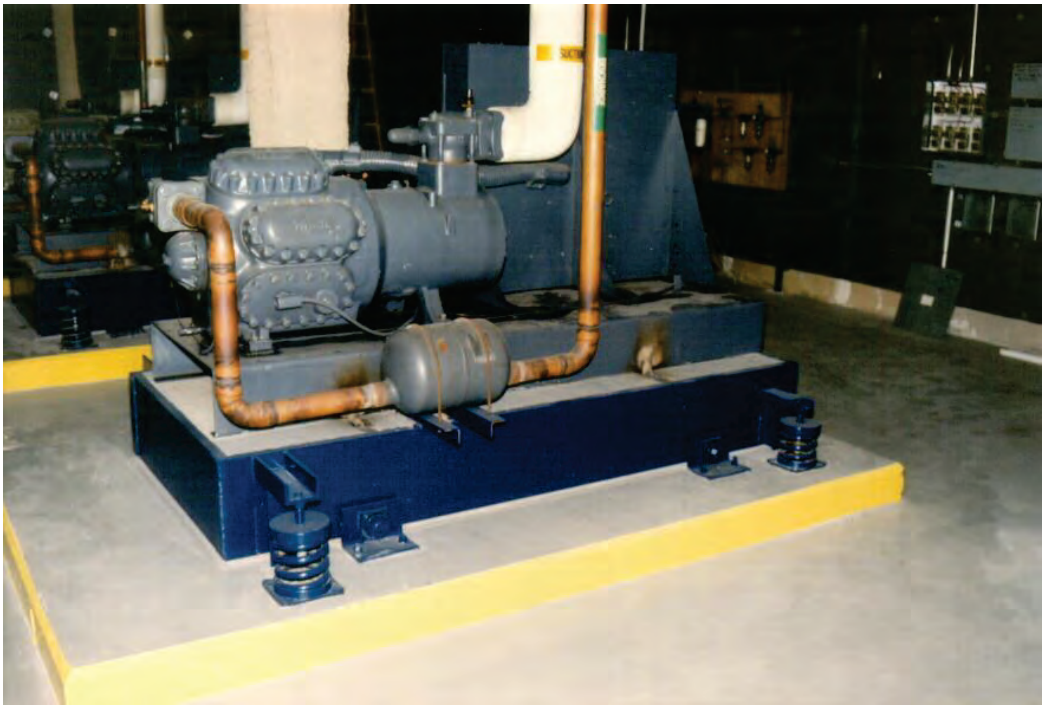


Figure 6.4.1.3-6 Open springs and snubbers used to support equipment (Photo courtesy of Mason Industries).



Figure 6.4.1.3-7 Seismic shake table testing of an air-handler unit and vibration isolation restraint system as part of the MCEER-ASHRAE project (Photos courtesy of André Filiatrault, MCEER).

MITIGATION DETAILS

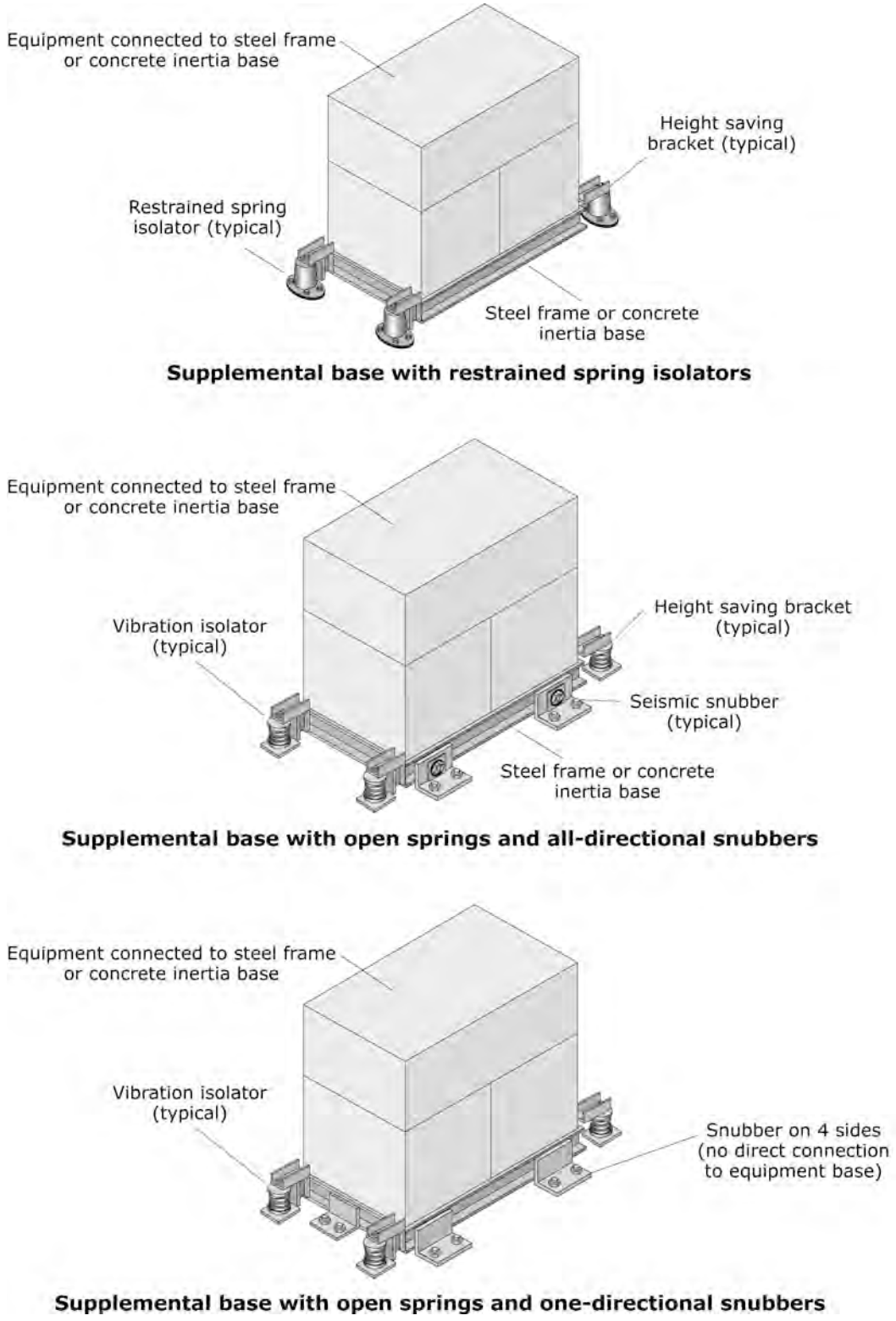


Figure 6.4.1.3-8 HVAC equipment with vibration isolation (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.1 Mechanical Equipment

6.4.1.4 HVAC Equipment without External Vibration Isolation

This includes dry-side HVAC equipment, typically of sheet metal construction, that is rigidly mounted to the floor, wall or roof, and components that are internally isolated. While internally isolated equipment is rigidly attached to the structure, internal components are installed on vibration isolators.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for HVAC equipment without external vibration isolation are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13. The principal objective is to prevent the component from sliding or overturning.

- Seismic loads for HVAC equipment without external vibration isolation are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13. The design forces for internally isolated components are substantially higher than those for non-isolated components.
- ASCE/SEI 7-10 requires anchorage for all equipment in Seismic Design Categories D, E, and F for all equipment weighing over 400 pounds, and items weighing over 20 pounds that are mounted over 4 feet above the floor. Lighter items may be exempt if the component Importance Factor $Ip = 1.0$.
- Items that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. They must also be provided with flexible connections between the equipment and associated pipes, ducts, or conduits or provided with other means to protect the connections from damage.

RETROFIT STANDARD PROVISIONS

In ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007), HVAC equipment without external vibration isolation is classified as force controlled. ASCE/SEI 41-06 requires compliance with the anchorage provisions of the standard when:

- The performance level is Immediate Occupancy

- The performance level is Life Safety in high seismicity areas, if
  - The item is gas-fired.
  - The item is part of an emergency power system,
  - The items weighs more than 400 pounds and is 6 feet or more in height,
  - The item is unanchored, weighs over 100 pounds, is 6 feet or more in height, and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 against overturning when design loads are applied.
  - The item weighs over 20 pounds and is mounted over 4 feet above the floor.

Typical Causes of Damage

- Unanchored or inadequately anchored items can slide, tilt, overturn, or fall.
- Connections of fuel lines, electrical lines or ductwork may be damaged; machinery may cease to function due to misalignment.
- Internally isolated components may experience substantially larger seismic forces than those without internal isolation. This results in higher demands on the component anchorage, and increases the vulnerability of the component to internal shaking damage.

DAMAGE EXAMPLES



Figure 6.4.1.4-1 Poorly anchored compressor jumped off the undersized anchor bolts in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.1.4-2 Unanchored rooftop units thrown off their supports during an earthquake (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.4.1.4-3 Numerous poorly anchored rooftop units toppled in the 2010 Chile Earthquake (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

Seismic Mitigation Considerations

- See Section 6.4.1.1 for rigid floor mount details and Section 6.4.1.3 for vibration isolation floor mount details.
- Special consideration is needed for rooftop units. Such units are typically mounted on curbs or platforms to facilitate waterproofing and flashing. Curbs may be custom-built on site or premanufactured. Detailing for seismic restraints must include a connection between the equipment and the curb and the curb and the roof framing. In addition, the curb itself must be sufficiently strong to deliver earthquake forces from the unit to the roof. If the equipment is internally isolated, the design forces for the anchorage should be increased appropriately.
- See FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) and FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for details for wall-mounts, roof-mount with flashing details, ducts and piping, and additional information regarding hardware and installation.

MITIGATION DETAILS

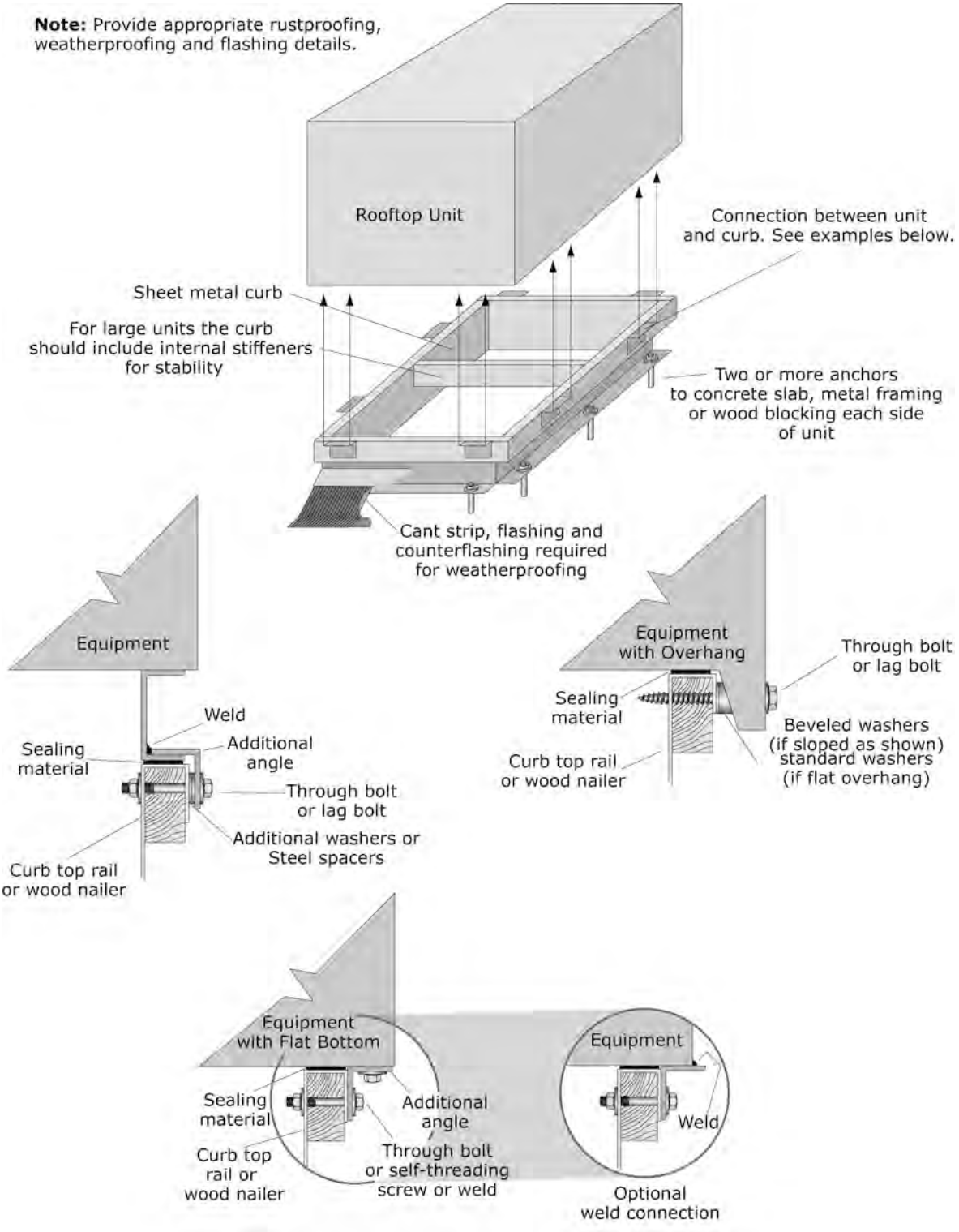


Figure 6.4.1.4-4 Rooftop HVAC equipment (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.1 Mechanical Equipment

6.4.1.5 HVAC Equipment Suspended In-Line with Ductwork

This in-line HVAC equipment typically includes suspended items of sheet metal construction such as fans, coils, VAV boxes, and blowers. The connection details for suspended equipment may also include vibration isolators.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for suspended HVAC equipment in-line with ductwork are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13. Depending on the nature of the equipment, the supports may include vibration isolators. The principal objective is to prevent the component from falling.

- ASCE/SEI 7-10 requires anchorage for all suspended equipment in Seismic Design Categories D, E, and F weighing over 20 pounds. Lighter items may be exempt if the component Importance Factor $I_p = 1.0$.
- Suspended HVAC equipment on vibration isolators should be designed using the appropriate design coefficients for isolated components, which will result in higher design forces. See Section 6.4.1.3.
- Equipment that is installed in-line with a duct system that has an operating weight greater than 75 pounds must be supported and laterally braced independent of the duct system. Equipment 75 pounds or less may be supported and braced integrally with the duct system, provided that the equipment is positively attached to the duct with mechanical fasteners.
- Unbraced piping attached to in-line equipment must be provided with flexibility adequate to accommodate seismic relative displacements.
- Items that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Flexible connections must be provided between the equipment and associated pipes, ducts, or conduits, or alternate measures should be employed to protect the connections from damage.

RETROFIT STANDARD PROVISIONS

Suspended HVAC equipment in-line with ductwork is classified as force-controlled by, ASCE 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007). ASCE 41-06 requires compliance with the anchorage provisions of the standard when:

- The performance level is Immediate Occupancy
- The performance level is Life Safety in high seismicity areas, if
    - The item is gas-fired,
    - The item is part of an emergency power system, or
    - The item weighs over 20 pounds and is mounted over 4 feet above the floor.
- The recommended evaluation procedure is to use a prescriptive approach, such as provisions in ASCE 7-10 Section 13.6.7.

Typical Causes of Damage

- Poorly supported items can fall.
- Items can swing and impact structural, architectural or other mechanical items. Internal components may be damaged by shaking or impact.
- Connections of fuel lines, water piping, electrical conduit or ductwork may be damaged. Equipment may cease to function due to misalignment or internal damage.

DAMAGE EXAMPLES



Figure 6.4.1.5-1 Damage to suspended HVAC, signs, and louvers was caused when suspended fans in the mechanical penthouse swung and impacted the louver panels. Holy Cross Medical Center in Sylmar, as a result of the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Robert Reitherman).

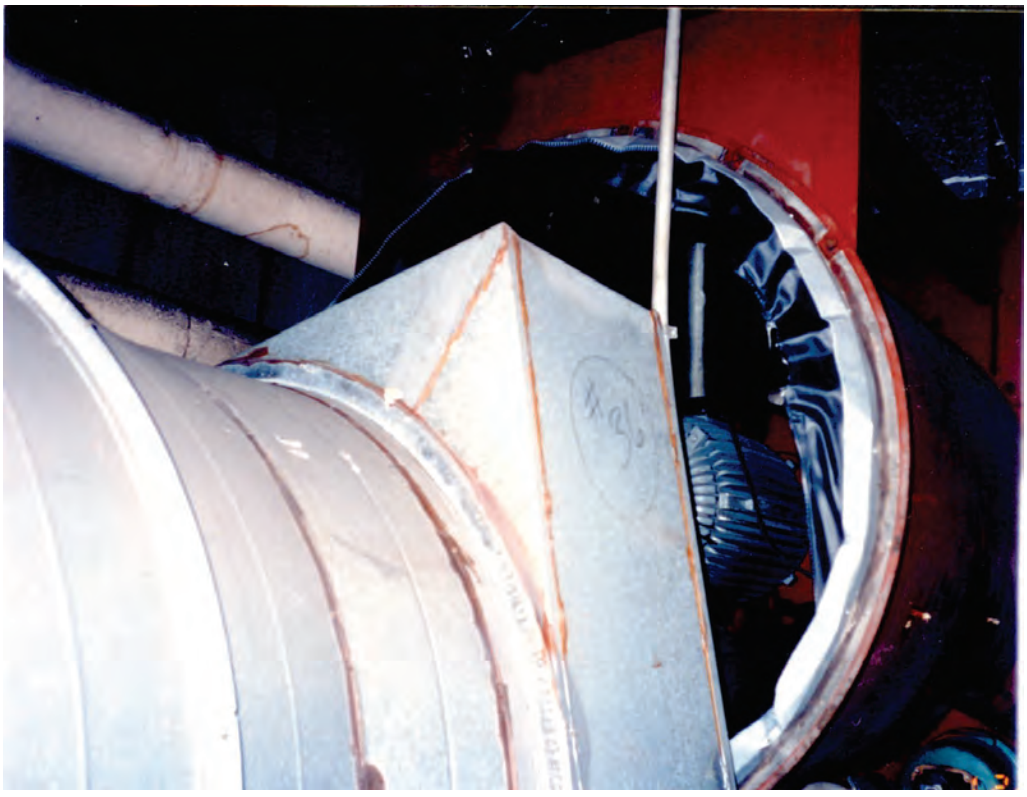


Figure 6.4.1.5-2 Sheet metal duct separated from suspended fan unit (Photo courtesy of Wiss, Jenney, Elstner Associates).



Figure 6.4.1.5-3 Suspended HVAC equipment came down at the Santiago airport terminal in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Gokhan Pekcan).

Seismic Mitigation Considerations

- Items should be braced to structural elements with sufficient capacity to resist the imposed loads. Do not brace to other equipment, ducts, or piping, unless specifically permitted by the reference standards. If installed on pipes, ducts, or conduit that are exempt from seismic bracing, in-line equipment must be supported and laterally braced independently, regardless of weight.
- Flexible connections should be provided for fuel lines and piping.
- Equipment may be suspended either with or without vibration isolation. The vibration isolators may allow more vertical motion in the hangers than in a non-isolated condition, resulting in larger lateral displacements. This should be considered when examining potential interaction with adjacent components and systems. Where vibration isolators are present, a bracing scheme that utilizes aircraft cable for lateral bracing rather than rigid element will prevent accidental transmission of vibration to the structure.
- Refer to FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) and FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for additional information and details.
- Several engineered seismic bracing systems are available for suspended equipment and can be customized for most applications. Other options may be found on the internet.

MITIGATION EXAMPLES

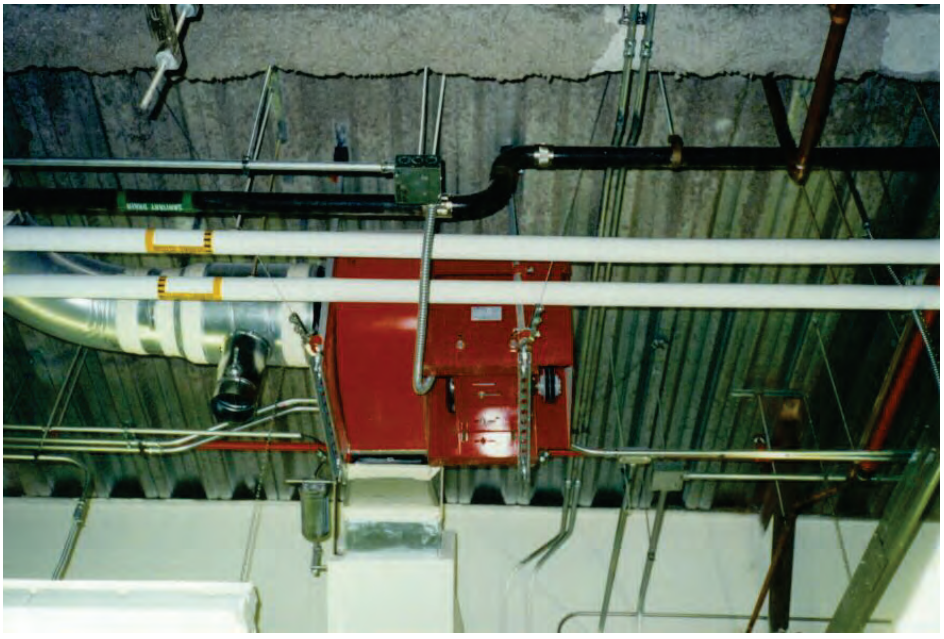


Figure 6.4.1.5-4 Suspended equipment with cable braces (Photo courtesy of Mason Industries).

MITIGATION DETAILS

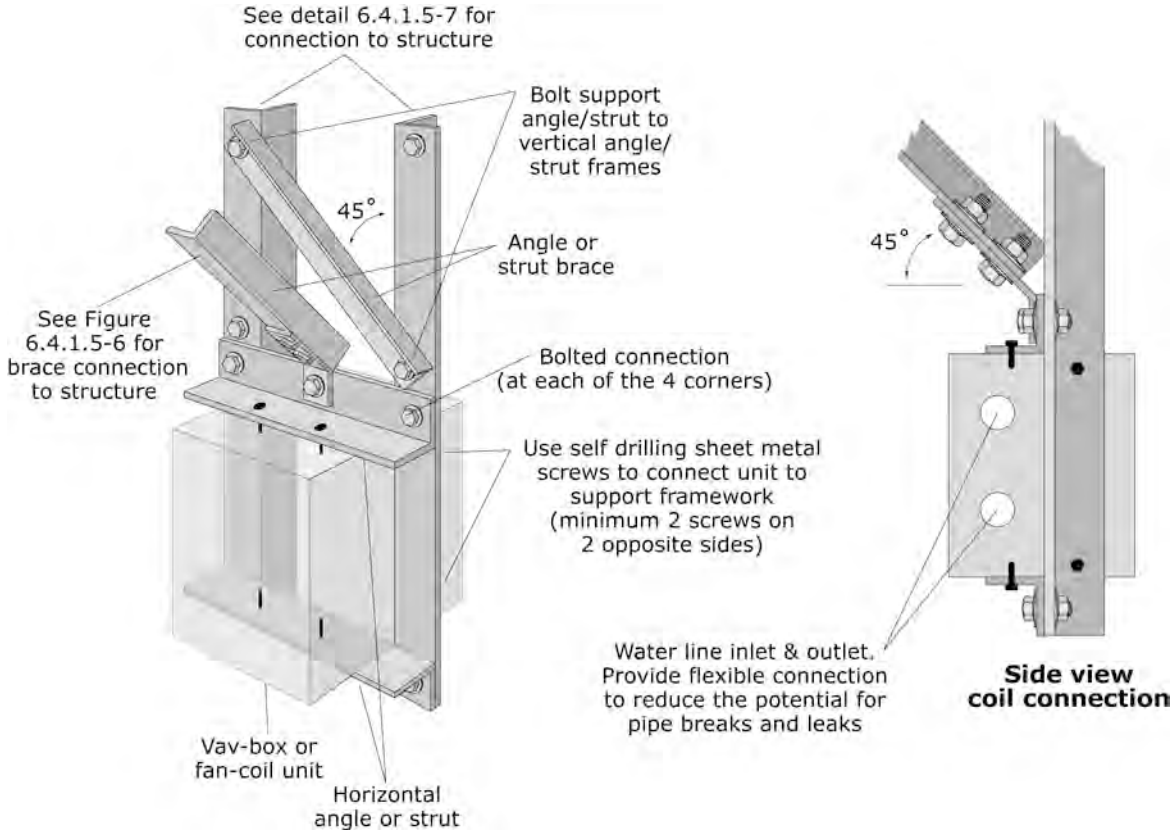


Figure 6.4.1.5-5 HVAC equipment suspended in-line with ductwork (ER).

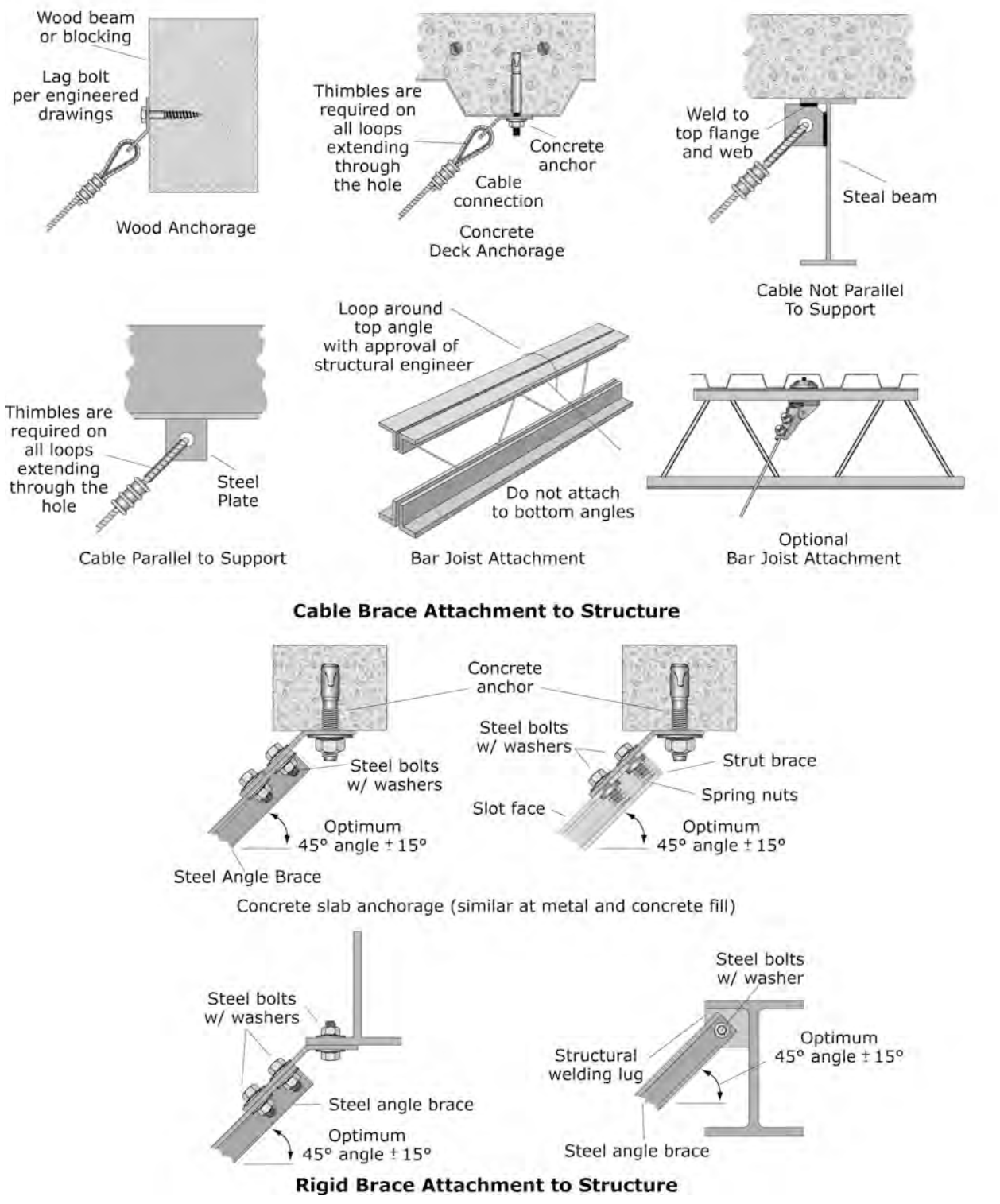


Figure 6.4.1.5-6 Cable and rigid brace attachments to structure (ER).

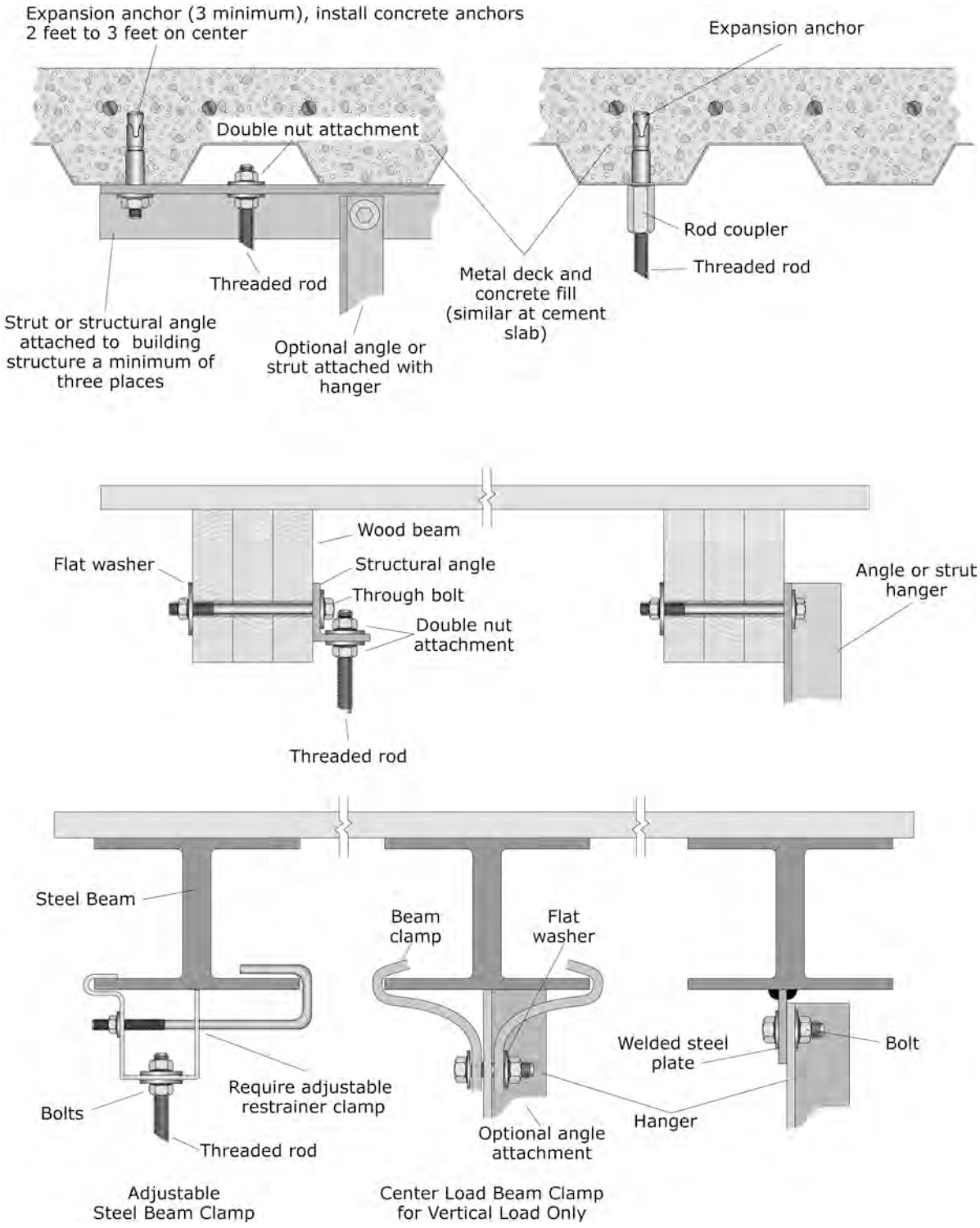


Figure 6.4.1.5-7 Hanger attachment details (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.1 Mechanical Equipment

6.4.1.6 Suspended Equipment

This category covers any type of suspended equipment items other than HVAC equipment suspended in-line with ductwork, such as unit gas heaters.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for suspended equipment are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13. The principal objective is to prevent the component from falling.

- ASCE/SEI 7-10 requires anchorage for all suspended equipment in Seismic Design Categories D, E, and F weighing over 20 pounds. Lighter items may be exempt if the component Importance Factor $I_p = 1.0$.
- Unbraced piping attached to in-line equipment must be provided with flexibility adequate to accommodate seismic relative displacements.
- Items that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Flexible connections must be provided between the equipment and associated pipes, ducts, or conduits.

RETROFIT STANDARD PROVISIONS

For suspended equipment, ASCE 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) requires compliance with the anchorage provisions of the standard when the performance level is Immediate Occupancy, or the performance level is Life Safety and the component is gas-fired and located in areas of high seismicity. These components are classified as force controlled.

- Anchorage should be provided if the item weighs over 20 pounds and is mounted over 4 feet above the floor.

Typical Causes of Damage

- Poorly supported suspended items may lose support and fall.

- Suspended items can swing and impact building elements or other equipment.
- Internal components may be damaged by shaking or impact.
- Connections of fuel lines or other connected piping may be damaged.
- Equipment may cease to function due to misalignment or internal damage.

DAMAGE EXAMPLES

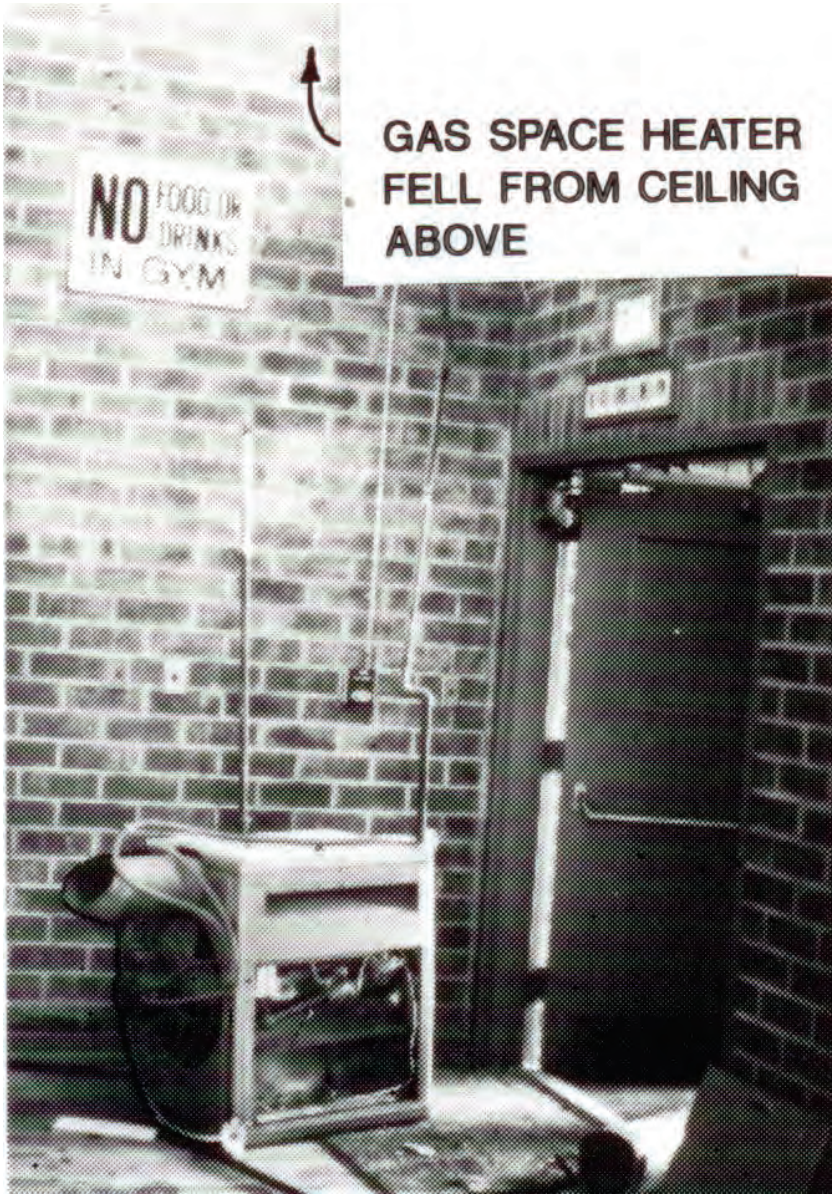


Figure 6.4.1.6-1 Gas space heater fell from ceiling above in the 1971 magnitude-6.6 San Fernando Earthquake (Photo courtesy of C. Wilton, Scientific Service, Inc.).

Seismic Mitigation Considerations

- Detail shown provides rigid attachment for small suspended equipment weighing less than 150 pounds. Two or more double angle assemblies could be used for larger items. If the equipment is suspended with rigid, unbraced hangers, the details shown may be adapted to provide diagonal bracing.
- Provide flexible connections for fuel lines.
- Refer to Section 6.4.1.5 for details for suspended HVAC items; these details can be adapted for multiple suspended items. See also FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) and FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for additional information and details.
- Several engineered seismic bracing systems are available for suspended equipment and can be customized for most applications, more options may be found on the internet.

MITIGATION DETAILS

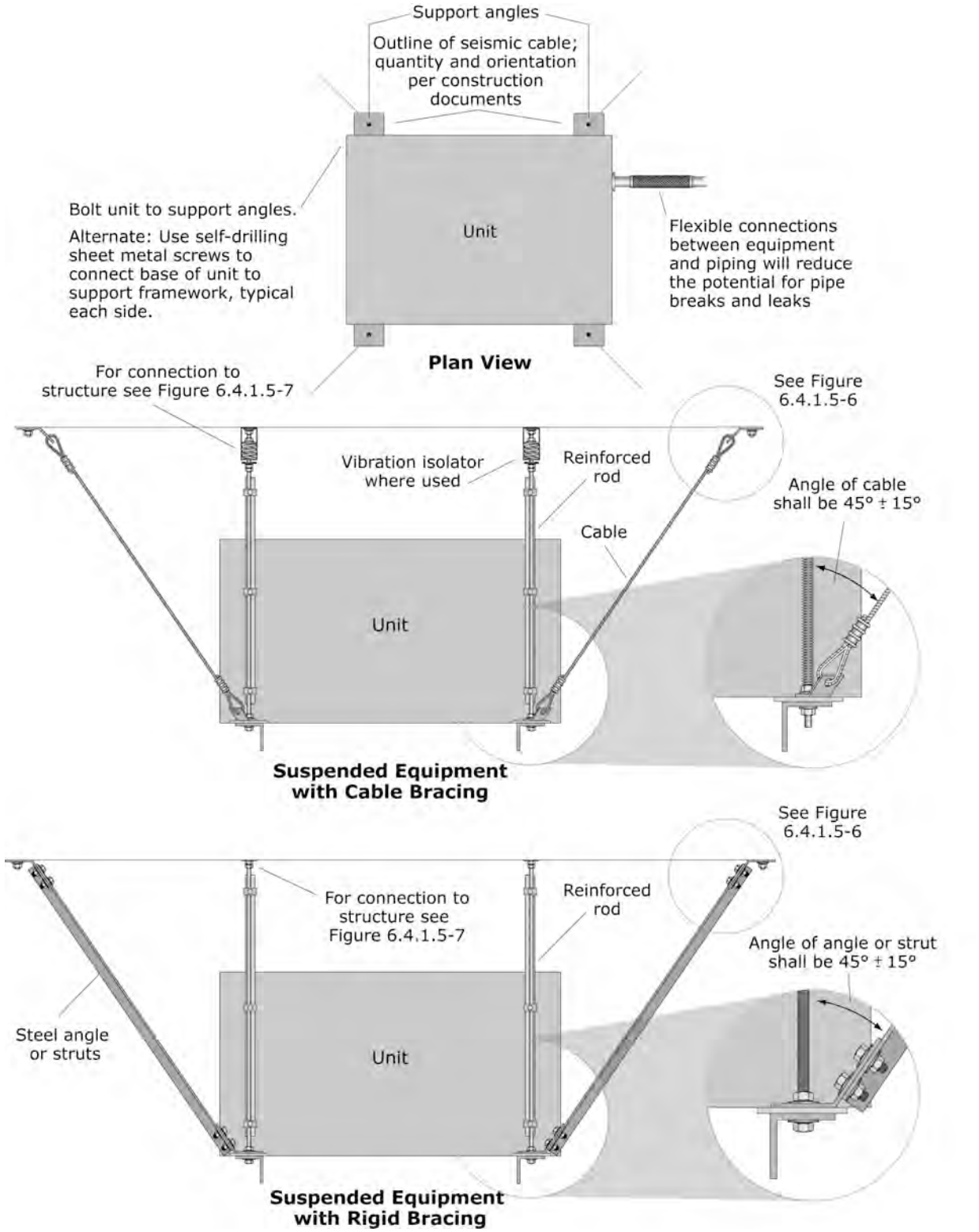


Figure 6.4.1.6-2 Suspended equipment (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.2 Storage Tanks and Water Heaters

6.4.2.1 Structurally Supported Tanks and Vessels

This category covers any type of tank or vessel supported on legs or a structural frame and may be either vertical or horizontal. Tanks may be made of steel, stainless steel, polyethylene, polypropylene, fiberglass reinforced plastic (FRP), or concrete.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for structurally supported tanks and vessels are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures,* (ASCE, 2010), Chapter 13, or Chapter 15 (Nonbuilding Structures) for large tanks that are not within buildings.

For tanks considered nonstructural components, ASCE/SEI 7-10 Chapter 13 requires anchorage for tanks in Seismic Design Categories D, E, and F weighing over 400 pounds. Lighter tanks may be exempt if the component Importance Factor $I_p = 1.0$.

- Tanks or vessels that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure or ground. The anchorage need not be designed or detailed on the construction documents. The components must be provided with flexible connections between the equipment and associated pipes or conduits or alternate means of protecting the connection should be implemented.
- ASCE/SEI 7-10 requires design of component supports and component anchorage where:
    - Component supports for the tank or vessel include the legs and attachment of the legs to the base plate and the tank or vessel wall, and
    - Component anchorage includes the attachment or anchors of the tank or vessel to the structure (e.g., anchor bolts to a concrete slab or bolts to a steel platform).

Requirements for structurally supported tanks and vessels classified as nonbuilding structures:

- ASCE/SEI 7-10 Section 15.7 contains extensive design requirements for elevated tanks on legs, saddles and skirts.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) classifies structurally supported tanks and vessels as force controlled, meaning that the principal objective is to prevent the component from sliding or overturning. These components are subject to the provisions of the standard when:

- The performance level is Immediate Occupancy.
- The performance level is Life Safety in high seismicity areas, if
    - The item is part of an emergency power system.
    - The item weighs more than 400 pounds and is 6 feet or more in height.
    - The item is unanchored, weighs over 100 pounds, is 6 feet or more in height, and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 against overturning when design loads are applied.
    - The item weighs over 20 pounds and is mounted over 4 feet above the floor.

Typical Causes of Damage

- If the tank is not anchored to the structural supports or the structural supports are not properly braced and anchored, the tanks may slide or fall. Poorly anchored tanks may damage the supports or damage the tank wall.
- The most common forms of damage are the following:
    - Failure of anchor bolts to the concrete deck or slab
    - Failure of the welds between the tank or vessel leg and the base plate
    - Buckling of the tank legs
    - Failure of the welds or connections between the supporting legs and the body of the tank or vessel
    - Buckling or local failure of the tank wall where the legs are attached
    - For saddle mounted tanks, failure of the straps or connectors that hold the tank in the saddle
- If the tank slides or rocks, the connections of supply lines or fuel lines may be damaged; contents may slosh or spill.

DAMAGE EXAMPLES



Figure 6.4.2.1-1 Tank shifted off support curb, Granada Hills Hospital in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of OSHPD).



Figure 6.4.2.1-2 A vertical tank at hospital overturned due to inadequate anchorage in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).



Figure 6.4.2.1-3 Horizontal tank strapped to structural support frame on hospital roof; one strap failed and tank slid six inches in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).



Figure 6.4.2.1-4 Wineries suffered extensive damage in the 2010 magnitude-8.8 Chile Earthquake with many barrels of wine spilled. This winery had damage to anchored tanks; tank anchorage failed, legs buckled, welds tore, anchor bolts pulled up, etc. The tank legs all have leveling bolts at the bottom, creating a weak zone between the bottom of the leg and the anchor plate. Similar unanchored tanks in this facility shifted position but were undamaged (Photos courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.1-5 Damage to tanks at the Pioneer Memorial Hospital at the 2012 Brawley Earthquake (Photo courtesy of Chris Tokas, OSHPD)

Seismic Mitigation Considerations

- Tanks must have adequate vertical and horizontal support. Provide anchorage and bracing for tank legs or support structure; provide positive attachment from tank to support structure. Provide concrete pad large enough to prevent tank from overturning.
- Provide flexible connections for fuel lines and piping.
- The details shown are for rigid connections; see also FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* (2002) for attachment details.
- For some installations where tanks have a low aspect ratio (i.e., the tank is relatively wide compared to the height) and are unlikely to overturn, it may be preferable to allow the tank to slide rather than providing rigid anchorage. As shown in the photos in Figure 6.4.2.1-4 taken at a winery, many stainless steel tanks on legs with base anchorage were damaged while nearby unanchored tanks shifted slightly but were undamaged. Flexible connections designed to accommodate sliding would be required

for tanks left free at the base. Tanks classified as nonstructural components that are specifically designed and detailed to accommodate seismic demands by sliding would be considered an Alternative Means of Compliance subject to the approval of the Building Official, since ASCE/SEi 7-10 explicitly requires that tanks and vessels be anchored. Tanks classified as nonbuilding structures that accommodate seismic demands by sliding may be designed using the provisions of ASCE/SEI 7-10 Section 15.7.5.

MITIGATION EXAMPLES



Figure 6.4.2.1-6 Braces added to four sides of tank support structure (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.1-7 Gusset plates and cross bracing added at base of vertical tank on four legs following the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

MITIGATION DETAILS

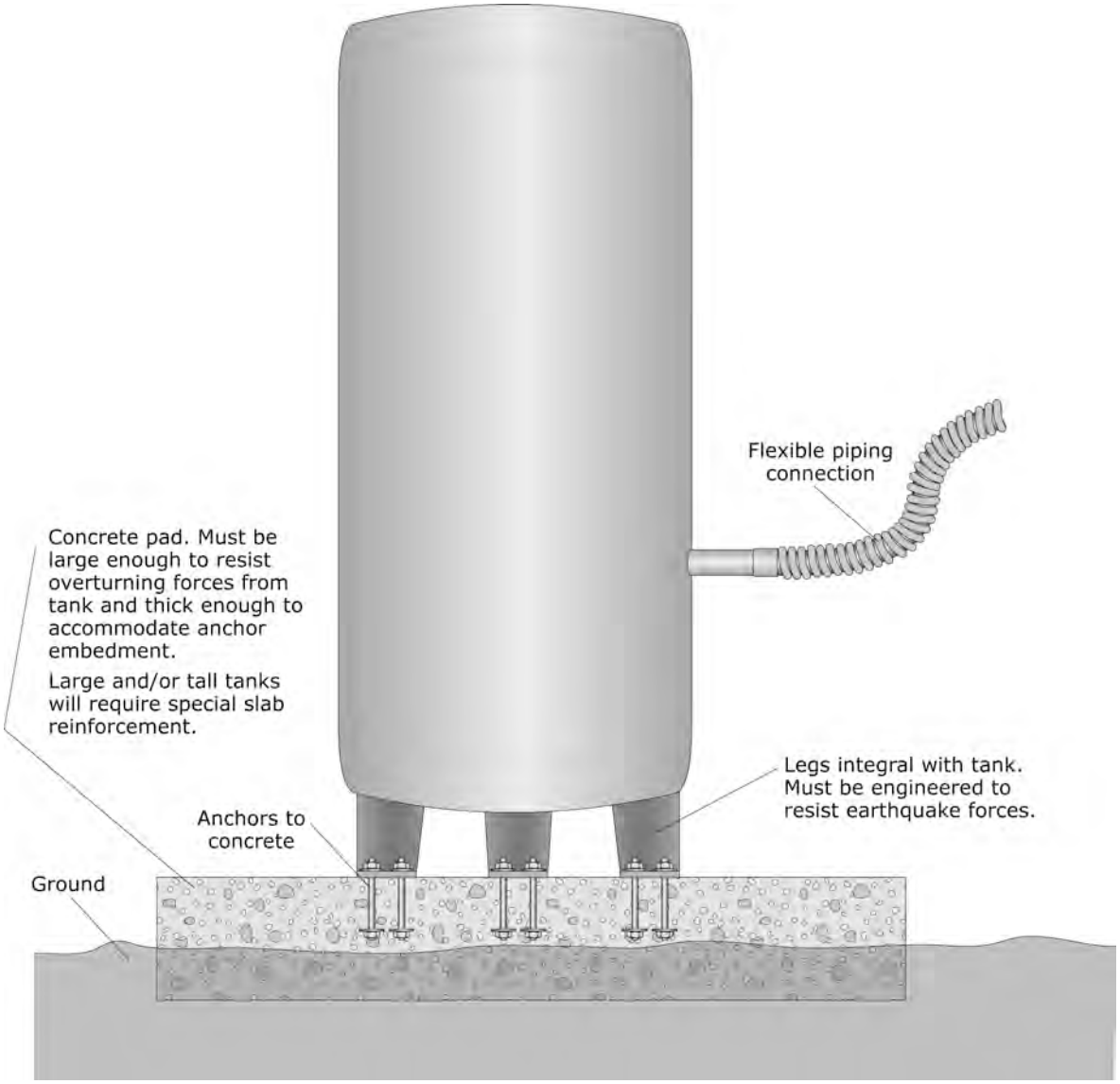


Figure 6.4.2.1-8 Vertical tank on legs (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.2 Storage Tanks and Water Heaters

6.4.2.2 Flat Bottom Tanks and Vessels

This category covers any type of flat bottom tank or vessel resting on a concrete pad at the base. These tanks may be made of steel, stainless steel, polyethylene, polypropylene, fiberglass reinforced plastic (FRP), or concrete.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for flat bottom tanks and vessels are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13, or Chapter 15 for large tanks that are not within buildings.

For tanks considered nonstructural components, ASCE/SEI 7-10 Chapter 13 requires anchorage for tanks in Seismic Design Categories D, E, and F weighing over 400 pounds. Lighter tanks may be exempt if the component Importance Factor $I_p = 1.0$.

- ASCE 7-10 requires consideration of component supports and component anchorage, as follows:
  - The component supports for the tank or vessel include the clips or brackets and attachment of the brackets to the tank or vessel wall,
  - The component anchorage includes the attachment or anchors of the tank or vessel to the structure (e.g., anchor bolts to a concrete slab or bolts to a steel deck or platform).
- Flat bottom tanks and vessels that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure or ground. The anchorage need not be designed or detailed on the construction documents. Flexible connections between the equipment and associated pipes or conduits must be provided or alternate means for protecting the connection shall be implemented.

Requirements for flat bottom tanks and vessels classified as nonbuilding structures:

- ASCE/SEI 7-10 Section 15.7 contains extensive design requirements for flat bottom tanks and vessels.

- Tanks and vessels at grade may be permitted to be designed without anchorage. See ASCE/SEI 7-10 Section 15.7.5 for additional information.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings,* (ASCE, 2007) classifies flat bottom tanks and vessels as force controlled, meaning that the principal objective is to prevent the component from sliding or overturning. Piping associated with the tank or vessel must meet the force and deformation requirements of the standard.

Tanks and vessels at grade are subject to the provisions of the standard when:

- The performance level is Immediate Occupancy
- The performance level is Life Safety in high seismicity areas, if
  - The item is part of an emergency power system,
  - The item weighs more than 400 pounds and is 6 feet or more in height,
  - The item is unanchored, weighs over 100 pounds, is 6 feet or more in height, and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 against overturning when design loads are applied.
  - The item weighs over 20 pounds and is mounted over 4 feet above the floor.

Typical Causes of Damage

- Unanchored tanks may slide or overturn; poorly anchored tanks may damage the hold down, damage the tank wall, and potentially slide or overturn. However, these tanks and vessels may be designed to resist seismic forces solely by friction between the tank bottom and the subgrade, if the tank meets certain restrictions. See the section on Seismic Mitigation Considerations, below.
- The shell of the tank or vessel may be damaged by fluid-structure interaction.
- Connections of supply lines or fuel lines may be damaged; contents may slosh or spill.

DAMAGE EXAMPLES



Figure 6.4.2.2-1 Damage to ductile connection at base of a 5000 cubic meter diesel fuel tank in the 2001 magnitude-8.4 Peru Earthquake. All eight connections were damaged; damage included bolt elongation, deformation of tank wall, and cracked concrete pad (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.2-2 Tank with "elephant's foot" buckle at the base in the 1964 magnitude-9.2 Anchorage, Alaska earthquake (Photo courtesy of PEER, Steinbrugge Collection, No. S2508)



Figure 6.4.2.2-3 Tank with "elephant's foot" and "elephant knee" in Port-au-Prince in the 2010 magnitude-7 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.2-4 Anchored tank damaged at base when anchorage failed; tank slid and ruptured attached piping in 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- The structural response of these tanks, especially large tanks, is influenced strongly by the fluid-structure interaction (sloshing). The magnitude of these forces depends on the geometry (height, H, to diameter, D, ratio) of the tank. See ASCE/SEI 7-10 Chapter 15, Section 15.7.6 for additional information.
- Small-diameter tanks and vessels are more susceptible to overturning and vertical buckling. As a general rule, a greater ratio of height to diameter (H/D) produces lower resistance to vertical buckling. Where H/D is greater than 2, the liquid tends to behave as a "rigid mass" and the loads due to sloshing are small.
- There are several alternatives for designing flat bottom tanks and vessels for seismic resistance
    - Provide adequate connections around the base of the tank. Do not weld to tanks with flammable contents.
    - For steel tanks, the lateral force may be resisted by friction between the tank bottom and the subgrade. See ASCE/SEI 7-10 Sections 15.7.5.5 and 15.7.6 for a description of the design approach and limitations.
- Provide flexible connections for fuel lines and piping or implement alternate measures to protect the pipe-to-tank connection.
- The detail shown is for a rigid connection; larger tanks require ductile details such as those shown in Figure 6.4.2.2-1.

MITIGATION EXAMPLES

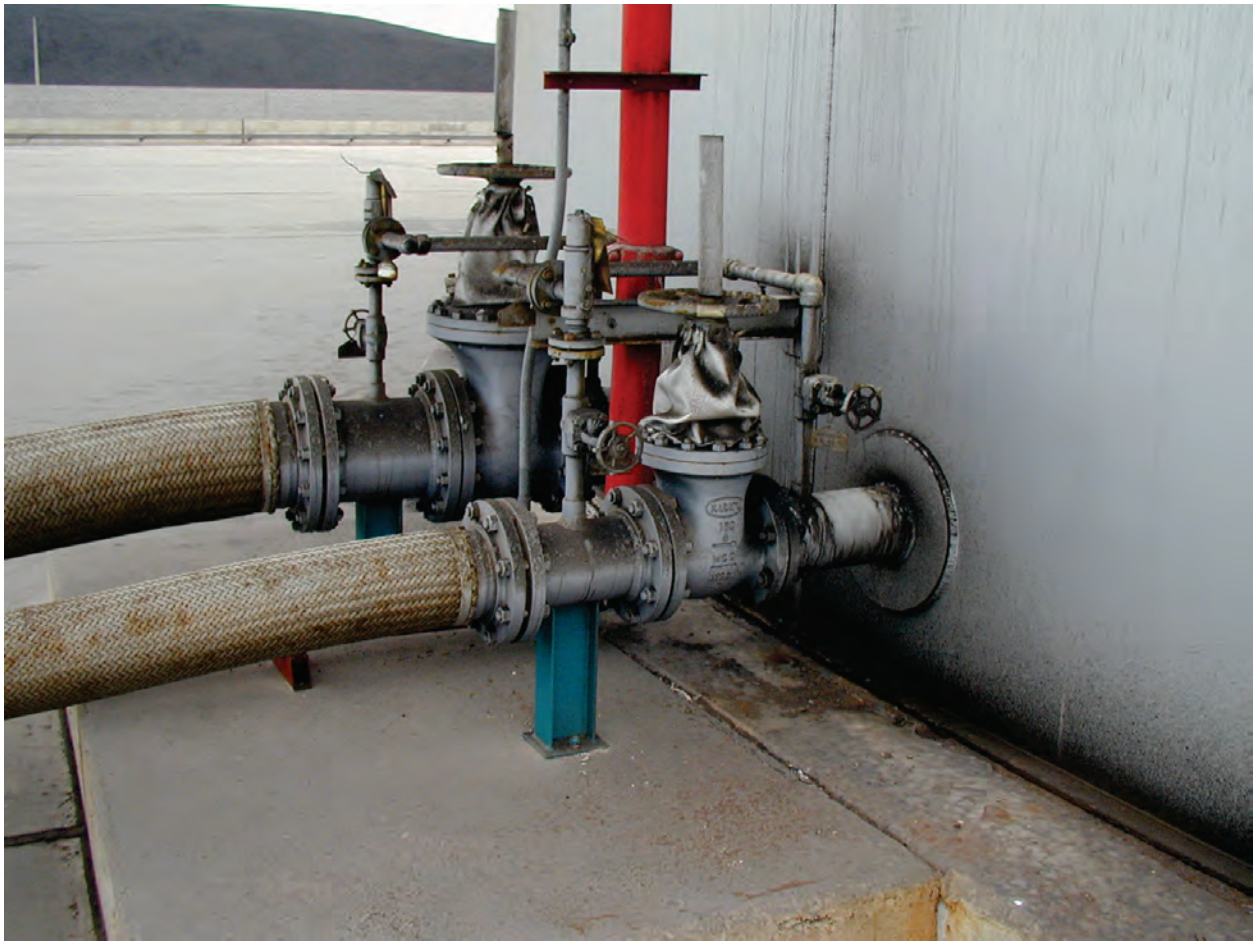


Figure 6.4.2.2-5 Flexible connections prevented piping damage in 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.2-6 Anchors at base of fiberglass reinforced plastic tank (Photo courtesy of Jeffrey Soulages, Intel).



Figure 6.4.2.2-7 Examples of rigid base anchorage for small circular tanks (Photos courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

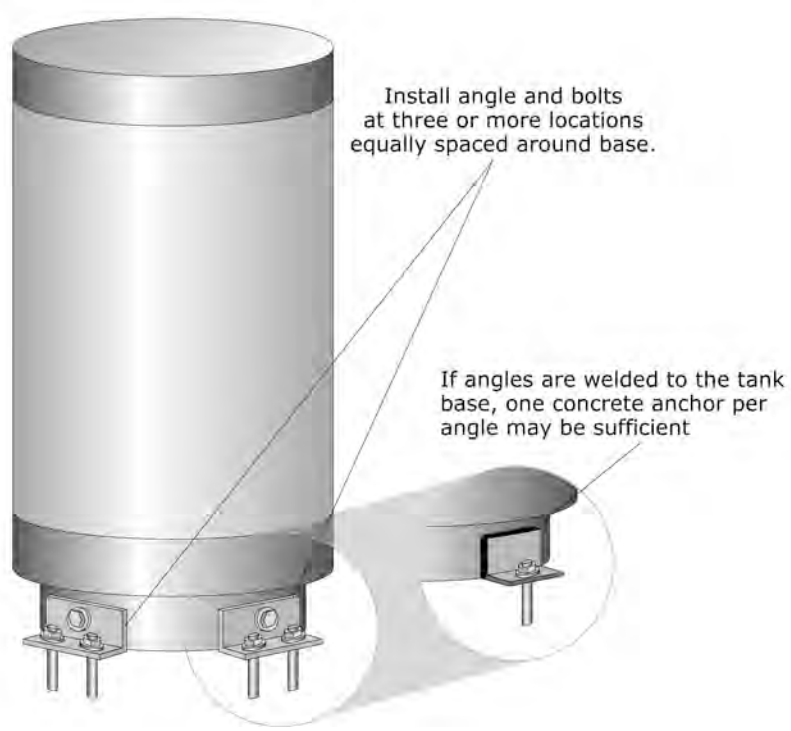


Figure 6.4.2.2-8 Flat bottom tank (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.2 Storage Tanks and Water Heaters

6.4.2.3 Compressed Gas Cylinders

This category includes single or multiple gas cylinders. These may be attached to piping, anchored to carts for mobility, or stored for future use.

Provisions

BUILDING CODE PROVISIONS

Since compressed gas cylinders are generally not permanently attached to the building utilities, they are considered "temporary or moveable equipment" and are exempt from the requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010).

When gas cylinders are connected to building utilities, ASCE/SEI 7-10 Chapter 13 requires anchorage for cylinders in Seismic Design Categories D, E, and F weighing over 400 pounds. Lighter cylinders may be exempt if the component Importance Factor $I_p = 1.0$. Cylinders that are exempt from the anchorage requirement are still required to be restrained to prevent damage between the gas cylinder and associated pipes.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings,* (ASCE, 2007) classifies compressed gas cylinders as hazardous materials storage. Anchorage of compressed gas cylinders requires compliance with the anchorage provisions of the standard when the performance level is Life Safety or higher. Prescriptive (non-engineered) anchorage approaches may be used.

Typical Causes of Damage

- Unanchored tanks may slide, overturn, and roll; connected piping may be damaged.
- Contents may be flammable or hazardous; leaking cylinders may be dangerous.
- Tank installations equipped with chains or straps are still susceptible to damage unless the chains or straps are properly secured around the tanks.

DAMAGE EXAMPLES



Figure 6.4.2.3-1 Unanchored tanks inside fenced enclosure in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of OSHPD).

Seismic Mitigation Considerations

- Wall restraint detail shown at top of Figure 6.4.2.3-8 is a non-engineered detail for tank storage; this detail does not provide sufficient restraint for tanks attached to piping.
- Engineered details with additional restraints are required for tanks attached to piping; see corral detail at bottom of Figure 6.4.2.3-7 or scheme shown in Figures 6.4.2.3-2 and 6.4.2.3-3.

MITIGATION EXAMPLES



Figure 6.4.2.3-2 Gas cylinder anchorage with attached gas lines undamaged in the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.3-3 Detail of undamaged gas cylinder installation (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.3-4 Wall-mounted cylinder restraints upgraded with stiffener plates following the 2001 Peru Earthquake(Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.3-5 Steel tube supports for mobile gas cylinder carts (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.3-6 Detail of steel tube supports and chains (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.2.3-7 Detail of enclosures for airgas tanks in a hospital; chains attached with quick release hooks (Photo courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

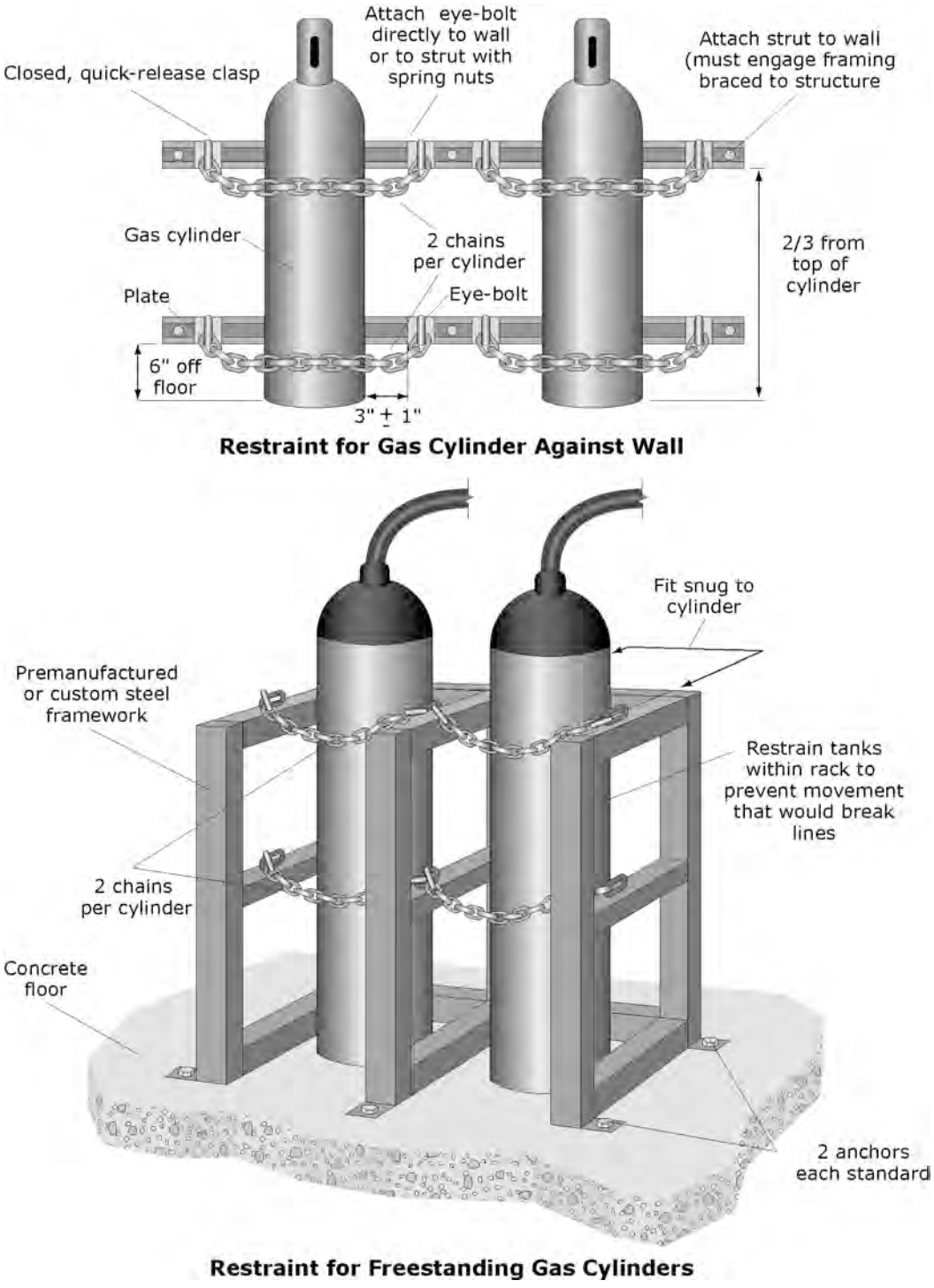


Figure 6.4.2.3-8 Compressed gas cylinders (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.2 Storage Tanks and Water Heaters

6.4.2.4 Water Heaters

This category includes residential or small commercial water heaters. Most water heaters rest on the floor although smaller units may be wall- or shelf-mounted. Tankless water heaters are often wall-mounted.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for water heaters are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The principal objective is to prevent the water heater from sliding or overturning. They may be floor mounted, wall mounted, or suspended from the level above.

- ASCE/SEI 7-10 requires anchorage design for all equipment in Seismic Design Categories D, E, and F if the equipment weighs over 400 pounds. Lighter components may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage design requirements must still be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Exempt items must also be provided with flexible connections between the equipment and associated pipes or conduits.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) contains specific requirements retrofit of water heaters. Compliance with the anchorage provisions of the standard is required when:

- The performance level is Immediate Occupancy.
- The performance level is Life Safety in High Seismicity areas and the water heater is more than 6 feet in height, or the unit is gas-fired.

Water heaters with a capacity less than 100 gallons may be retrofitted using prescriptive approaches. Larger water heaters must meet the force provisions of the standard.

Typical Causes of Damage

- Unanchored or poorly anchored tanks may slide or overturn.
- Even if the restraint is strong enough to prevent complete overturning, if it is not rigid enough, the connections to gas and water lines may be damaged by tank movement and lead to fire or to water leakage

DAMAGE EXAMPLES



Figure 6.4.2.4-1 Unanchored water heaters overturned (Photo courtesy of Mason Industries).



Figure 6.4.2.4-2 Water damage at the Talca Hospital in the 2010 magnitude-8.8 Chile Earthquake; water leaking from tank at right. This building was closed due to nonstructural damage, dominated by water damage (Photos courtesy of Bill Holmes, Rutherford & Chekene).



Figure 6.4.2.4-3 Damaged water heater in the 2010 magnitude-6.5 Eureka Earthquake. The water heater strap pulled out from the supporting concrete wall as a result of inadequate anchorage. The tank moved sufficiently to break interconnected water lines which were rigidly connected to the tank.

Seismic Mitigation Considerations

- Details shown are for tanks resting on the floor adjacent to a structural wall. Where the water heater is not located adjacent to a wall, it may be necessary to construct a frame around the tank or adjacent to the tank to provide anchorage.
- Flexible connections should be provided for the gas and water lines.
- Provide noncombustible spacers between the tank and wall for older units; newer units often have insulation inside the housing as part of the assembly and do not require the additional spacers.
- Larger tanks may be floor-mounted as shown for flat bottom tanks in Section 6.4.2.2 or as pictured in Figure 6.4.2.4-5.
- See also *Guidelines for Earthquake Bracing of Residential Water Heaters* (California Department of General Services, 2005c) online at www.documents.dgs.ca.gov/dsa/pubs/**waterheaterbracing_11_30_05**.pdf for additional information.

MITIGATION EXAMPLES



Figure 6.4.2.4-4 Corner installation using a commercially available strap; note flex copper tubing for water hook up (Photo courtesy of Cynthia Perry, BFP Engineers).



Figure 6.4.2.4-5 Base-mounted water heater located in a school; equipment supplied with metal base for mounting (Photo courtesy of EQE for the Salt Lake City School District).

MITIGATION DETAILS

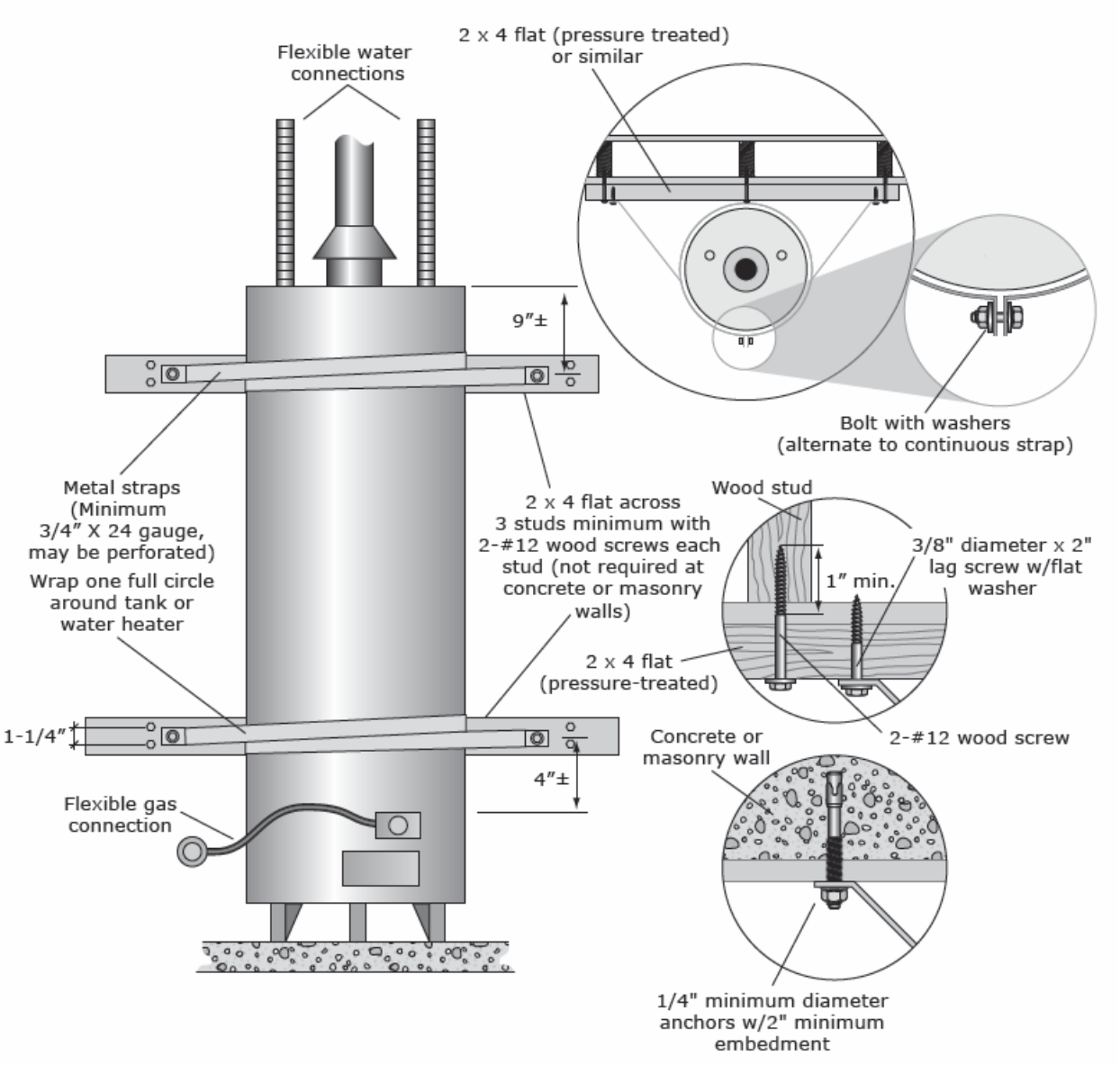


Figure 6.4.2.4-6 Water heater (PR).

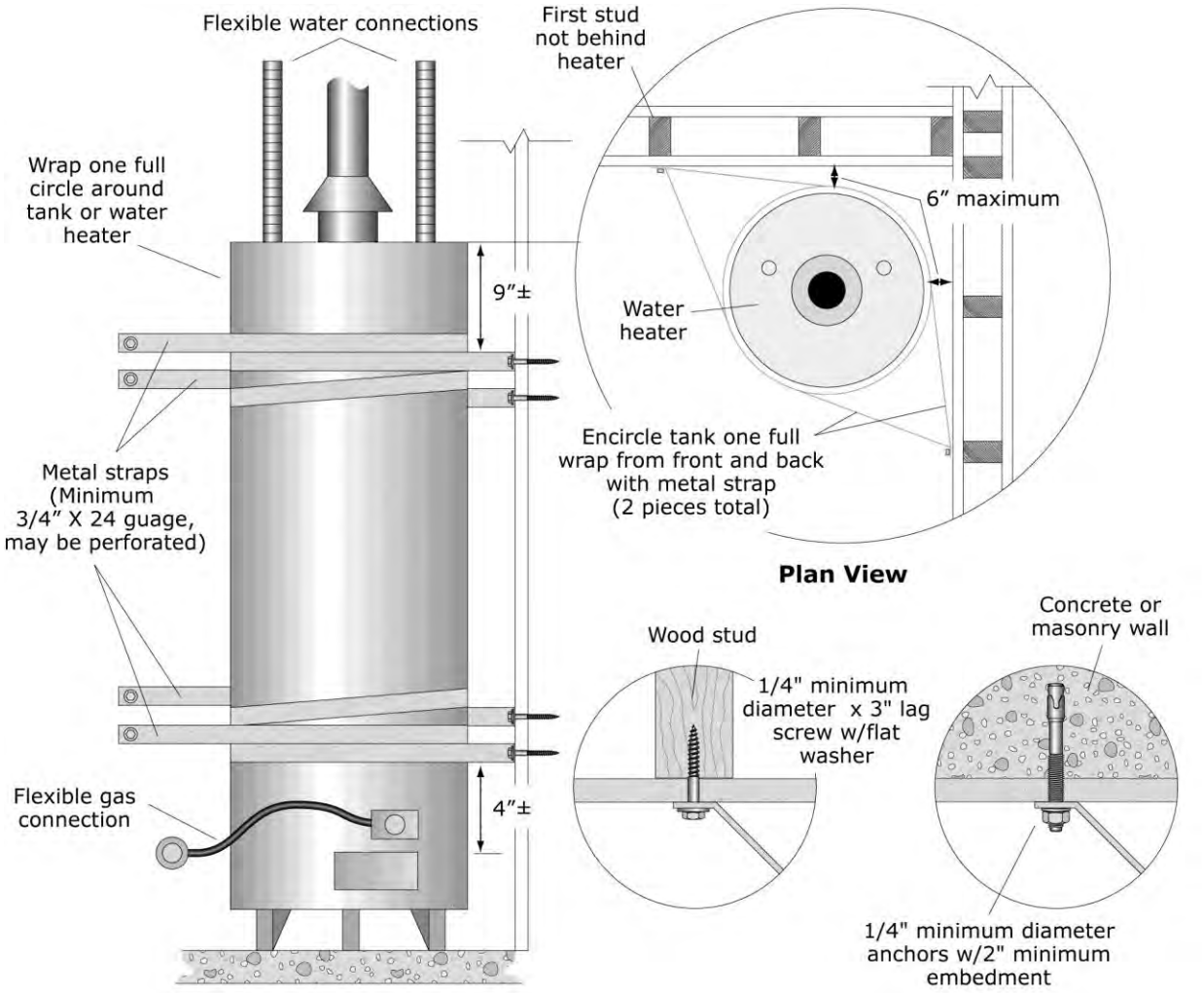


Figure 6.4.2.4-7 Water heater - corner installation (PR).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.3 Pressure piping

6.4.3.1 Suspended Pressure Piping

There are many types of piping systems which convey a wide variety of fluids and gases in and around buildings. In this section, pressure piping refers to "all piping (except fire suppression piping) that carries fluids which, in their vapor stage, exhibit a pressure of 15 psi, gauge, or higher." See Sections 6.4.4 and 6.4.5 for other piping categories. This example addresses seismic restraint details for suspended piping; see Sections 6.4.3.2 through 6.4.3.8 for other types of piping system restraints as shown in Figure 6.4.3.1-10.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for suspended pressure piping are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The principal objective is to prevent the system from falling. Depending on the configuration of the piping, it may also be sensitive to building displacements if it is connected to multiple levels in the same structure, or is supported by adjacent structures.

- ASCE/SEI 7-10 exempts suspended pressure piping from seismic bracing requirements in Seismic Design Category C if $I_p = 1.0$.
- ASCE/SEI 7-10 requires seismic design for all distribution systems in Seismic Design Categories D, E, and F that weighs more than 5 pounds per linear foot.
- Unbraced piping attached to in-line equipment must be provided with flexibility adequate to accommodate seismic relative displacements.
- Pressure piping systems, including their supports, may be designed either using the provisions of ASME B31 *Process Piping* (ASME, 2008) or ASCE/SEI 7-10. If ASME B31 is used, the forces and displacements of ASCE/SEI 7-10 must be used for design. See Section 6.4.4 for issues related to fire protection piping systems.
- ASCE/SEI 7-10 contains a number of bracing exemptions for suspended piping:
    - Trapeze assemblies are used to support piping whereby no single pipe exceeds certain size limits and the total weight of the piping supported by the trapeze assemblies is less than 10 lb/ft

  - Suspended piping where the hangers are less than 12 inches long. Rod hangers must be detailed to prevent bending of the rod.
  - High-deformability or limited deformability piping (such as steel and copper pipe) where the pipe diameter is small (anywhere from 1- to 3-inch diameter depending on the Seismic Design Category and occupancy). Provisions must be made to accommodate anticipated movement (such as by providing flexible connections, as shown in Section 6.4.3.3) and to avoid impact with other structural or nonstructural components or to protect the piping in the event of such impact
- Allowable stresses are provided in ASCE/SEI 7-10 for suspended pressure piping that is not design to ASME B31 or other approved material standards or design bases.

RETROFIT STANDARDS PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies suspended pressure piping as force controlled, meaning that the principal objective is to prevent the piping from falling. Where piping runs between floors or crosses seismic joints it as also deformation controlled. Suspended pressure piping must meet the force and deformation requirements of the standard.

- For suspended pressure piping, ASCE/SEI 41-06 requires compliance with the anchorage provisions of the standard when the performance level is Life Safety or higher.
- Rehabilitation may utilize prescriptive standard.

Typical Causes of Damage

- Improperly supported pipes can become dislodged and fall.
- Pipes are particularly vulnerable to damage at joints, bends, penetrations through walls or structural members, and connections to equipment.
- Unbraced piping can sway and impact adjacent items.
- Piping may be damaged as a result of differential movement between points of attachment.
- Fluids may leak from damaged joints or broken pipe; property losses and business outages are often attributed to fluid leaks from piping.

DAMAGE EXAMPLES

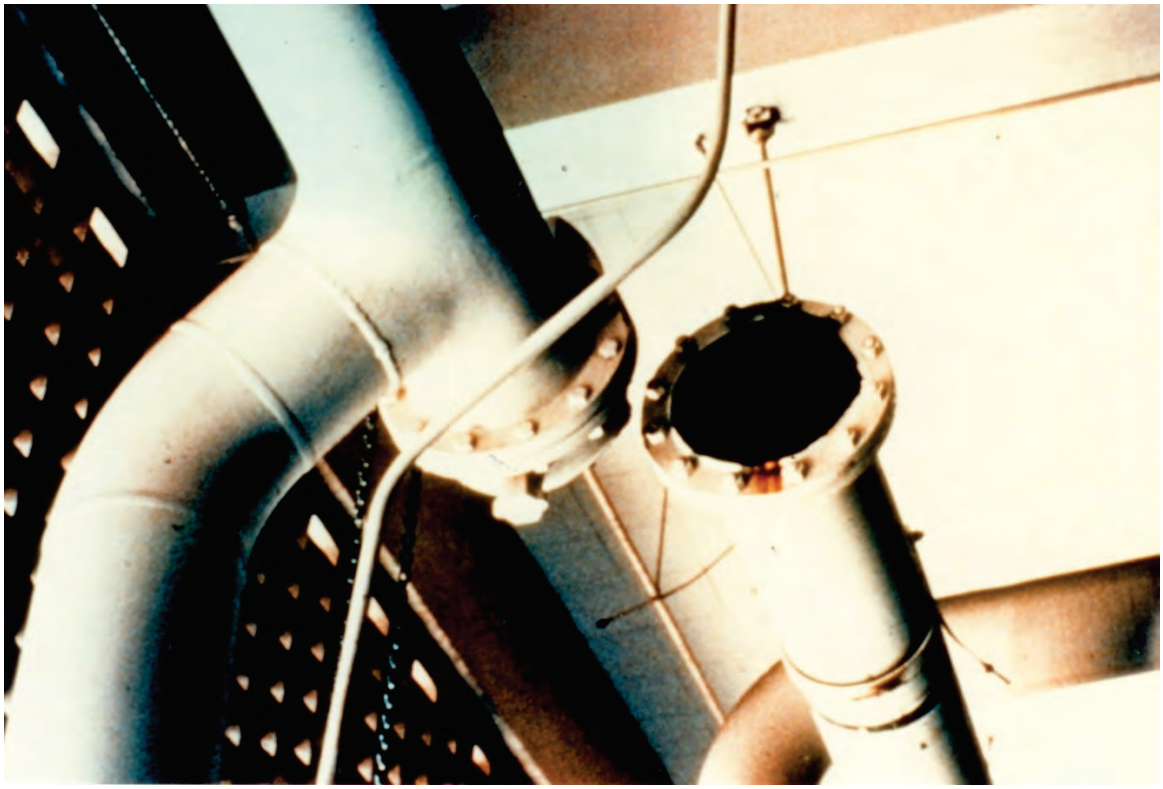


Figure 6.4.3.1-1 Pipe joint failure in the 1971 magnitude-6.6 San Fernando Earthquake (Photo courtesy of John F. Meehan).

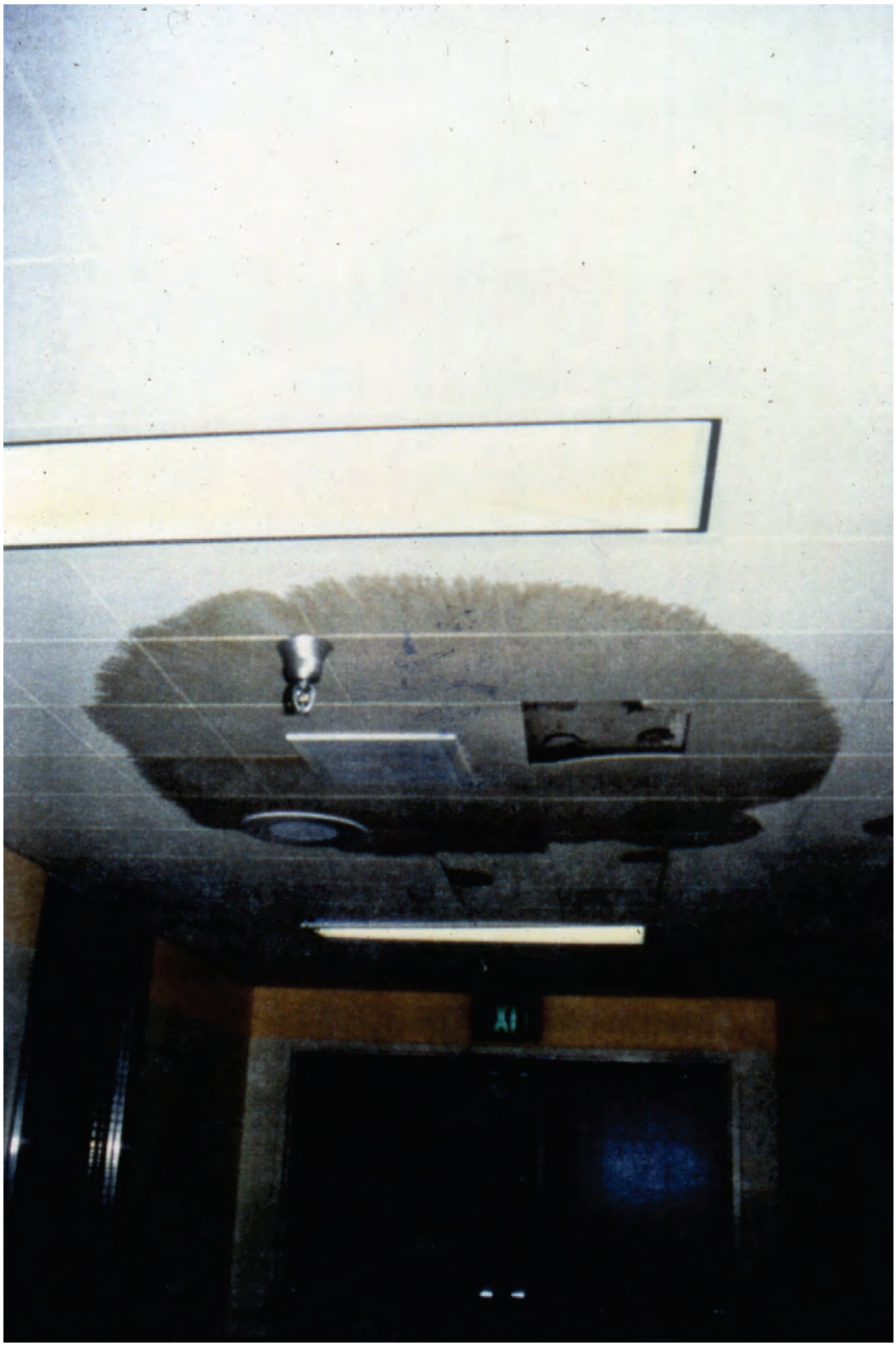


Figure 6.4.3.1-2 Leakage caused by pipe damage at joint in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Degenkolb Engineers).



Figure 6.4.3.1-3 Pipe brace failed at connection in 1994 Northridge Earthquake; insulation removed prior to photo (Photo courtesy of Mason Industries).

Seismic Mitigation Considerations

- Details shown are for overhead attachments for suspended piping. Seismic detailing for pipes requires both transverse and longitudinal braces; while these are shown here as separate details, both types of bracing are required. The spacing of pipe bracing is dependent on the level of seismicity, location in a building, size of the pipe, type of pipe, and strength of connections to the structure.
- Many vendors supply specialized hardware used for the seismic anchorage or sway bracing of piping systems. These vendors offer a wide variety of products and services including design, installation and inspection manuals, load tables, load rated hardware, spring loaded hangers, couplers and fittings, pipe dampers, preassembled seismic bracing kits, AUTOCAD details, calculation packages, and technical support.
- Longitudinal pipe bracing requires the use of a pipe clamp, riser clamp, welded lug or device that provides positive attachment to the pipe and will not slip along the length of the pipe. Longitudinal pipe supports should not rely on friction connections such as U-bolts as these do not provide reliable longitudinal restraint during an earthquake and are likely to slip. Some vendors have items with names such as “seismic pipe clamp” or “longitudinal restraint device” that are intended for use with longitudinal restraints.
- Virtual Design and Construction (VDC) and Building Information Models (BIM) involve the development of 3D computer models depicting all the structural and many nonstructural components of buildings. Increasing use of these 3D models that incorporate all the MEP systems will facilitate the design and coordination of these components with the structural system and other nonstructural components. An example of a BIM model with piping and pipe supports is shown in Figure 6.4.3.1-9.
- Piping systems are typically combinations of horizontal and vertical runs of pipe; vertical runs are often called risers. Pipes may be suspended overhead as shown in this example or floor-mounted, roof-mounted, or wall-mounted. Flexible connections are often required at fixed equipment or where piping crosses an expansion joint or seismic separation. Pipe runs also typically include penetrations through floor slabs, roof slabs, and walls or structural framing. Details for many restraint conditions can be found in FEMA 414 *Installing Seismic Restraints for Duct and Pipe (2004).* Some of these conditions are shown in Sections 6.4.3.2 through 6.4.3.8 (See Figure 6.4.3.1-11).

MITIGATION EXAMPLES

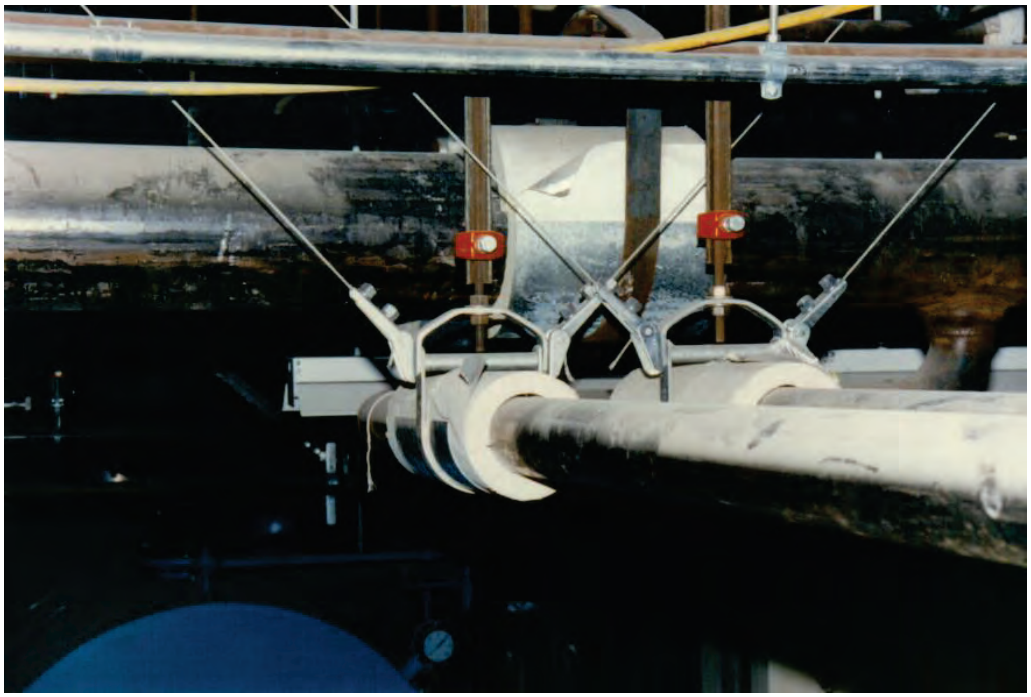


Figure 6.4.3.1-4 Single clevis hanger support with transverse cable bracing at the restraining bolt (Photo courtesy of Mason Industries).



Figure 6.4.3.1-5 Pipe clamp supports with transverse and longitudinal angle braces; note pipe clamp for longitudinal brace in direct contact with pipe (Photo courtesy of Mason Industries).



Figure 6.4.3.1-6 All-directional cable bracing of suspended piping (Photo courtesy of ISAT).



Figure 6.4.3.1-7 Transverse bracing with J-hanger and strut at the restraining bolt. Note that longitudinal brace shown is ineffective because the J-hanger can slip along the length of the pipe; a pipe clamp or equivalent is required for a longitudinal brace (Photo courtesy of Cynthia Perry, BFP Engineers).



Figure 6.4.3.1-8 Viscous damper used as restraint on large insulated pipe (Photo courtesy of Eduardo Fierro, BFP Engineers).

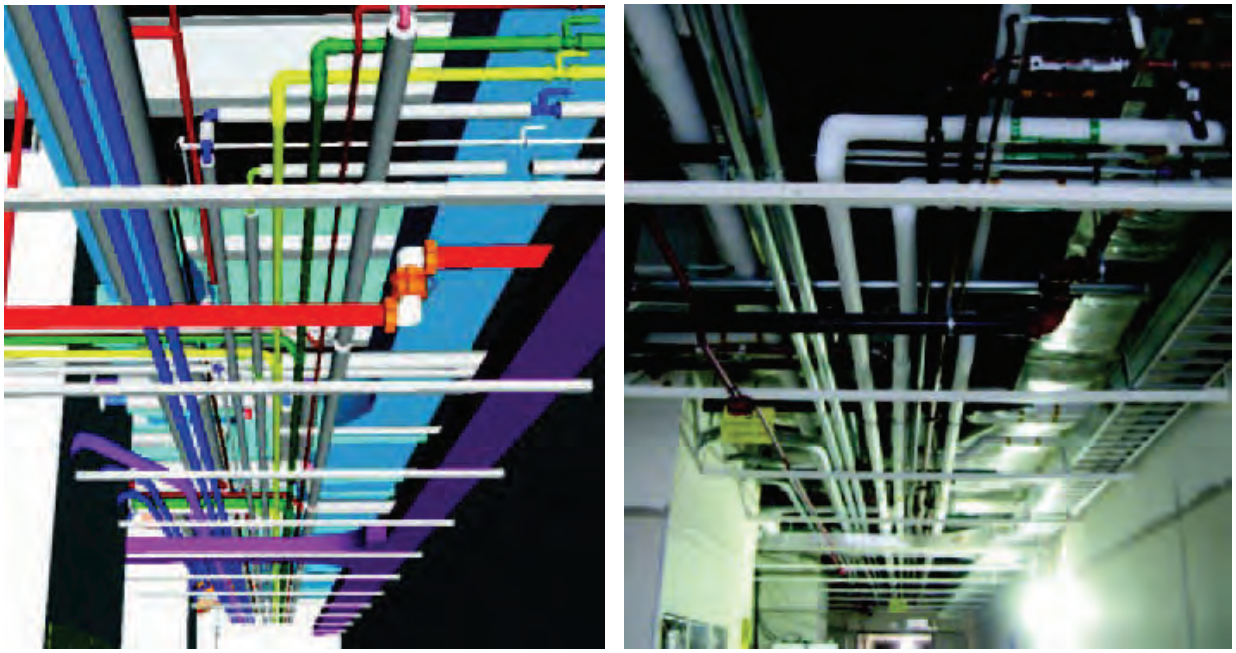


Figure 6.4.3.1-9 Example of BIM Model (left) compared to installed piping (right) (Photo and image courtesy of ISAT).

MITIGATION DETAILS

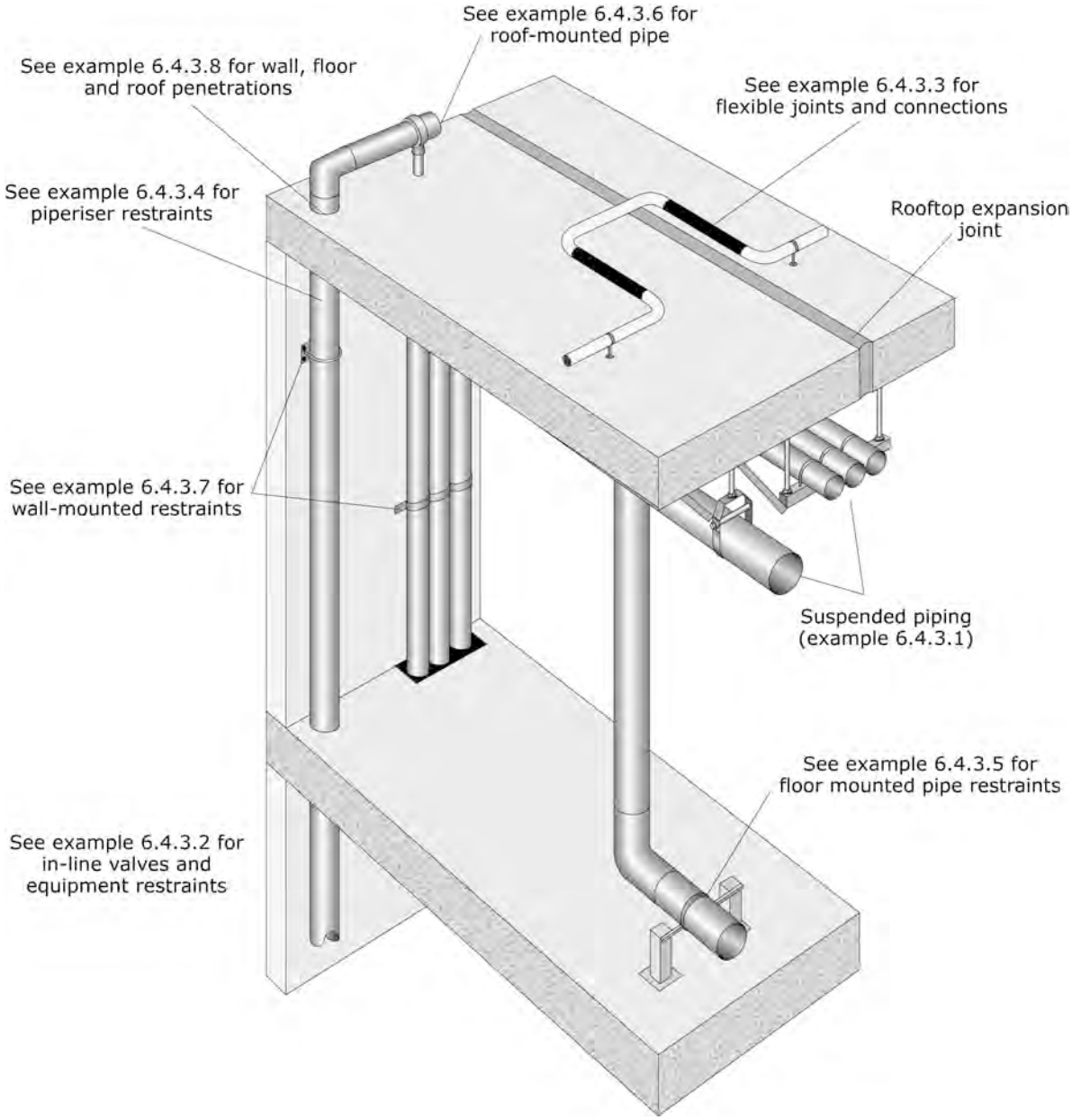


Figure 6.4.3.1-10 Schematic of seismic restraint conditions for piping (ER)

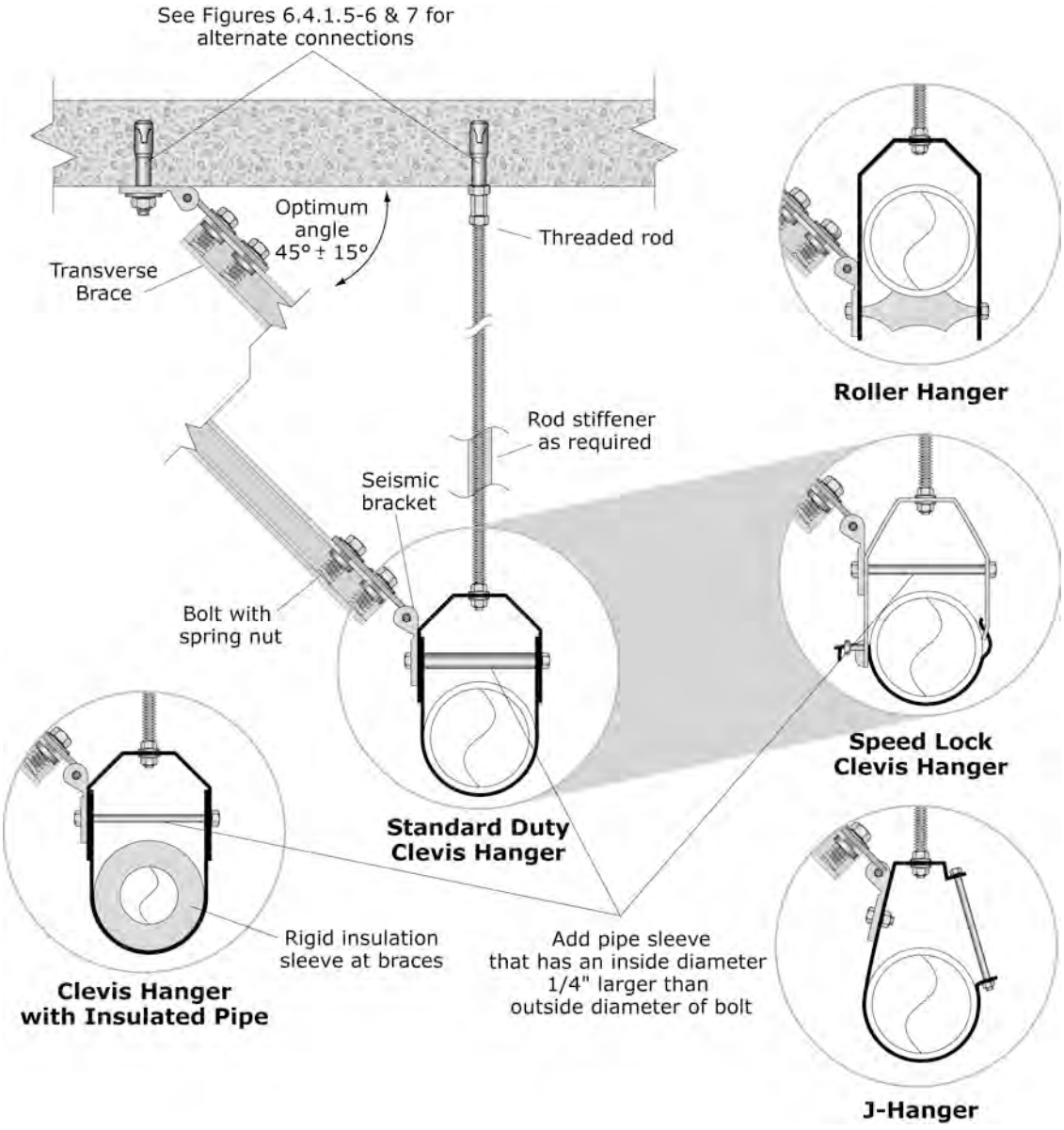


Figure 6.4.3.1-11 Rigid bracing - single pipe transverse (ER). Note that insulated pipes need special rigid insulation sleeves at hangers and braces to prevent compression of the insulation.

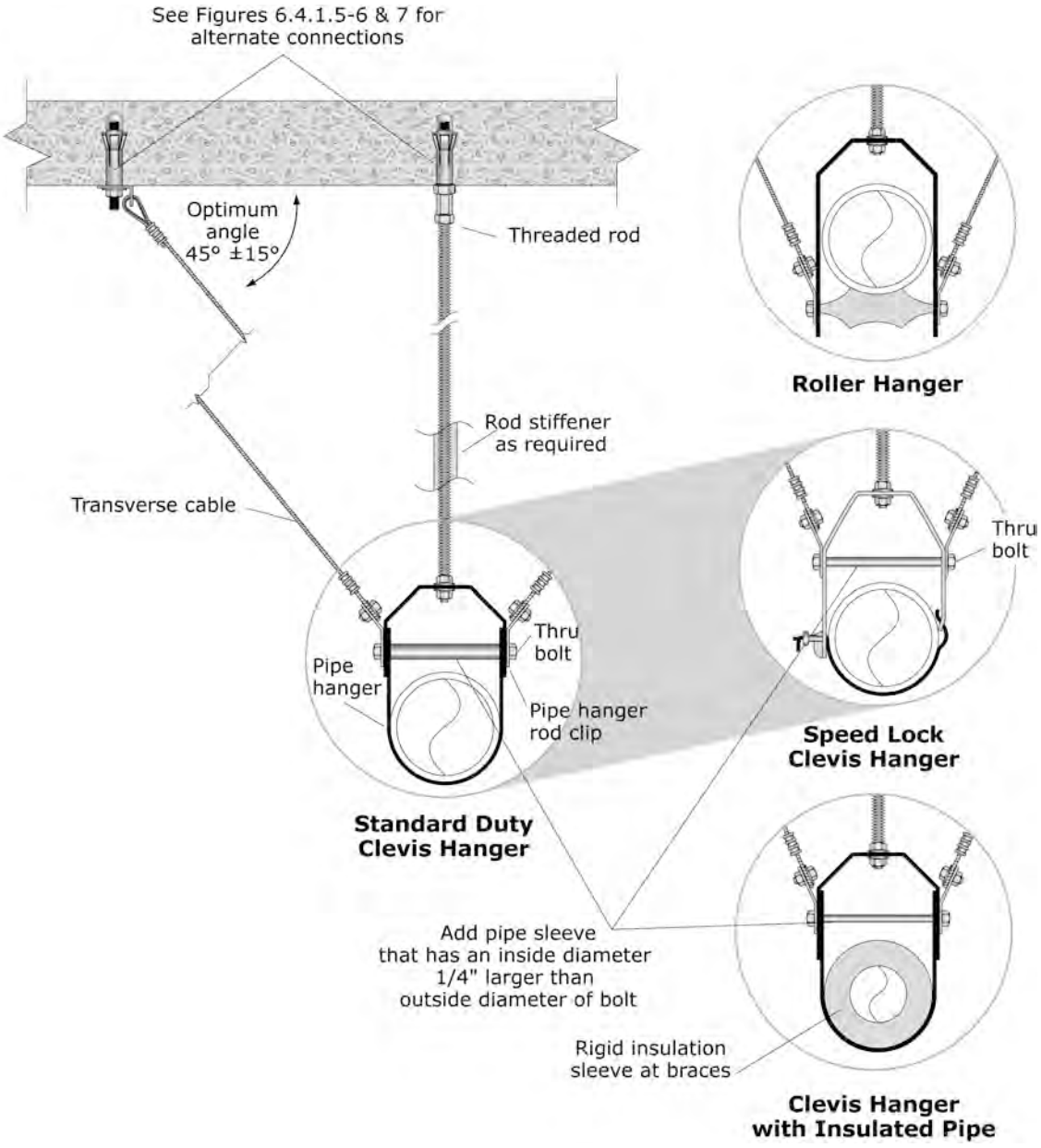


Figure 6.4.3.1-12 Cable bracing - single pipe transverse (ER). Note that insulated pipes need special rigid insulation sleeves at hangers and braces to prevent compression of the insulation.

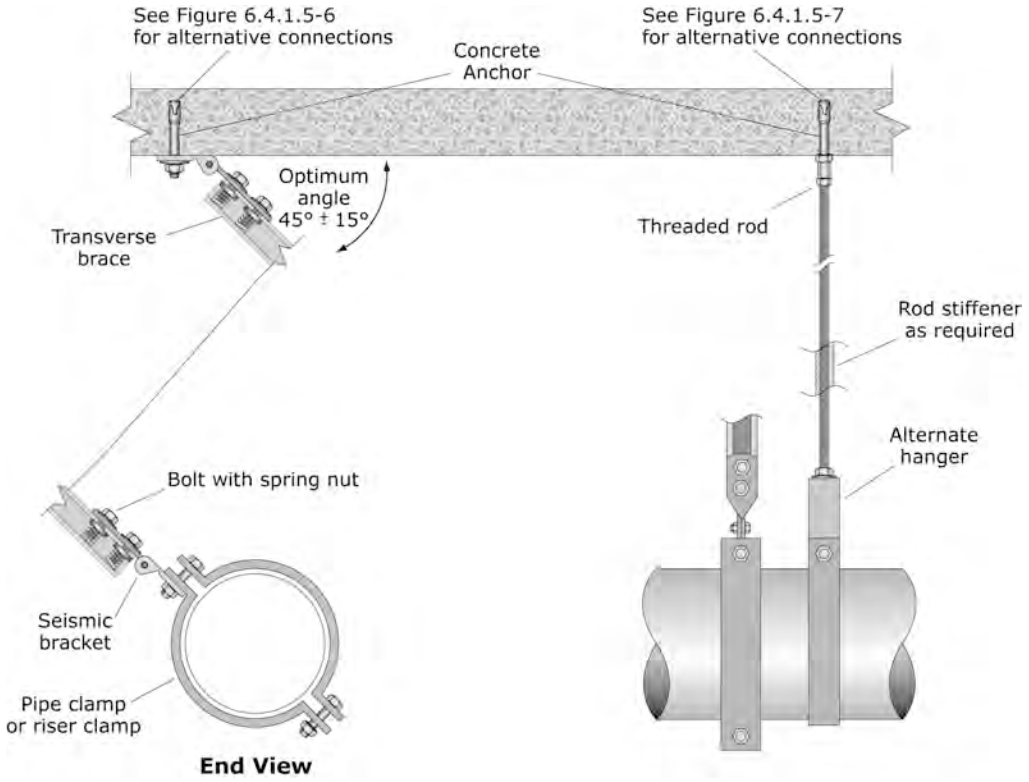


Figure 6.4.3.1-13 Rigid bracing - single pipe alternate transverse (ER).

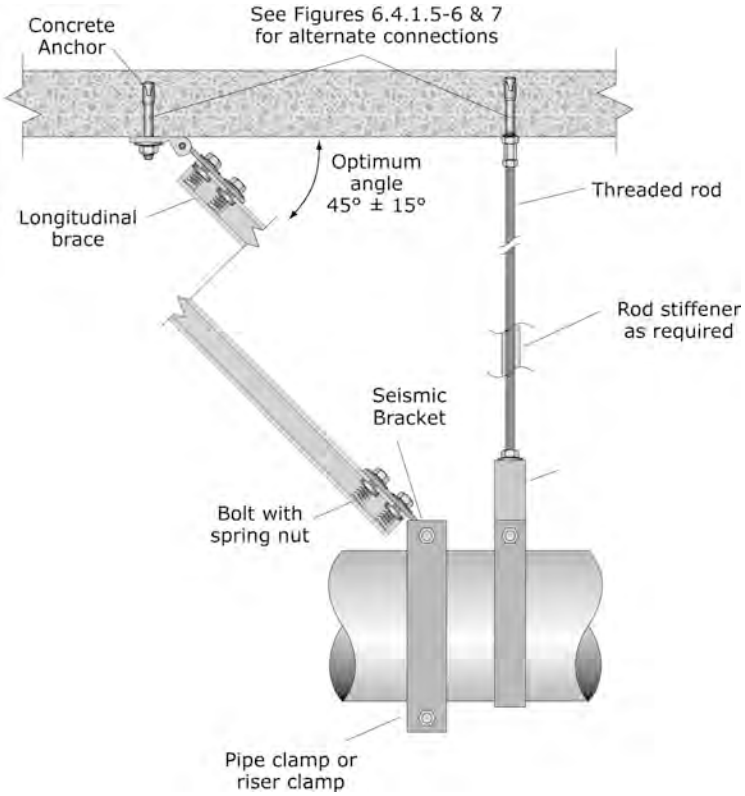


Figure 6.4.3.1-14 Rigid bracing - single pipe longitudinal (ER).

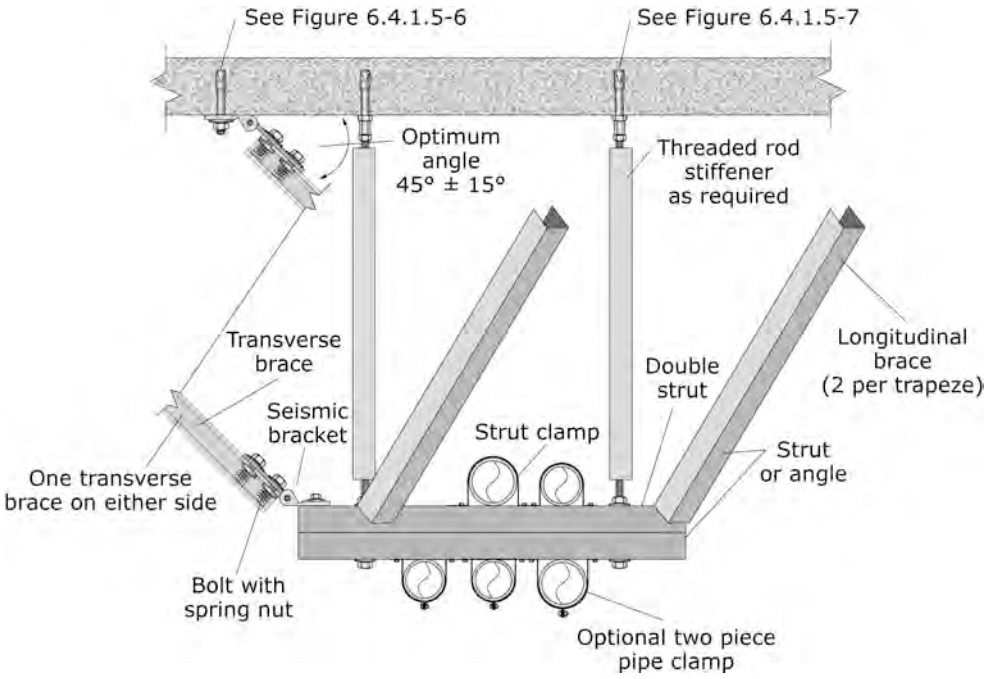


Figure 6.4.3.1-15 Rigid bracing - Trapeze supported piping (ER).

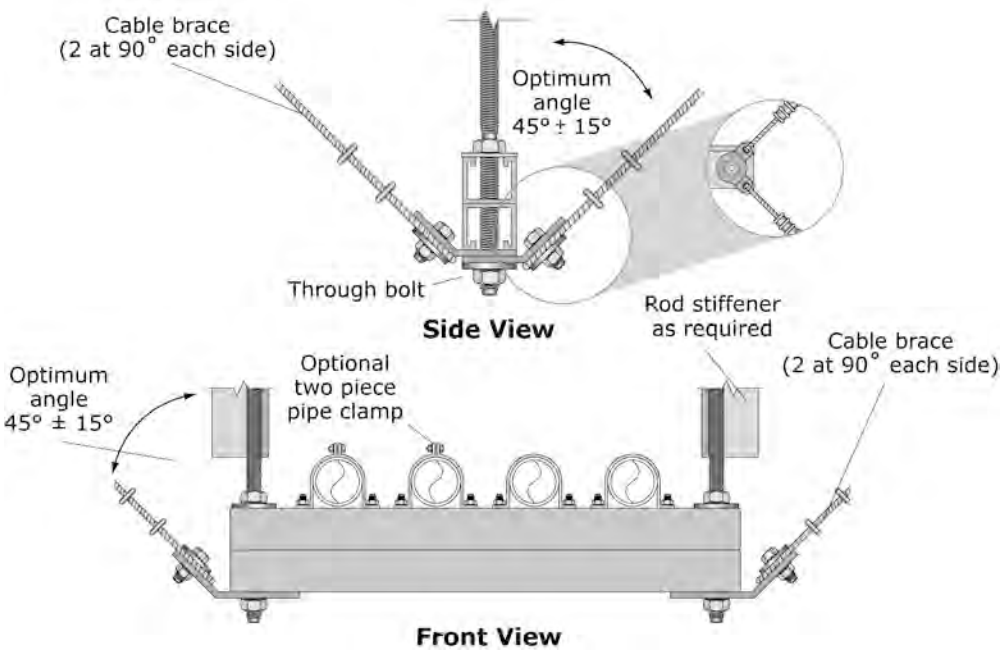


Figure 6.4.3.1-16 Cable bracing - Trapeze supported piping (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.3 Pressure Piping

6.4.3.2 In-Line Valves and Pumps

This category covers equipment that is in-line with pressure piping. These items may be valves or pumps and may be suspended, floor-mounted, roof-mounted, or wall-mounted. They may be mounted with or without vibration isolation.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for equipment that is in-line with pressure piping are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The principal objective of the code provisions is to prevent the component from falling, sliding or overturning. The design approach is dependent on the mounting configuration of the in-line equipment.

- Seismic loads for suspended in-line pumps are determined using the ASCE/SEI 7-10, design coefficients for pumps, not piping. Pumps must be independently supported for gravity loads. Pumps in Seismic Design Categories D, E, and F weighing 20 pounds or less do not require lateral bracing if the component Importance Factor $I_p = 1.0$.
- Seismic loads for suspended in-line valves are determined using the ASCE/SEI 7-10, design coefficients for piping. Design coefficients may be reduced based on the construction of the valve. For example, in a steel piping system the in-line valves may be cast iron, increasing the design seismic load by at least 50 percent. Valves should be independently supported for gravity load if they weigh more than 20 pounds. Valves weighing 20 pounds or less do not require lateral bracing if the component Importance Factor $I_p = 1.0$ for the piping system.
- In-line valves and pumps in Seismic Design Categories D, E, and F that are mounted at 4 ft (1.22 m) or less above a floor level and weigh less than 400 pounds or less do not require lateral bracing if the component Importance Factor $I_p = 1.0$ for the piping system.
- Items that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or

detailed on the construction documents. Flexible connections between the equipment and associated pipes, or conduits must be provided.

- Unbraced piping attached to in-line equipment must be provided with flexibility adequate to accommodate seismic relative displacements.
- The seismic design force for vibration isolated pumps is doubled if the "air gap" (the distance between the equipment support frame and the restraint) is greater than 0.25 inches.

RETROFIT STANDARD PROVISIONS

In ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) equipment that is in-line with pressure piping classified as force controlled, meaning that the principal objective is to prevent the component from falling if suspended, or sliding or overturning if floor-mounted. ASCE/SEI 41-06 requires compliance with the anchorage provisions of the standard when:

- The performance level is Immediate Occupancy.
- The performance level is Life Safety in high seismicity areas, if
  - The item is part of an emergency power system.
  - The items weighs more than 400 pounds and is 6 feet or more in height,].
  - The item is unanchored, weighs over 100 pounds, is 6 feet or more in height, and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 against overturning when design loads are applied.
  - The item weighs over 20 pounds and is mounted over 4 feet above the floor.

Typical Causes of Damage

- Poorly restrained in-line valves or equipment may fall. Pumps may be damaged if not properly restrained; these items may slide or fall. Movement of the in-line equipment may result in damage to the attached piping at the connection or at adjacent pipe joints. Equipment or piping damage may result in leaks.

Seismic Mitigation Considerations

- Details shown are for overhead restraints for items in-line with suspended piping. Generally, seismic restraint in the form of typical pipe bracing is provided on each side of the connected item.

- Details for other conditions such as equipment in-line with floor- or wall-mounted piping can be found in FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004). Section 6.4.1.5 also includes general details for suspended equipment.
- Many vendors supply specialized hardware for seismic anchorage of piping including load rated anchorage assemblies, spring loaded hangers, and pipe dampers.
- In-line pumps on vibration isolators require special consideration.
    - Although the code exempts smaller pumps on vibration isolators from bracing requirements, even small pumps should be carefully evaluated, since vibration isolators tend to amplify the seismic response of the component.
    - The "air gap", or distance between the snubber and the pump should be limited to less than 0.25 inches, to avoid significant dynamic amplification when the pump contacts the snubber.
    - Metal-to-metal contact between snubbers and the supporting frame, or the isolator housing and the mounting bolt to the pump, should be avoided. The snubbers should have an elastomeric or resilient surface to lessen the impact effects during strong shaking. For housed springs, an elastomeric grommet will prevent hard surface impact.
    - Flexible connections should be provided for conduit and piping.

MITIGATION EXAMPLES



Figure 6.4.3.2-1 Inline pump mounted on independent concrete inertia pad with vibration isolation and seismic snubbers (Photo courtesy of Mason Industries).

MITIGATION DETAILS

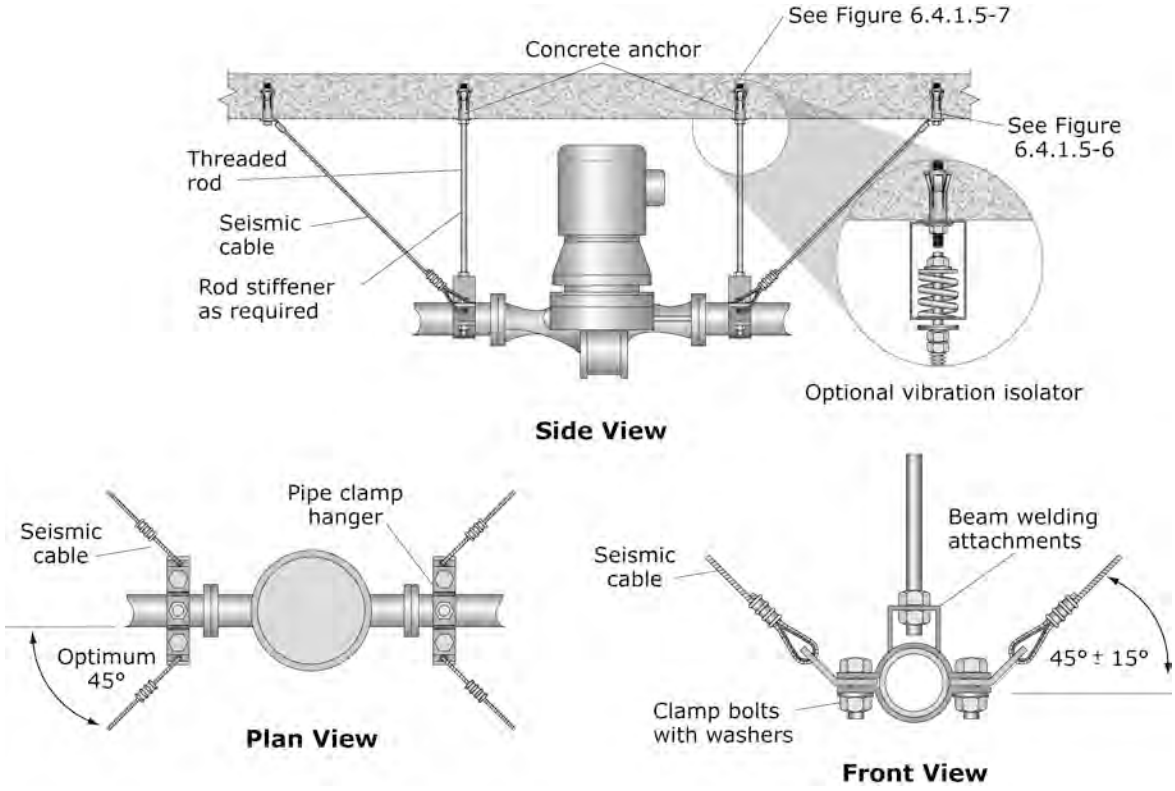


Figure 6.4.3.2-2 In-line valves and pumps (ER).

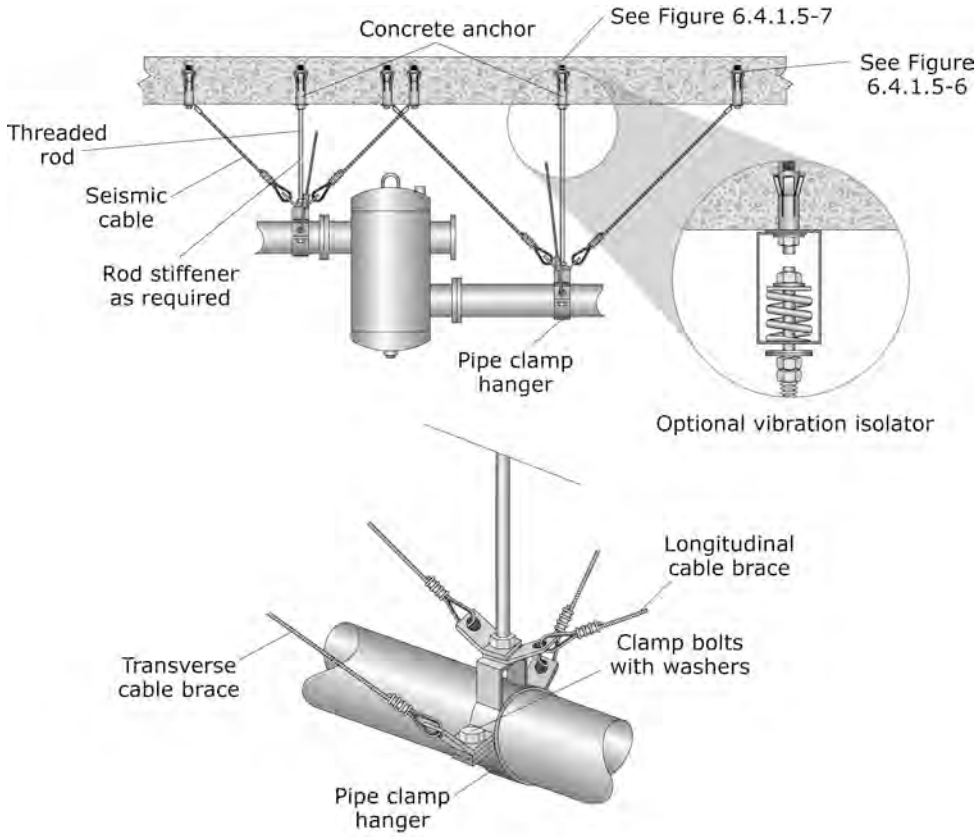


Figure 6.4.3.2-3 In-line valves and pumps (ER).

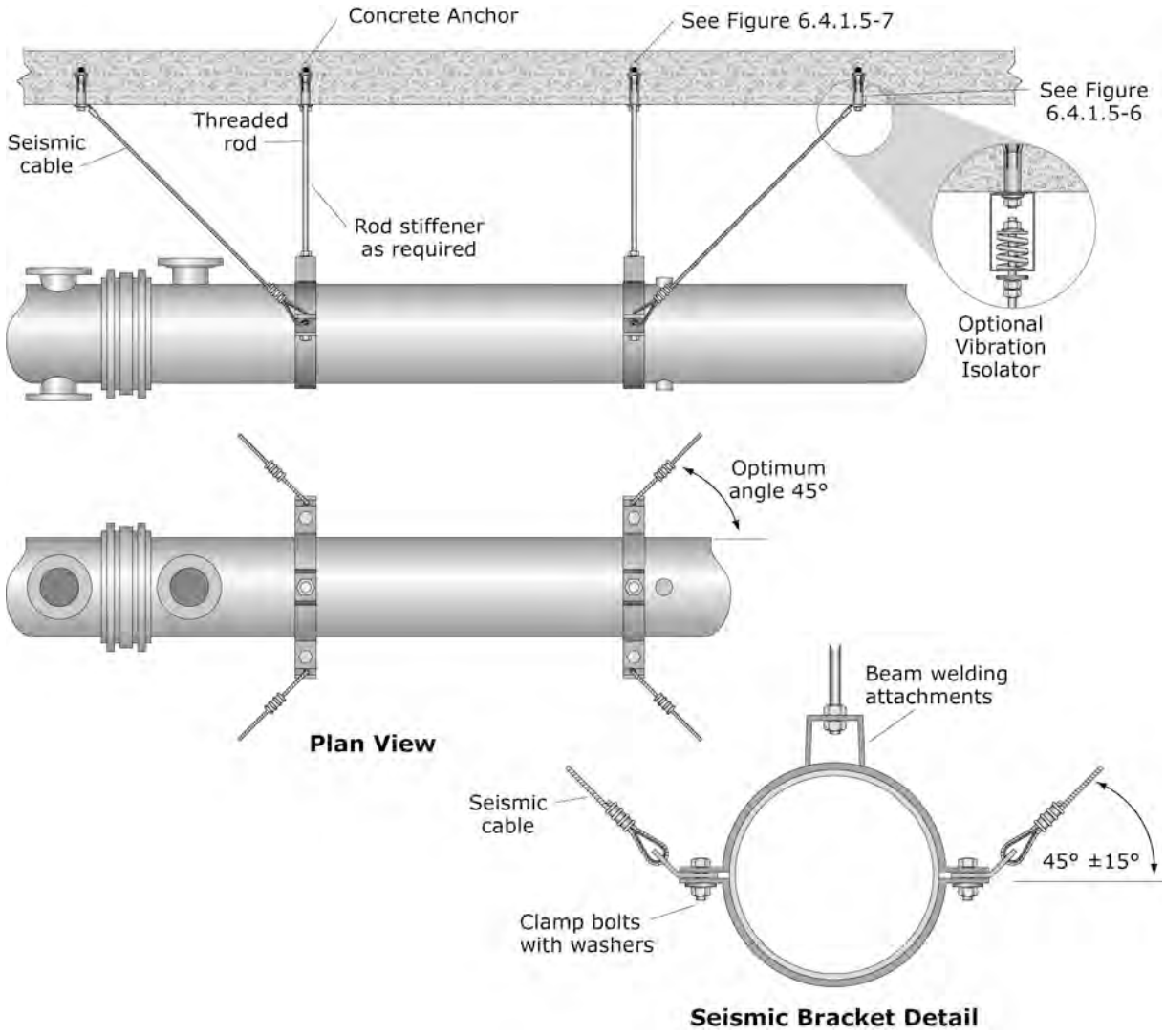


Figure 6.4.3.2-4 In-line valves and pumps (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.3 Pressure piping

6.4.3.3 Flexible Connections, Expansion Joints, and Seismic Separations

This category covers the flexible piping connections required to accommodate differential movement at seismic separations between buildings or between floors, at the interface between piping and equipment, or to accommodate thermal expansion.

Provisions

BUILDING CODE PROVISIONS

Displacement demands for flexible connections are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13. The objective is to provide sufficient capacity to accommodate the design building drifts without failure.

- Flexible connections are required between unbraced distribution systems (pipes, ducts, raceways, conduit, etc.) and braced equipment, braced distribution systems and unbraced equipment, and equipment that is supplied by distribution systems supported by the level above the component (drops).
- When equipment is supplied by drops, the length of the pipe, duct, conduit, or raceway that must accommodate the drift may be substantially less than the story height. For example, a floor mounted boiler, (which can be idealized as a rigid body) is supplied by pipes dropping from the floor level above. When the building displaces laterally, all the story drift must be accommodated by the pipe drops over the distance between the top of the boiler and the piping suspended from the floor above.
- At expansion and seismic separation joints, the distribution system must be able to accommodate the displacements between structures. Since the structures can move independently in any direction (towards each other, away from each other, etc.), the minimum and maximum displacements must be determined. Distribution systems crossing at expansion and seismic separations joints must accommodate movements that compress, extend, and shear the system crossing the joint.

RETROFIT STANDARD PROVISIONS

Flexible connections are considered deformation and acceleration sensitive in ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007). Flexible connections must be capable

of accommodating the required relative displacements. Detailed requirements depend upon the nature of the piping (or other distribution) system. Refer to the discussions of different distribution systems for more specific information.

Typical Causes of Damage

- Differential movement between adjacent buildings or adjacent wings of buildings can cause damage to interconnected piping if relative movement has not been specifically accounted for. Differential movement between the fixed and base isolated portions of buildings can damage piping crossing the isolation plane. Failure to accommodate seismic displacements can rupture piping.
- Differential movement between anchored or restrained equipment and attached piping can cause damage to the equipment, the piping, or both.

DAMAGE EXAMPLES

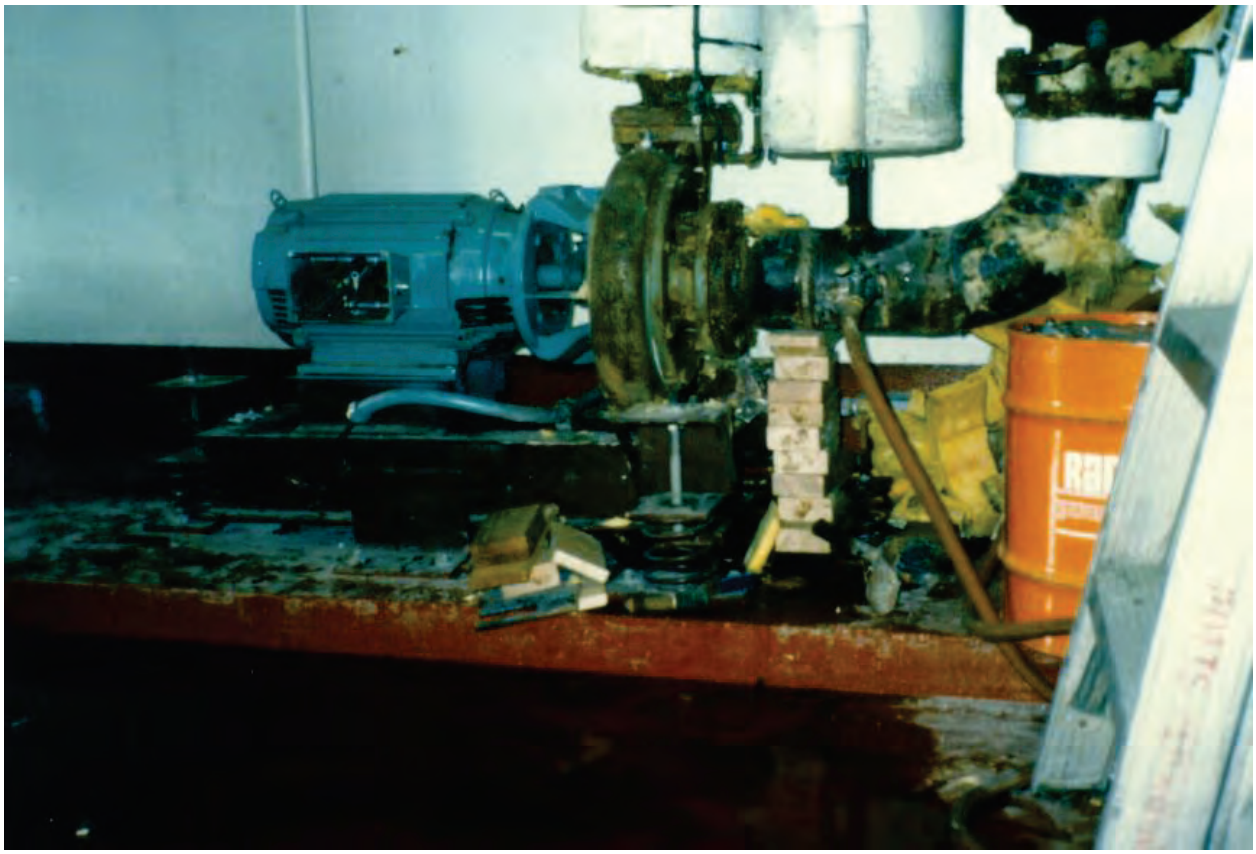


Figure 6.4.3.3-1 Failure at rigid connection to equipment on isolators without lateral restraint in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries).

Seismic Mitigation Considerations

- Flexible couplings are needed to accommodate relative displacement in a pipeline. Locations that may require flexible couplings include connections between piping and anchored equipment, wall or slab penetrations, seismic joints between buildings, and seismic joints in base isolated buildings. Selection of a specific coupling detail will depend on the magnitude of the anticipated relative displacements, the diameter of the pipe, and the type of pipe and its location.
- It is usually preferable for piping to be detailed to accommodate seismic relative displacements between the first seismic support upstream or downstream from connections to other seismically supported components or headers. This is preferably achieved by means of pipe flexibility or, where this is not possible, flexible supports. Piping not otherwise detailed to accommodate such seismic relative displacements must be provided with connections having sufficient flexibility in the connecting element or in the component or header to avoid failure of the piping. The option to use a flexible connecting element may be less desirable due to the need for greater maintenance efforts to ensure continued proper function of the flexible element.Several different types of flexible connections are shown; details for other conditions including floor and roof penetrations can be found in FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004). Many vendors supply specialized hardware to create articulated joints or flexible tubing for these applications.
- Connections must provide sufficient flexibility to accommodate the expected differential movement in all directions.
- It is generally good seismic resistant design practice to provide a flexible connection between piping and equipment.

MITIGATION EXAMPLES



Figure 6.4.3.3-2 Examples of flexible couplings that performed well in the 2010 magnitude-7 Haiti Earthquake; the building suffered relatively minor damage (Photo courtesy of Tom Sawyer, Engineering News Record).

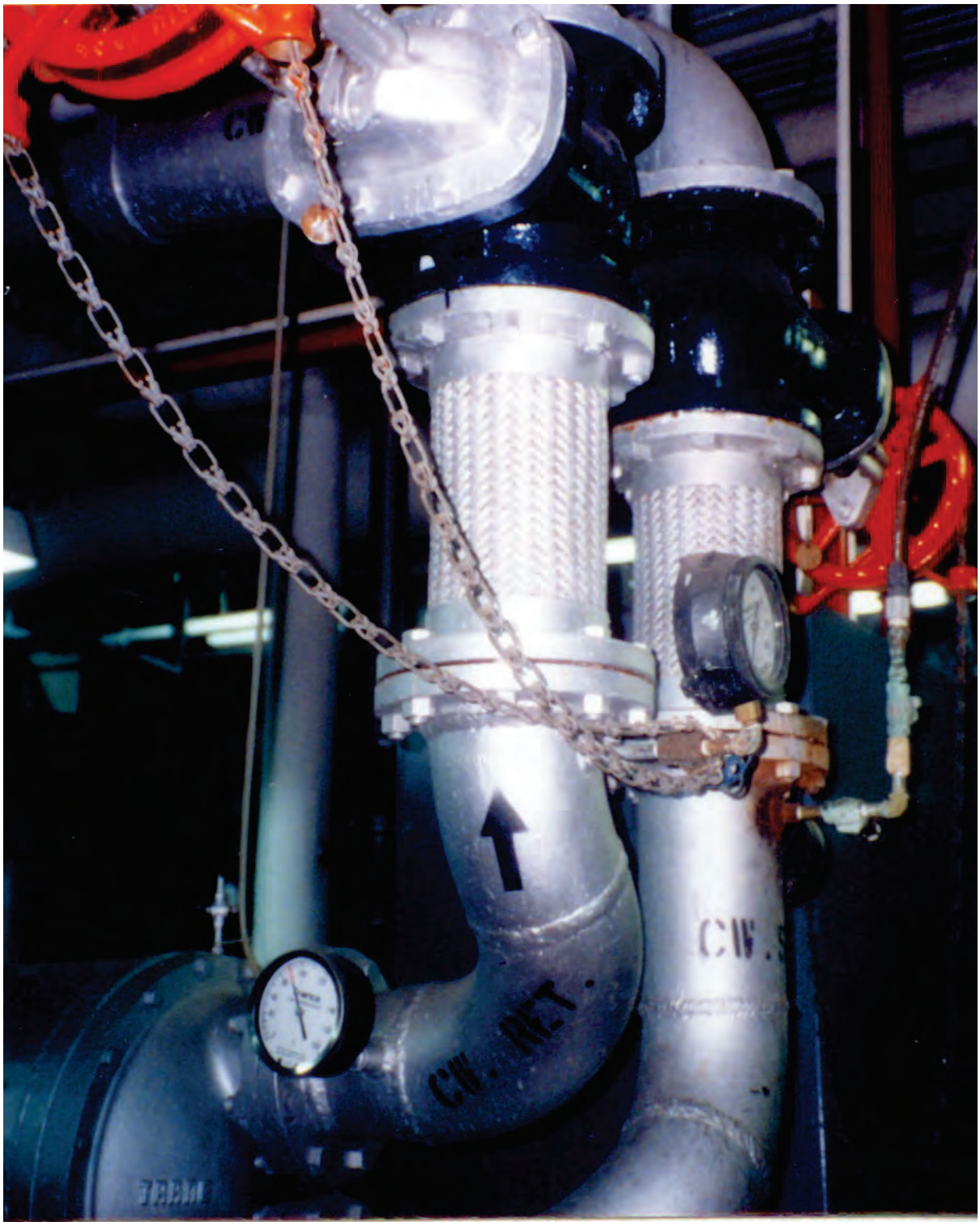


Figure 6.4.3.3-3 Flexible connection at pipe attachment to rigidly mounted tank (Photo courtesy of Wiss, Janney, Elstner, Associates).



Figure 6.4.3.3-4 Flexible pipe connections at rooftop expansion joint (Photo courtesy of Maryann Phipps, Estructure).

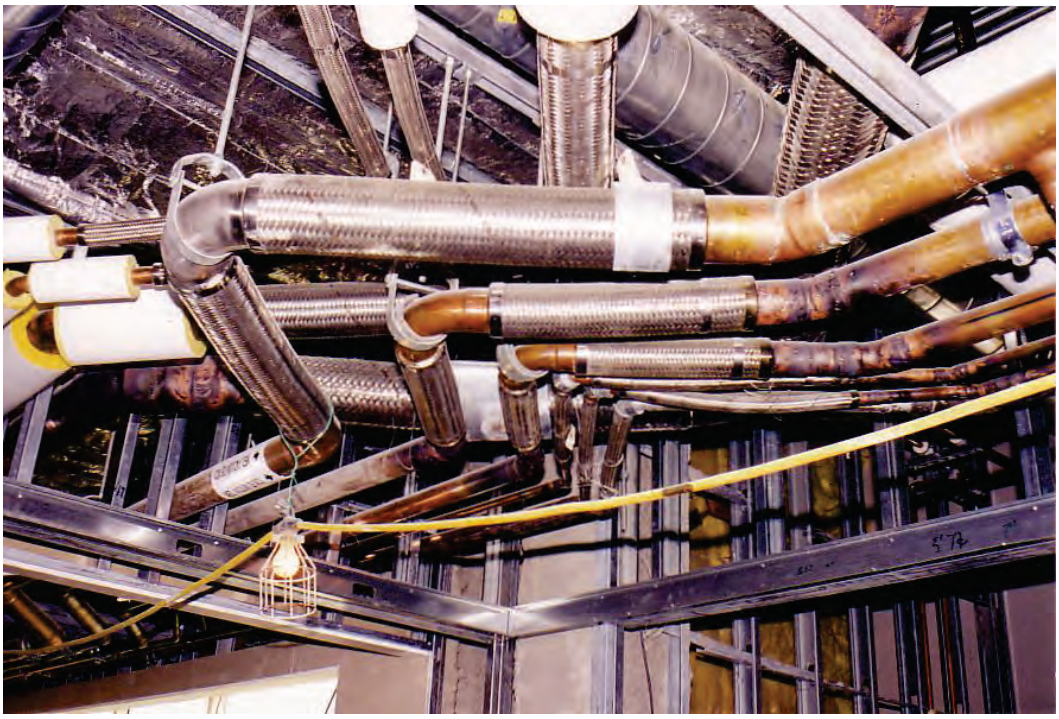


Figure 6.4.3.3-5 Flexible pipe connections at building separation (Photo courtesy of Mason Industries).

MITIGATION DETAILS

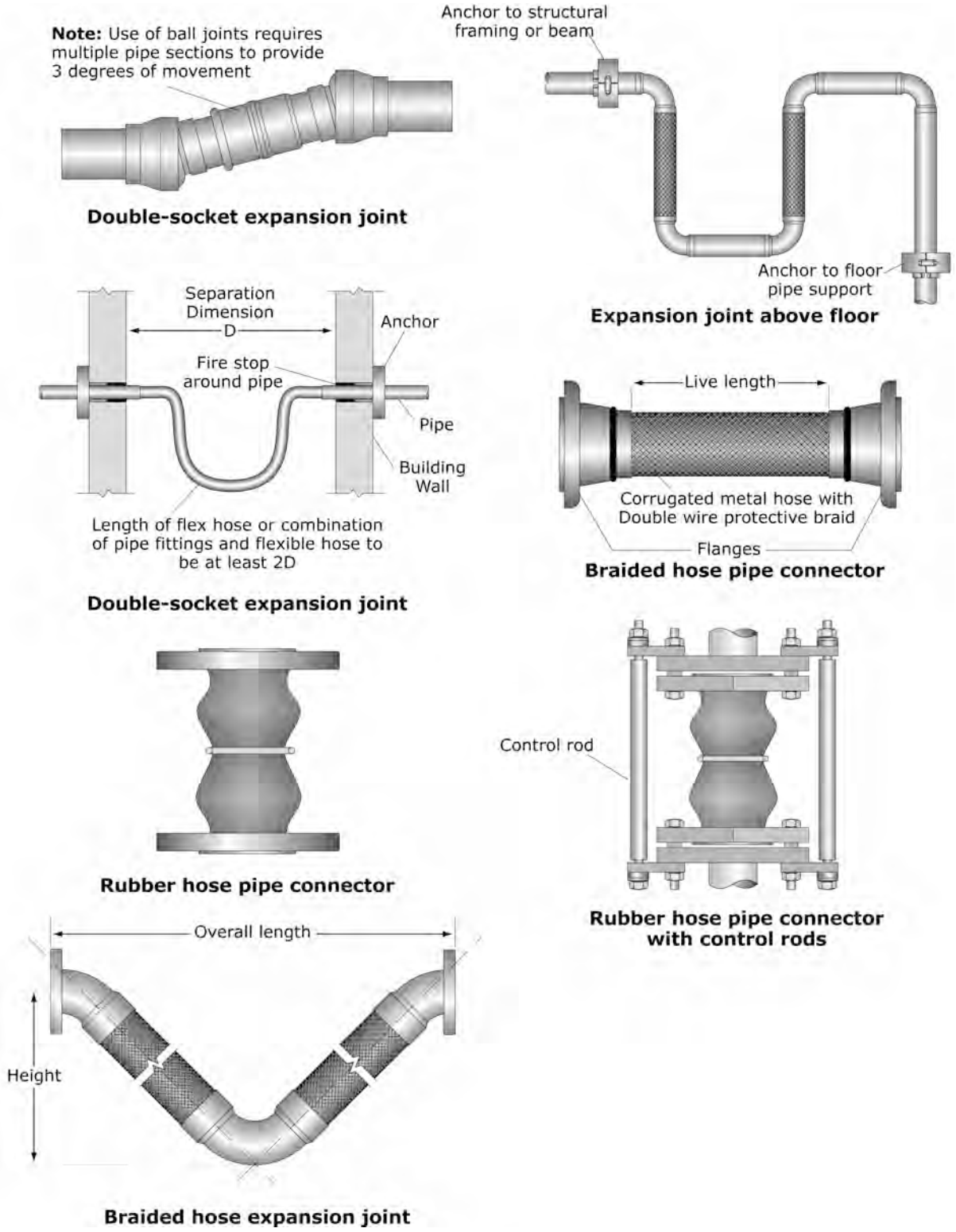


Figure 6.4.3.3-6 Flexible connections and expansion joints (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.3 Pressure Piping

6.4.3.4 Pipe Risers

This category covers pipe risers for pressure piping, that is, vertical runs of pressurized piping such as those used in multistory buildings. Risers are typically supported by a combination of wall-mounted supports and additional floor-mounted or roof-mounted supports at the locations of penetrations. Due to their length, thermal movement may be an important consideration and seismic restraints must be designed to accommodate the anticipated inter-story drift and the thermal movement.

Provisions

BUILDING CODE PROVISIONS

Displacement demands for pipe risers are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The objective is to provide sufficient capacity to accommodate the design building drifts without failure. The effects of story drifts must be considered in combination with displacements caused by other loads such as those due to thermal expansion. The required displacement capacity can be accomplished through pipe flexibility or connections with sufficient flexibility to avoid failure of the pipe.

RETROFIT STANDARD PROVISIONS

Pipe risers are considered deformation and acceleration sensitive in ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007). Pipe risers running between floors must be capable of accommodating the required relative displacements. Detailed requirements depend upon the nature of the piping system. Refer to the discussions of different piping systems for more specific information.

Typical Causes of Damage

Pipe risers must be designed to accommodate inter-story drift between adjacent floors, that is, differential movement between the points of support located on different floors of the building. If the pipe supports are not designed to accommodate this movement during an earthquake, the supports may fail or the pipes or pipe joints may fail and leak. Improperly supported pipes can become dislodged and fall; unbraced risers can sway and impact adjacent items.

- Pipes are vulnerable at penetrations, thus floor and roof penetrations must be sufficiently oversized to prevent impact. Unrestrained movement of pipes at penetrations may damage the piping and pipe restraints but may also damage flooring, ceilings, partitions, insulation, fire-proofing or other architectural finishes. For insulated risers, the piping insulation may also be damaged if the pipe chafes at the restraint. If risers are mounted to lightweight partitions, the partitions may be damaged unless they have been designed and braced to resist the piping loads.
- Because risers often involve very long pipe runs, the thermal movement may be significant. Unless seismic restraints are designed to accommodate thermal movement, the piping, pipe joints or rigid seismic restraints could be damaged under operating conditions and fail to perform properly in an earthquake.
- Pipe risers in multistory buildings are typically located in utility shafts or pipe chases; thus, they usually do not pose a significant falling hazard to occupants but riser damage could cause significant leakage resulting in property losses and business outage.

DAMAGE EXAMPLES



Figure 6.4.3.4-1 Movement of unbraced risers damaged ceiling finishes and insulation in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries).

Seismic Mitigation Considerations

- See the general discussion of pipe bracing in Section 6.4.3.1.
- It is usually preferable for pipe risers to be detailed to accommodate seismic relative displacements by means of pipe flexibility, or flexible supports where this is not possible. When the riser cannot accommodate seismic relative displacements by such means, connections having sufficient flexibility are needed. Flexible connections may be less desirable due to the need for greater maintenance.
- Standard steel pipe expands or contracts at a rate of 0.8 inch per 100 feet per 100 degrees Fahrenheit; supports and bracing for tall risers or piping subject to large temperature variations must be explicitly designed to accommodate thermal movement. Riser details for chilled water piping may need to accommodate additional insulation.

Riser calculations should be performed assuming the full weight of water is at the bottom of the pipe riser.

- Pipe risers require vertical support (longitudinal restraints) as well as lateral bracing. Risers are typically supported and braced by a combination of wall-mounted restraints and floor- or roof-mounted supports or guides at the locations of penetrations. They may also be supported by hangers located on horizontal branch lines within 24 inches of the centerline of the riser. Suspended support details are sometimes used at the top of the riser. The pipes may be rigidly mounted, for instance at the base of the riser, or mounted with elastomeric pads, sliding guides or vibration isolation. Specially designed riser clamps are often used to provide vertical support for pipe risers. Isolated piping should be supported independently from rigidly braced piping; rigid pipe attachments to lightweight walls may cause vibration problems under operating conditions.
- All vertical risers should have lateral restraints at the top and bottom of the riser and at each intermediate floor at a maximum spacing of 30 foot intervals. When installed as a riser, nonductile piping, such as no-hub cast iron piping, should include joint stabilizers where the joints are unsupported between floors.
- Pipe penetrations through structural elements such as beams, walls, and slabs must be coordinated with a structural engineer. Pipe penetrations through nonstructural walls, architectural finishes or roof membranes must be coordinated with an architect. Riser penetrations may require thermal insulation, fire proofing, sound proofing or weather proofing and unless properly detailed, these architectural and safety features may be compromised during an earthquake. See Section 6.4.3.8 for additional information about detailing pipe penetrations.

MITIGATION EXAMPLES



Figure 6.4.3.4-2 Riser supports provide lateral restraint with vertical sliding guides that allow thermal movement; restraint hardware consisting of tube sections is welded to either side of pipe (Photo courtesy of Mason Industries).

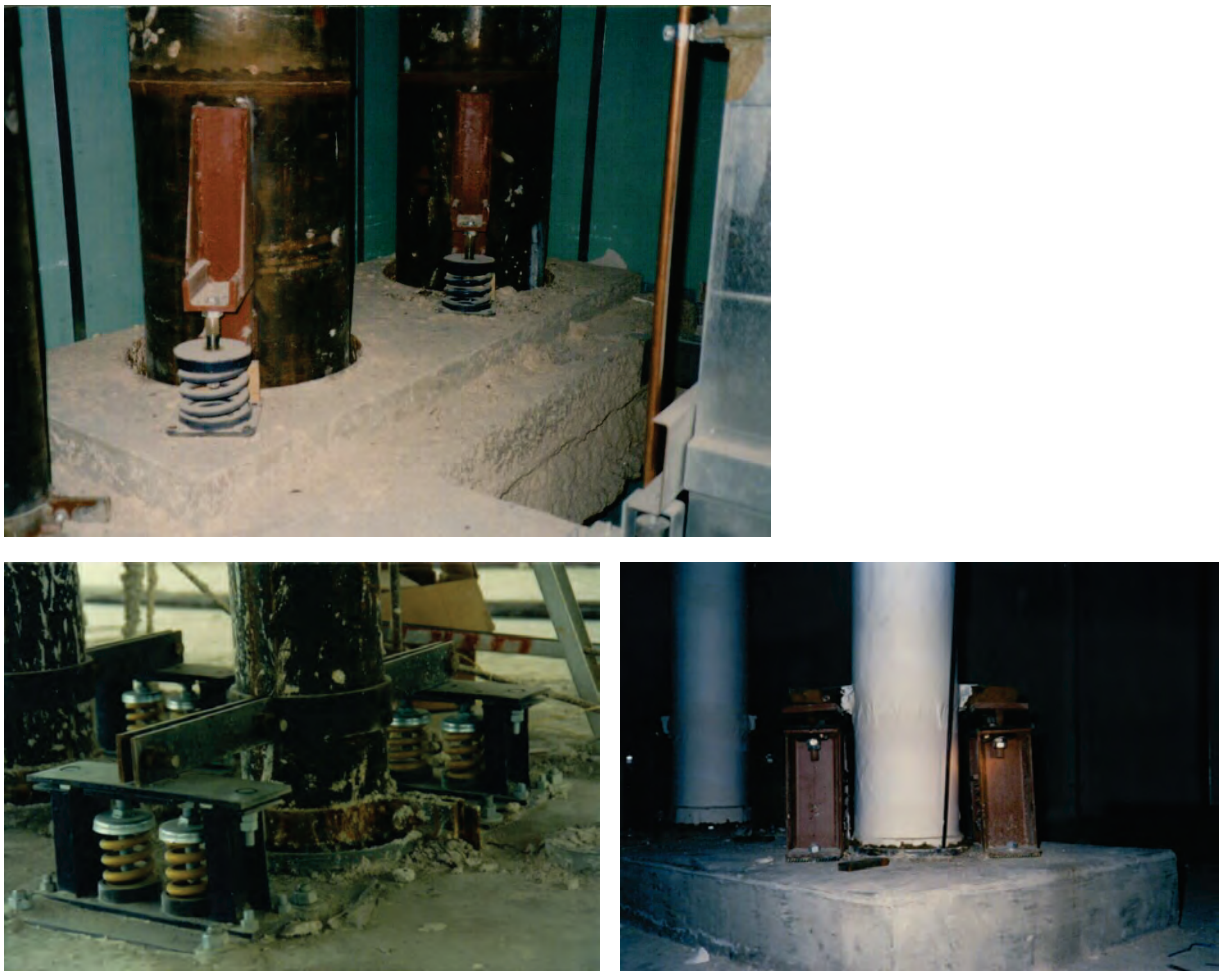


Figure 6.4.3.4-3 Different schemes for riser supports at floor penetrations with vibration isolation: first one with restraint hardware welded to pipe, second with two sets of riser clamps, and third with riser clamp inside the insulation (Photos courtesy of Mason Industries).



Figure 6.4.3.4-4 Insulated boiler pipe risers with welded lugs (small pipe sections) which travel vertically in guides providing lateral seismic restraint (Photo courtesy of Eduardo Fierro, BFP Engineers).

MITIGATION DETAILS

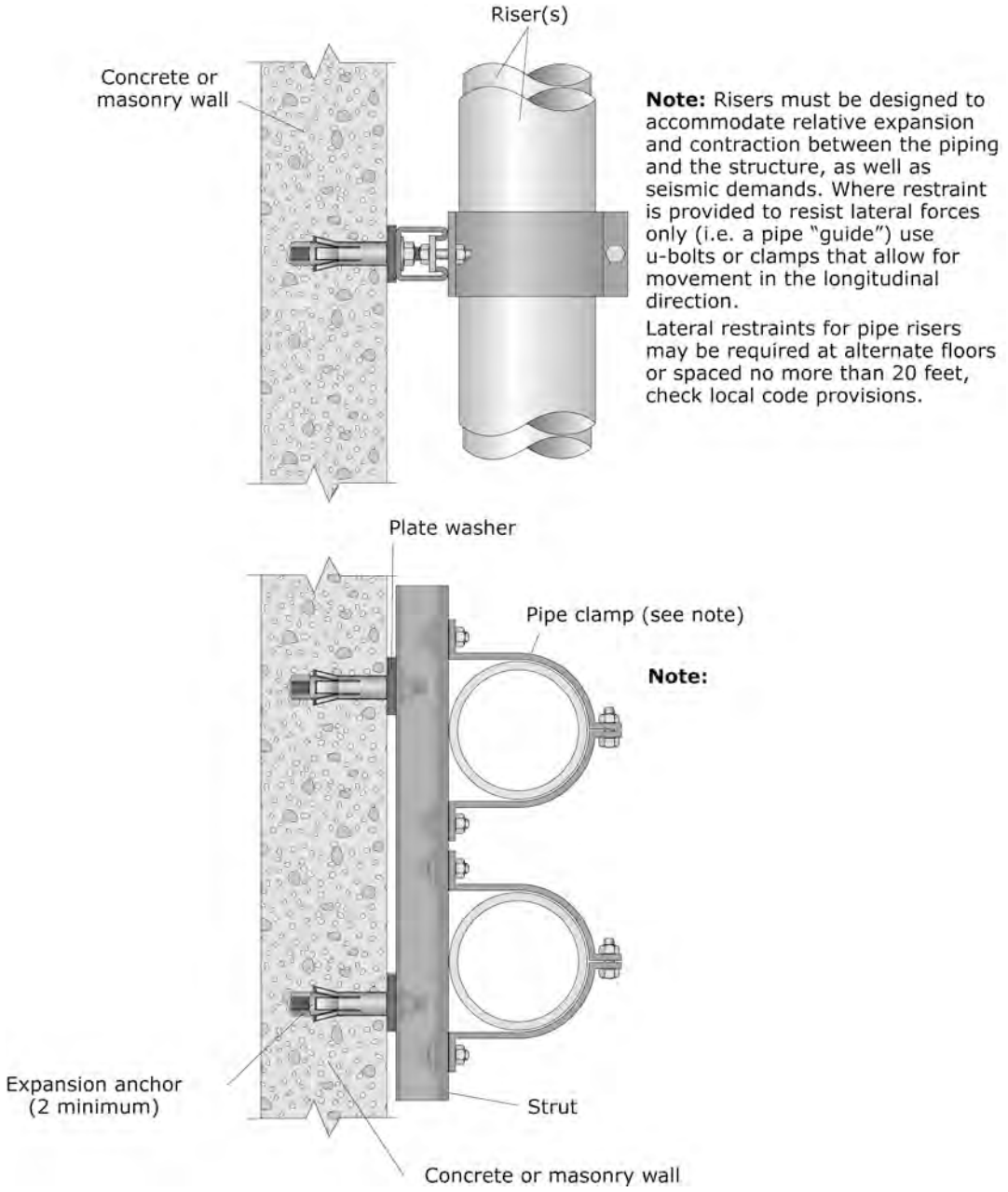


Figure 6.4.3.4-5 Wall-mounted pipe riser restraint/support (ER).

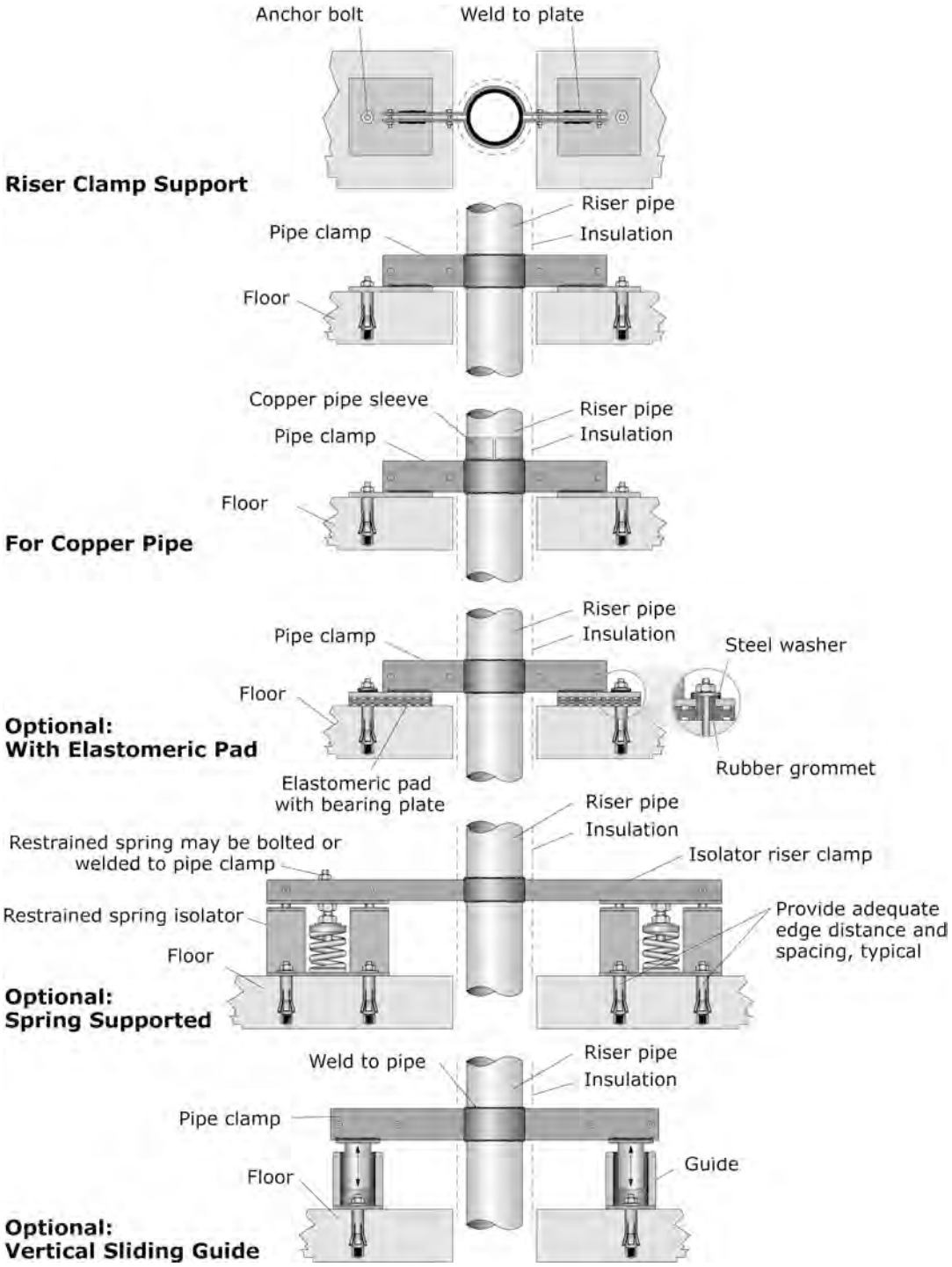


Figure 6.4.3.4-6 Riser restraint/support at floor penetrations – variations with pipe clamp, vibration isolation, and sliding guides (ER).

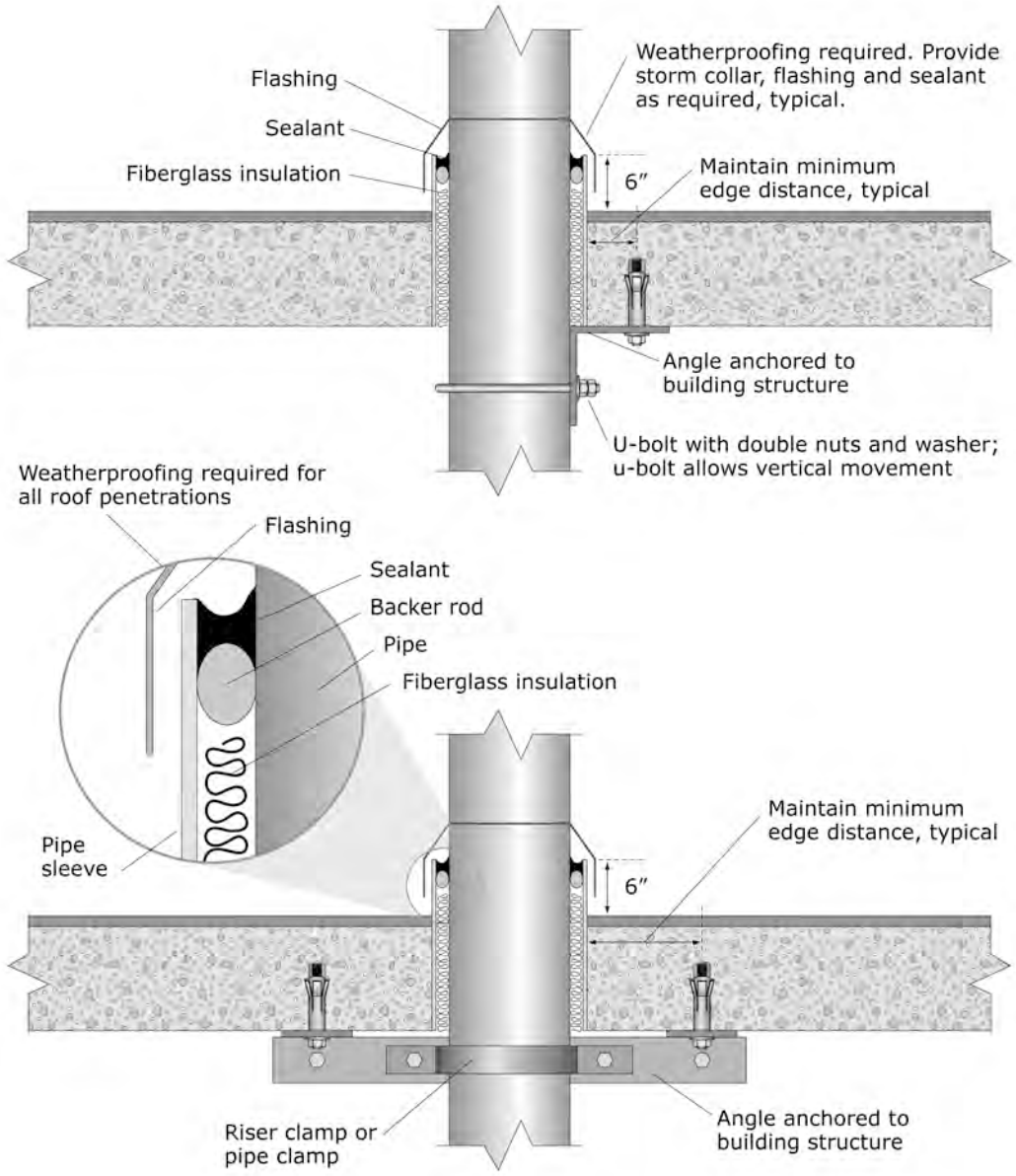


Figure 6.4.3.4-7 Riser restraint/support at roof penetration – variations with U-bolt or pipe clamp (ER).

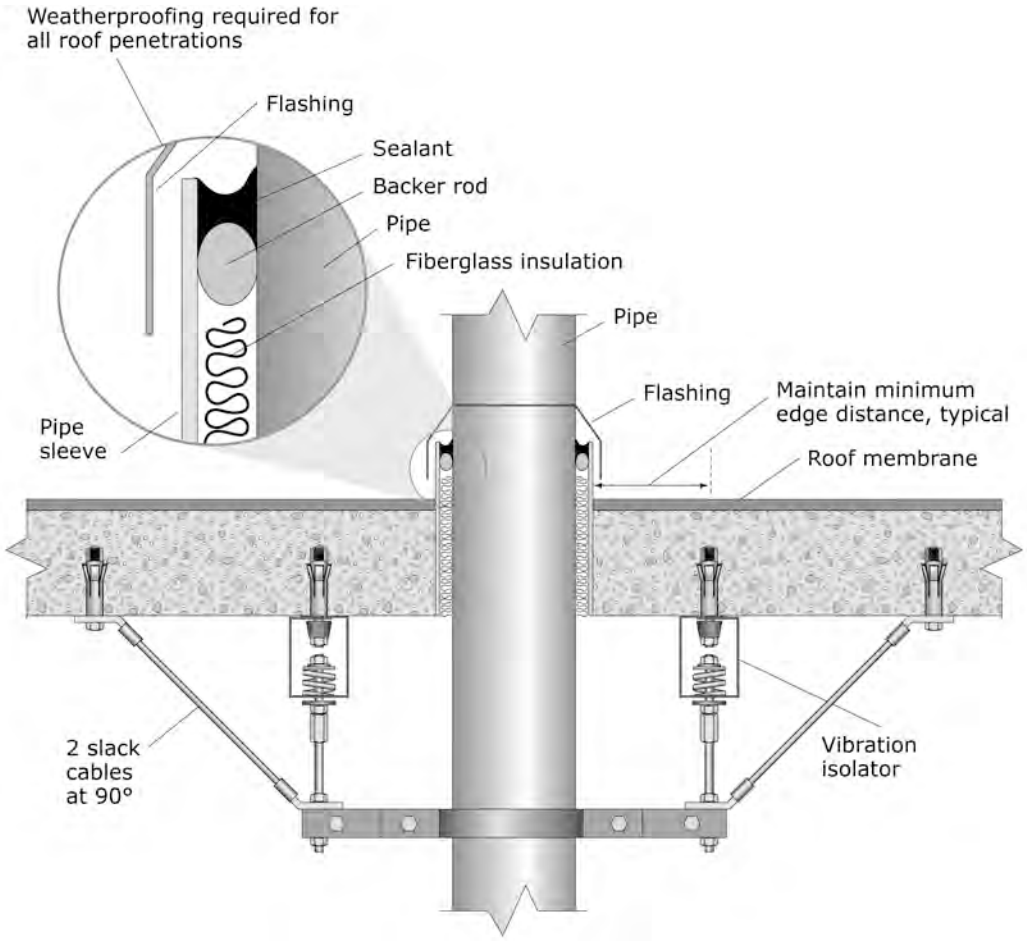


Figure 6.4.3.4-8 Roof penetration with vibration isolation (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.3 Pressure Piping

6.4.3.5 Floor-mounted supports

This category covers floor-mounted supports for pressure piping. Floor-mounted supports may be used to support either horizontal or vertical pipe runs with or without vibration isolation, either indoors or outdoors. Floor-mounted supports typically involve steel shapes anchored to structural framing or a structural concrete slab. These supports may have one cantilevered support member, one propped cantilever member, or be built up of multiple elements to form a trapeze or braced frame.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13 classifies floor-mounted supports as "Component Supports". The design for component supports may be based on reference standards, proprietary systems, or calculated forces. When calculating seismic forces, the design coefficients for the supports are typically the same as those used for the piping. However, in no case should the value of R_p used for support design be greater than 6.0.

- ASCE/SEI 7-10 exempts piping from seismic bracing requirements in Seismic Design Category C if $I_p = 1.0$.
- ASCE/SEI 7-10 requires seismic design for all distribution systems including piping in Seismic Design Categories D, E, and F that weighs more than 5 pounds per linear foot.
- ASCE/SEI 7-10 exempts high-deformability or limited deformability piping (such as steel and copper pipe) where the pipe diameter is small (anywhere from 1- to 3-inch diameter depending on the Seismic Design Category and occupancy). Provisions must be made to accommodate anticipated movement (such as by providing flexible connections, as shown in Section 6.4.3.3) and to avoid impact with other structural or nonstructural components or to protect the piping in the event of such impact.

The stiffness of the support should be designed to be compatible with its' intended function. For example, a relatively slender, flexible cantilever pipe support may not provide effective restraint for a stiff, large diameter steel pipe.

RETROFIT STANDARD PROVISIONS

The requirements for component supports in ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) depend on the type of piping system. Refer to the discussions of different distribution systems for more specific application information. Floor-mounted supports are acceleration sensitive, and when retrofit is required, they must meet the force requirements of the standard.

Typical Causes of Damage

- Failure of pipe supports may result in damage to the support in question, damage to adjacent supports which are overloaded due to the initial failure, damage to the piping or pipe joints, damage to insulation, leakage of the contents, and outage of the system that the pipes support. Joints may fail if the layout of the seismic restraints is poor or where the restraints are inadequate for the anticipated forces and displacements. Piping damage may occur at building separations, seismic joints, or penetrations if the piping has not been detailed to account for the differential movement.
- Several failure mechanisms exist for floor-mounted supports: failure at base if anchorage is undersized, yielding of cantilever elements causing excessive deflection, and buckling of braced elements if braces are undersized.
- Unrestrained piping supported directly on the floor is vulnerable to damage due to excessive movement. Section 6.4.3.8 provides more information about potential damage at pipe penetrations.
- Low lying piping, regardless of the mounting details, is vulnerable to damage due to items falling from above. Pipes may be knocked loose or crushed if heavy items fall on them.

DAMAGE EXAMPLES



Figure 6.4.3.5-1 Pipe and support assembly seem intact but photo shows evidence of longitudinal movement of the pipe in the U-bolts (Photo courtesy of BFP Engineers). A rubber pad was installed between the U-bolt and pipe in order to increase the friction coefficient, but was not sufficient to provide longitudinal restraint.



Figure 6.4.3.5-2 Damage to piping, stud wall and finishes due to movement of poorly restrained floor-mounted piping in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries).

Seismic Mitigation Considerations

- Horizontal and vertical pipe runs need vertical, lateral, and longitudinal restraints. Floor-mounted supports can be used to provide restraint for any combination of these loads, can be designed for many different configurations, may be used with or without vibration isolation, and may be used either indoors or outdoors.
- If the pipe supports are vibration isolated, analysis is required to determine the appropriate seismic design force.
- Longitudinal restraints require positive support to the pipe with a pipe clamp or welded lug; U-bolts do not provide sufficient longitudinal restraint, as observed in Figure 6.4.3.5-1. For insulated piping, longitudinal restraint hardware may need to be located beneath the insulation in order to prevent longitudinal slip.
- In an existing concrete slab, care must be taken to locate rebar or post-tensioned tendons prior to drilling holes for anchor bolts. If the base plate for the pipe support is near the edge of a concrete curb or slab, care must be taken to provide sufficient edge distance and embedment for the anchor bolts. Some types of anchors are not

recommended for use with vibratory loads. FEMA 414, Installing Seismic Restraints for Duct and Pipe (2004) provides additional precautions regarding the installation of anchor bolts and general guidance on pipe restraints.

MITIGATION EXAMPLES



Figure 6.4.3.5-3 Floor-mounted supports for insulated pipe with vibration isolation (Photo courtesy of Mason Industries).



Figure 6.4.3.5-4 Floor/ground-mounted supports for industrial piping in Chile; piping undamaged in the 2010 magnitude-8.8 Chile Earthquake. Pipe supports include concrete pedestal, base plate, and built-up welded support stand. (Photos courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).



Figure 6.4.3.5-5 Floor-mounted supports for industrial piping in Chile; piping undamaged in the 2010 Chile Earthquake. The Chilean Industrial Code (Norma Chilena 2369) requires that shear forces be resisted by shear keys as shown; lower photo is detail of piping at upper right (Photos courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).

MITIGATION DETAILS

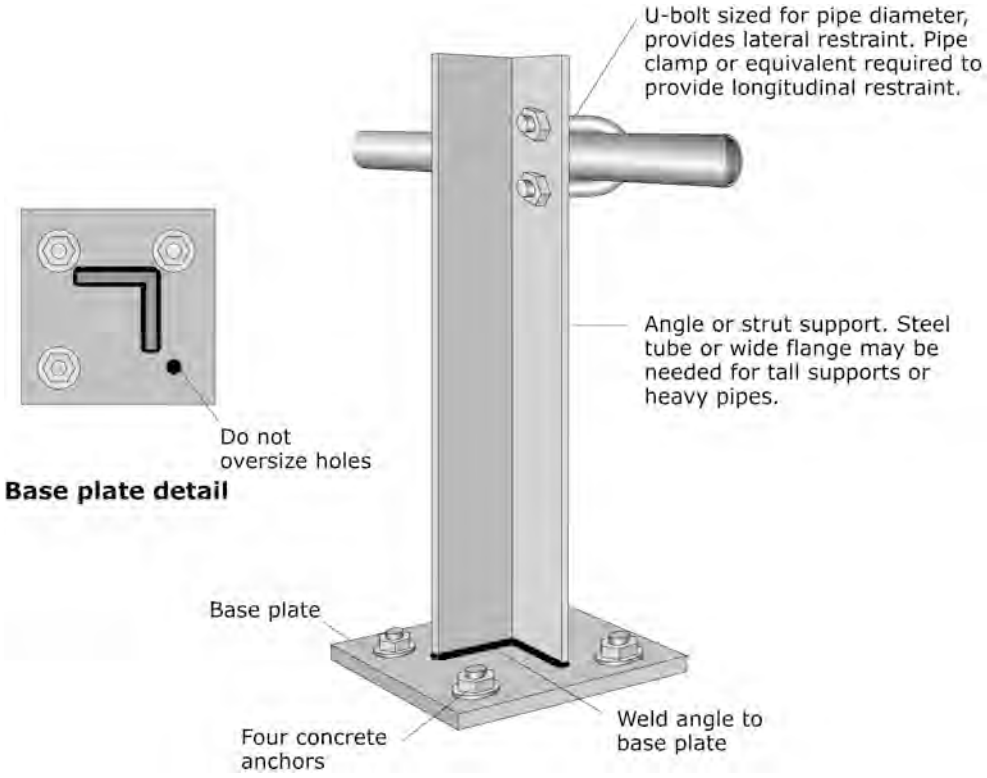


Figure 6.4.3.5-6 Floor-mounted single vertical pipe support (ER).

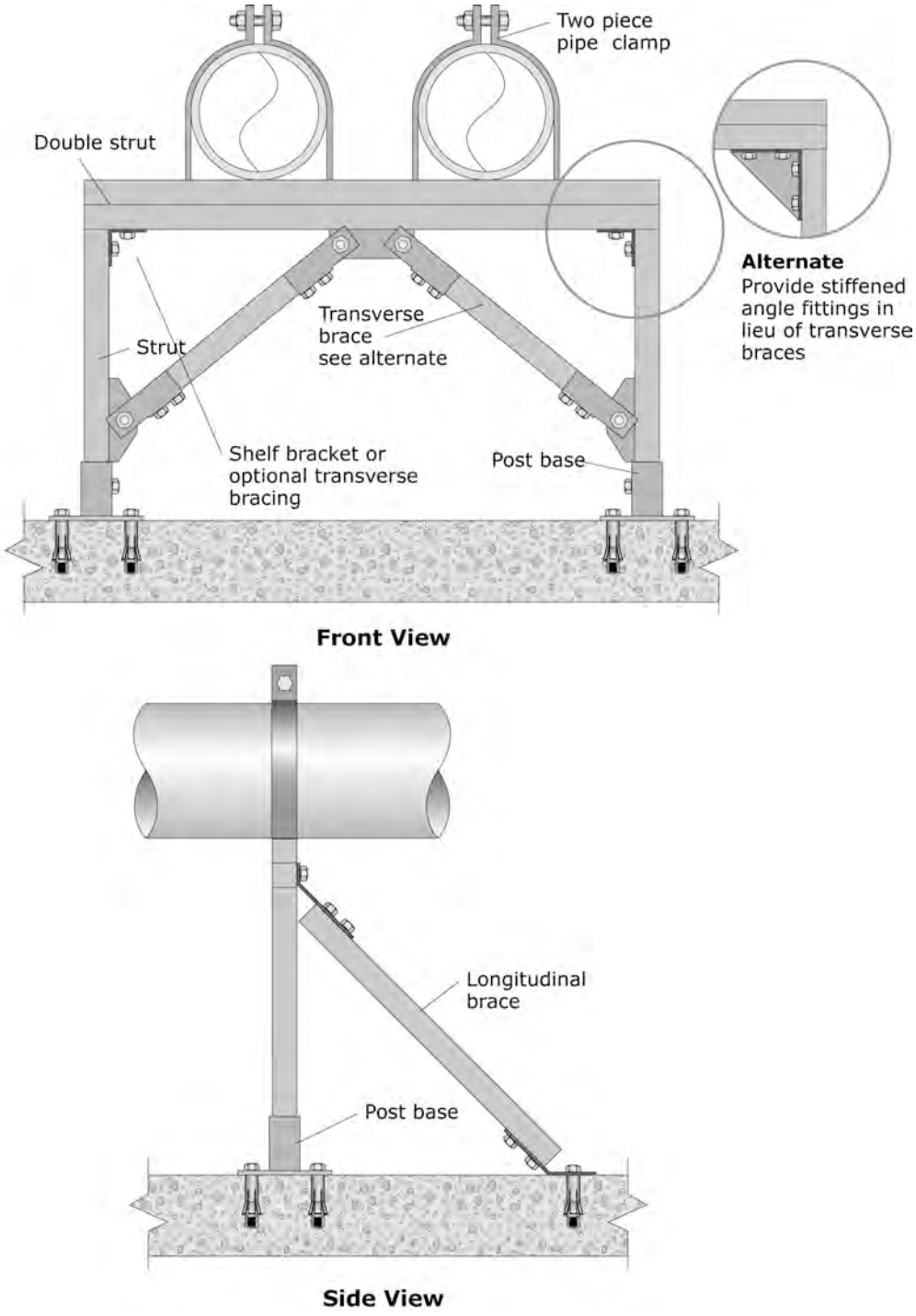


Figure 6.4.3.5-7 Floor-mounted pipe stand (strut frame) (ER).

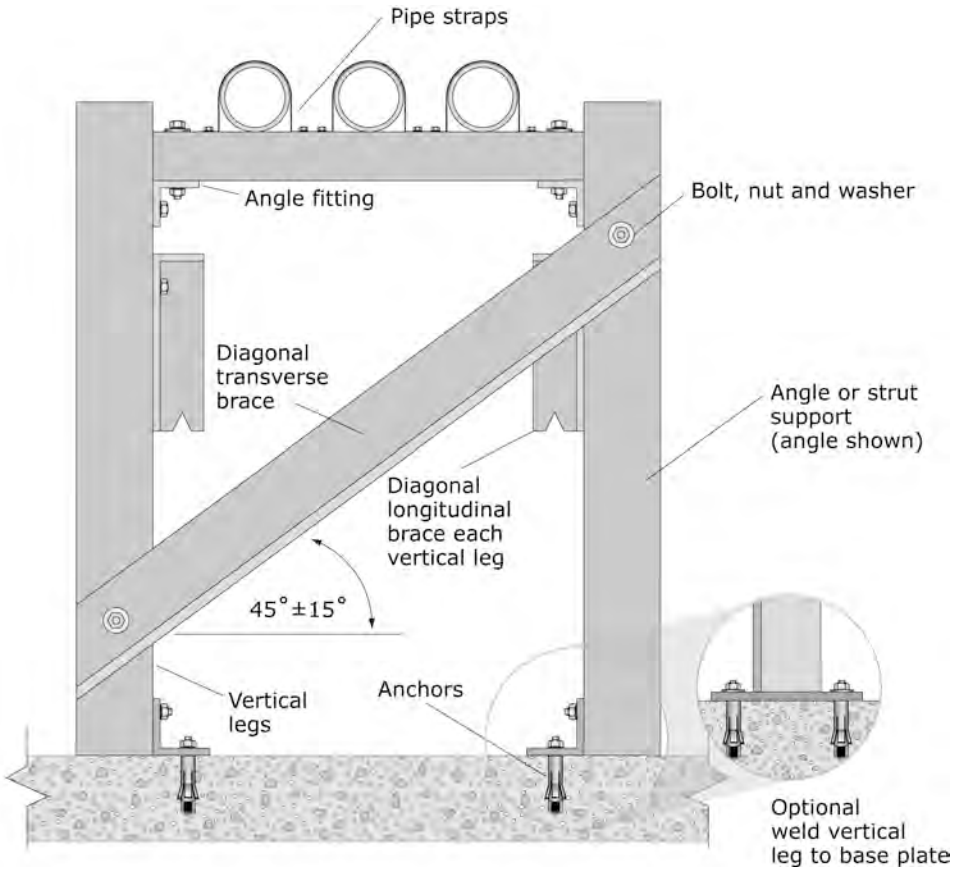


Figure 6.4.3.5-8 Floor-mounted pipe stand (steel shapes) (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.3 Pressure Piping

6.4.3.6 Roof-Mounted Supports

This category covers roof-mounted supports for pressure piping. Roof-mounted supports may be used to support either horizontal or vertical pipe runs. Roof-mounted supports consist of wood blocking or steel shapes anchored to structural framing or a structural concrete slab and may be mounted with or without vibration isolation. These supports may be flush with the roof surface, have one cantilevered support member, one propped cantilever member, or be built up of multiple elements to form a trapeze or braced frame.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13 classifies roof-mounted supports as "Component Supports." The design for component supports may be based on reference standards, proprietary systems, or calculated forces. When calculating seismic forces, the design coefficients for the supports are typically the same as those used for the piping. However, in no case should the value of R_p used for support design be greater than 6.0.

- ASCE/SEI 7-10 exempts piping from seismic bracing requirements in Seismic Design Category C if $I_p = 1.0$.
- ASCE/SEI 7-10 requires seismic design for all distribution systems including piping in Seismic Design Categories D, E, and F that weighs more than 5 pounds per linear foot.
- ASCE/SEI 7-10 exempts high-deformability or limited deformability piping (such as steel and copper pipe) where the pipe diameter is small (anywhere from 1 to 3 inch diameter depending on the Seismic Design Category and occupancy). Provisions must be made to accommodate anticipated movement (such as by providing flexible connections, as shown in Section 6.4.3.3) and to avoid impact with other structural or nonstructural components or to protect the piping in the event of such impact

The stiffness of the support should be designed to be compatible with its' intended function. For example, a relatively slender, flexible cantilever pipe support may not provide effective restraint for a stiff, large diameter steel pipe.

RETROFIT STANDARD PROVISIONS

The requirements for component supports in ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) depend on the type of piping system. Refer to the discussions of different distribution systems for more specific application information. Roof-mounted supports are acceleration sensitive, and when retrofit is required, they must meet the force requirements of the standard.

Typical Causes of Damage

- Failure of pipe supports may result in damage to the support in question, damage to adjacent supports which are overloaded due to the initial failure, damage to the piping, damage to insulation or roofing, leakage of the contents, and outage of the system that the pipes support. Joints may fail if the layout of the seismic restraints is poor or where the restraints are inadequate for the anticipated forces and displacements. Piping damage may occur at locations where piping runs across roof separations or seismic joints if the piping has not been detailed to account for the differential movement.
- Seismic accelerations are often highest at the roof level and thus roof-mounted items are particularly vulnerable to failure unless properly designed. Several failure mechanisms exist for roof-mounted supports: failure at base if anchorage is undersized, yielding of cantilever elements causing excessive deflection, and buckling of braced elements if braces are undersized.
- Unrestrained piping supported directly on the roof is vulnerable to damage due to excessive movement. Unanchored wood sleepers may overturn or slide.
- Damage to roof-mounted items may also result in damage to the roofing membrane causing subsequent water damage.

DAMAGE EXAMPLES



Figure 6.4.3.6-1 Damaged supports and piping on roof-mounted HVAC unit in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries). Both the roof-mounted wood sleepers and strut supports failed.



Figure 6.4.3.6-2 Unrestrained wood sleepers on roof-mounted piping slid a foot in either direction in 2010 magnitude-6.5 Eureka Earthquake (Photos courtesy of Maryann Phipps, Estructure).



Figure 6.4.3.6-3 Unrestrained roof-mounted piping broke at the connection to the equipment in the 2010 Eureka Earthquake. Piping mounted on wood sleepers should typically be restrained to the roof, not free to slide (Photo courtesy of Maryann Phipps, Estructure).

Seismic Mitigation Considerations

- Pipe runs need vertical, lateral and longitudinal restraints. Roof-mounted supports can be used to provide restraint for any combination of these loads, can be designed for many different configurations, and may be used with or without vibration isolation. Longitudinal restraints require positive support to the pipe with a pipe clamp or welded lug; U-bolts do not provide effective longitudinal restraint.
- Seismic accelerations are often highest at the roof level; roof-mounted supports may need to be more robust than those located elsewhere in a building. They additionally need to be protected from corrosion and deterioration or they will be ineffective during an earthquake.
- If the pipe supports are vibration isolated, analysis is required to determine the appropriate seismic design force.In an existing concrete roof slab, care must be taken to locate rebar or post-tensioned tendons prior to drilling holes for anchor bolts. If the base plate for the pipe support is near the edge of a concrete curb or slab, care must be taken to provide sufficient edge distance and embedment for the anchor bolts. Some

types of anchors are not recommended for use with vibratory loads. FEMA 414, *Installing Seismic Restraints for Duct and Pipe* (2004) provides additional precautions regarding the installation of anchor bolts.

- Weatherproofing is an important consideration for roof-mounted supports; any penetration of the roof membrane must be adequately sealed to prevent roof leakage. Refer to Section 6.4.3.8 for additional discussion of pipe penetrations.
- Seismic restraint hardware for any exterior exposure should be specified using materials or coatings to reduce corrosion and may require periodic painting or replacement to maintain the effectiveness of the restraint. Items exposed to salt air, or deicing compounds such as in a parking structure, may be especially at risk.

MITIGATION EXAMPLES



Figure 6.4.3.6-4 Roof-mounted supports with vibration isolation (Photo courtesy of Mason Industries).

MITIGATION DETAILS

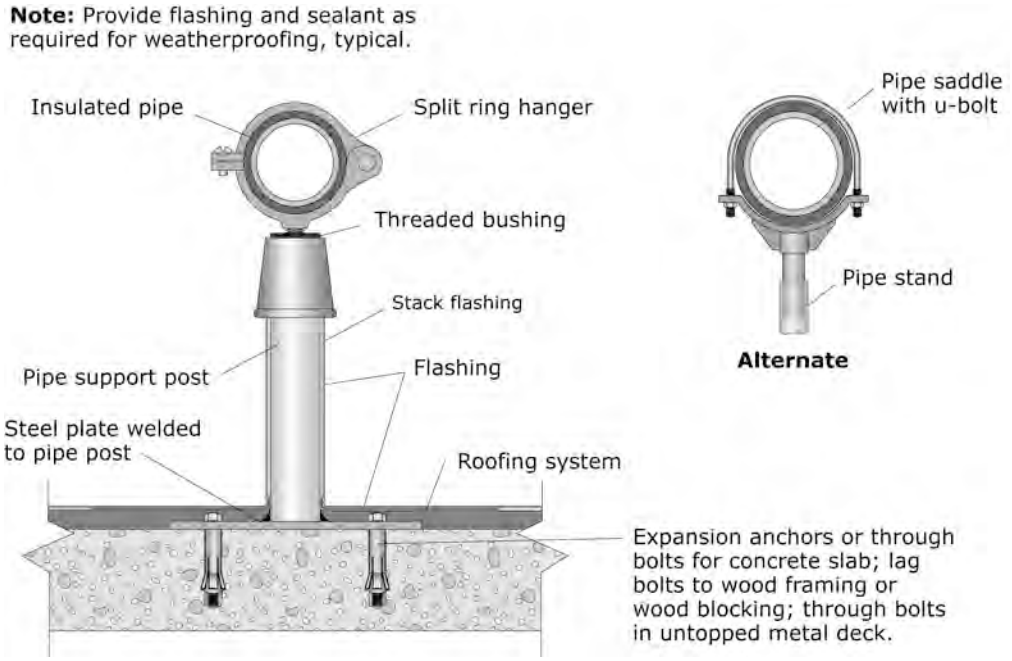


Figure 6.4.3.6-5 Roof-mounted single vertical pipe support (ER).

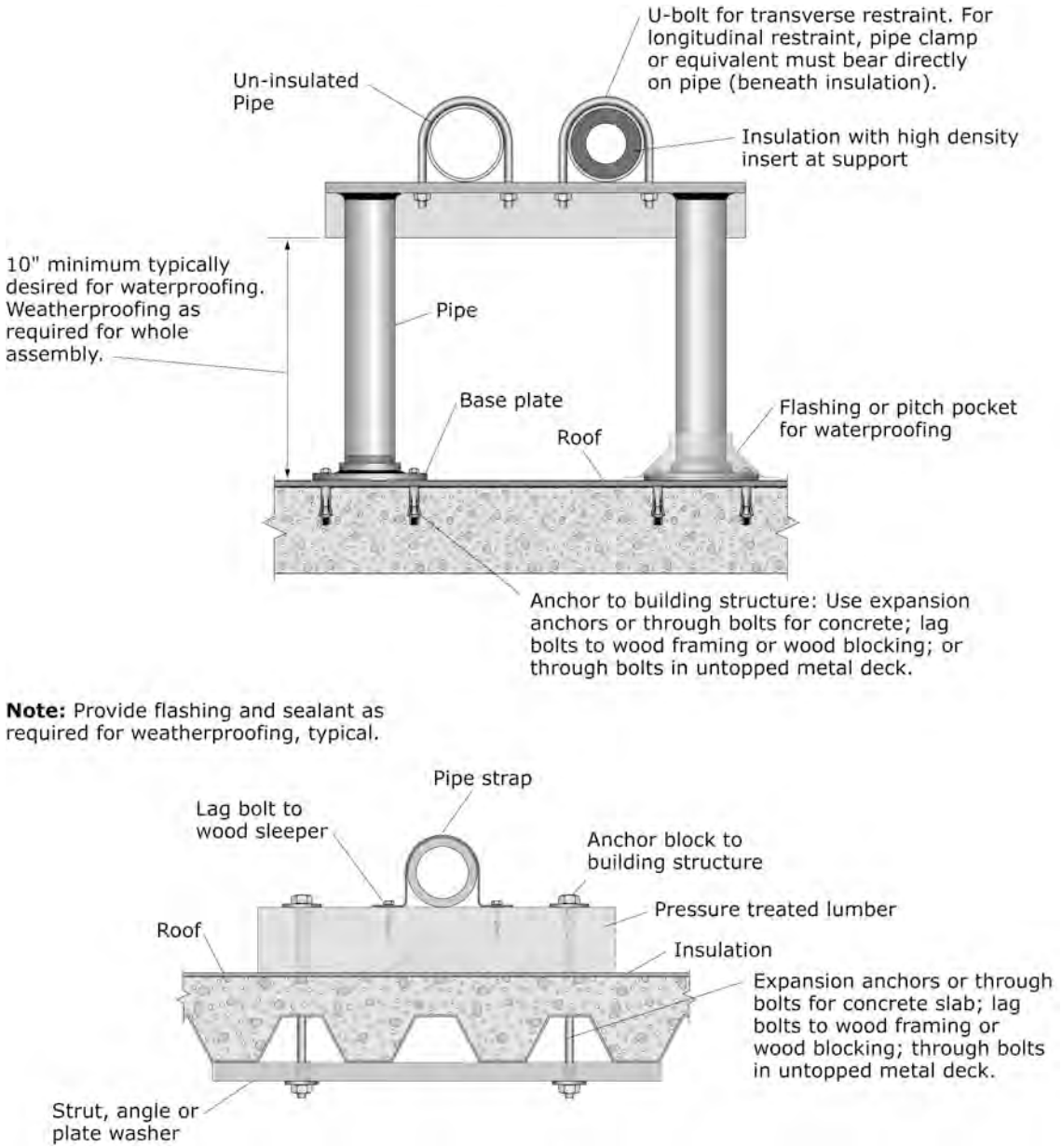


Figure 6.4.3.6-6 Roof-mounted pipe stand and sleeper anchored to slab (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.3 Pressure Piping

6.4.3.7 Wall-Mounted Supports

This category covers wall-mounted supports for pressure piping. Wall-mounted supports may be used to support either horizontal or vertical pipe runs, may be used with or without vibration isolation, and may be used either indoors or outdoors. Wall-mounted supports may be mounted flush or be built up out of assemblies of steel shapes anchored to structural framing or a structural wall.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13 classifies wall-mounted supports as "Component Supports". The design for component supports may be based on reference standards, proprietary systems, or calculated forces. When calculating seismic forces, the design coefficients for the supports are typically the same as those used for the piping. However, in no case should the value of R_p used for support design be greater than 6.0.

- ASCE/SEI 7-10 exempts piping from seismic bracing requirements in Seismic Design Category C if $I_p = 1.0$.
- ASCE/SEI 7-10 requires seismic design for all distribution systems including piping in Seismic Design Categories D, E, and F that weighs more than 5 pounds per linear foot.
- ASCE/SEI 7-10 exempts high-deformability or limited deformability piping (such as steel and copper pipe) where the pipe diameter is small (anywhere from 1- to 3-inch diameter depending on the Seismic Design Category and occupancy). Provisions must be made to accommodate anticipated movement (such as by providing flexible connections, as shown in Section 6.4.3.3) and to avoid impact with other structural or nonstructural components or to protect the piping in the event of such impact.

The stiffness of the support should be designed to be compatible with its' intended function. For example, a relatively slender, flexible cantilever pipe support may not provide effective restraint for a stiff, large diameter steel pipe.

RETROFIT STANDARD PROVISIONS

The requirements for component supports in ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) depend on the type of piping system. Refer to the discussions of different distribution systems for more specific application information. Wall-mounted supports are acceleration sensitive, and when retrofit is required, they must meet the force requirements of the standard.

Typical Causes of Damage

- Failure of pipe supports may result in damage to the support in question, damage to adjacent supports which are overloaded due to the initial failure, damage to the piping or pipe joints, damage to insulation, leakage of the contents, and outage of the system that the pipes support.
- Joints may fail if the layout of the seismic restraints is poor or where the restraints are inadequate for the anticipated forces and displacements. Piping damage may occur at building separations or seismic joints if the piping has not been detailed to account for the differential movement. Wall-mounted piping often passes thru penetrations; piping may be vulnerable unless the penetrations are properly detailed.
- Several failure mechanisms exist for wall-mounted supports: failure at wall plate if anchorage is undersized, yielding of cantilever elements causing excessive deflection, and buckling of braced elements if braces are undersized. Piping attached to nonstructural walls or walls of insufficient strength may also result in damage to the wall or partition and the architectural finishes or fire-proofing.

DAMAGE EXAMPLES



Figure 6.4.3.7-1 Wall-mounted supports for horizontal and vertical pipe runs with exterior exposure. Photo shows minor damage at wall penetration of green pipe and minor movement at some U-bolts, but restraints generally performed well (Photo courtesy of Eduardo Fierro, BFP Engineers). Note that lateral restraint near an elbow can be used to provide longitudinal restraint for a perpendicular pipe run.



Figure 6.4.3.7-2 Pipe supports attached to wall of damaged silo (Photo courtesy of Eduardo Fierro, BFP Engineers). In spite of structural damage to silo, cast-in-place pipe supports were still intact and the piping did not fall.

Seismic Mitigation Considerations

- Horizontal and vertical pipe runs need vertical, lateral and longitudinal restraints. Wall-mounted supports can be used to provide restraint for any combination of these loads, can be designed for many different configurations, may be used with or without vibration isolation, and may be used either indoors or outdoors. Pipes may be mounted flush to the wall or offset; make sure to check that the wall or partition is capable of carrying the piping loads and will not develop vibration problems.
- If the pipe supports are vibration isolated, analysis is required to determine the appropriate seismic design force.
- Longitudinal restraints require positive support to the pipe with a pipe clamp or welded lug; U-bolts do not provide sufficient longitudinal restraint. For insulated piping, longitudinal restraint hardware may need to be located beneath the insulation in order to prevent longitudinal slip.
- In an existing concrete or masonry wall, care must be taken to locate rebar prior to drilling holes for anchor bolts so the rebar is not cut. Anchorage for isolated piping should be independent of anchorage for rigidly mounted pipe. In addition, some types of anchors are not recommended for use with vibratory loads. FEMA 414, Installing

Seismic Restraints for Duct and Pipe (2004), provides additional precautions regarding the installation of anchor bolts and general guidance on pipe restraints.

MITIGATION EXAMPLES



Figure 6.4.3.7-3 Wall-mounted pipe restraint examples using standard strut shapes and connectors (Photo courtesy of Cynthia Perry, BFP Engineers). Bottom view still under construction; pipes temporarily attached with plastic ties.

MITIGATION DETAILS

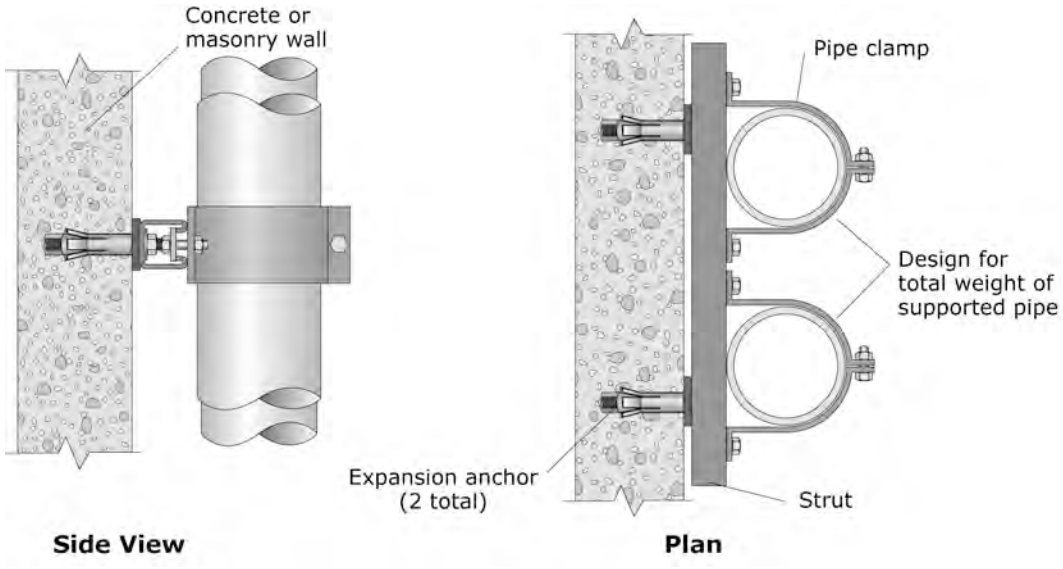


Figure 6.4.3.7-4 Surface-mount to structural wall (ER).

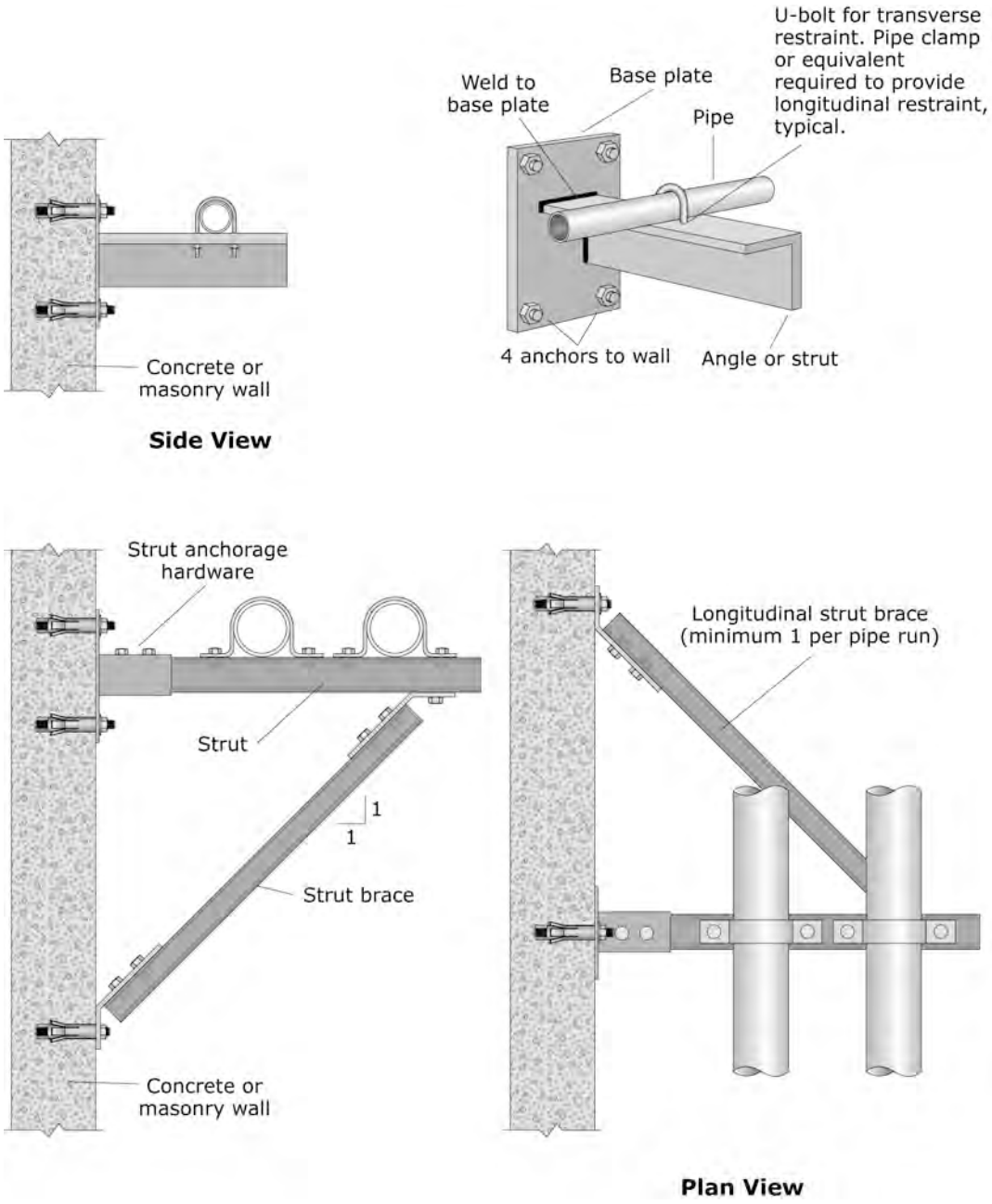


Figure 6.4.3.7-5 Wall-mount with steel shape or struts welded to concrete wall (ER).

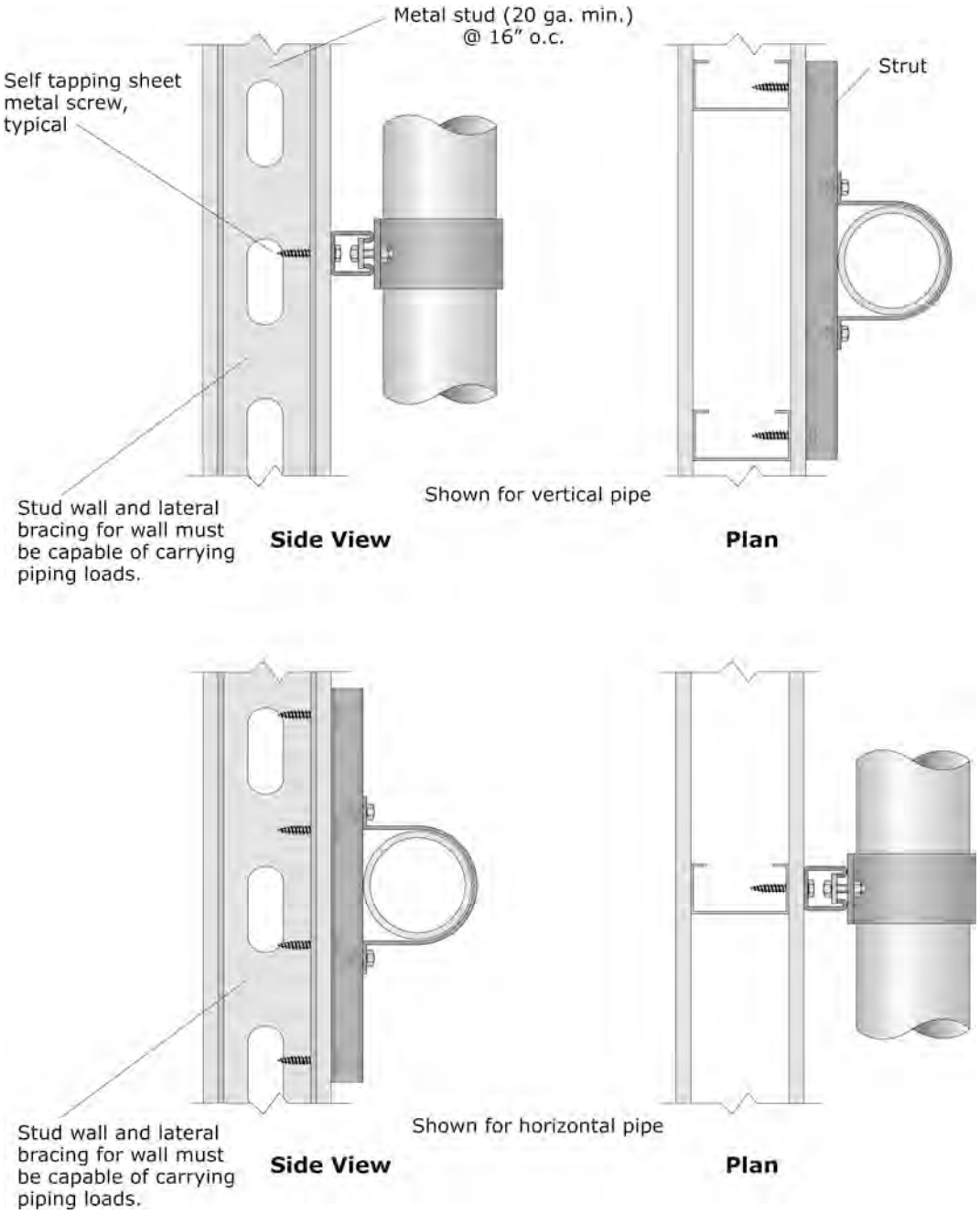


Figure 6.4.3.7-6 Wall-mount using strut channels to metal stud wall (ER).

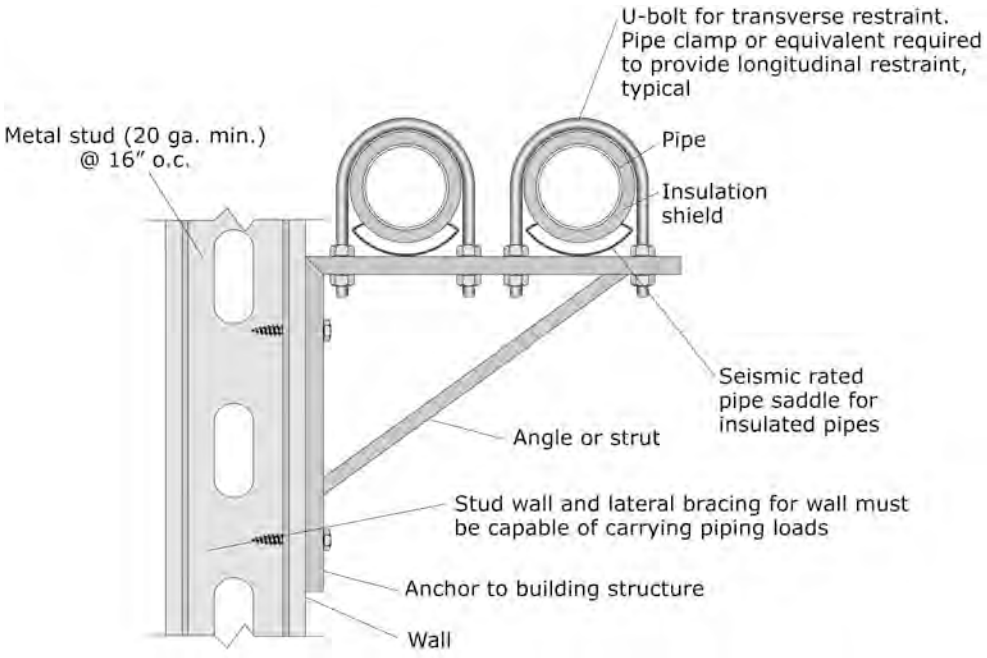


Figure 6.4.3.7-7 Wall-mount to stud wall with pre-manufactured brackets (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.3 Pressure Piping

6.4.3.8 Penetrations

This section addresses locations where pressure piping passes through floor, roof, or wall penetrations in either architectural or structural components. Penetrations usually fall into one of three categories: 1) the penetration is sufficiently oversized to prevent impact between the pipe and surrounding wall or slab; 2) a seismic restraint is located at or near the penetration so the pipe and surrounding wall or slab are constrained to move together; or 3) the penetration is not properly detailed and becomes an unintended restraint in the piping run which may result in damage to the piping, wall, slab, or finishes. Structural and nonstructural elements may require strengthening around penetrations or may need special detailing to provide fire-proofing, sound-proofing, and weather-proofing or improve the appearance of architectural finishes.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13, Nonstructural Components states that when seismic design is required, interaction between the components and the supporting structures, including other mechanical and electrical components, shall also be considered. Pressure piping with an Importance Factor I_p greater than 1.0 must be designed to eliminate seismic impact for:

- Components vulnerable to impact,
- Components constructed of nonductile materials, and
- Cases where material ductility will be reduced due to service conditions (e.g., low temperature applications).

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies pressure piping systems as force and deformation sensitive. Compliance with the requirements of the standard is necessary when the performance level is Immediate Occupancy or Life Safety in areas of High and Moderate seismicity. There are no specific requirements for pipe

penetrations in ASCE/SEI 41-06. Retrofit in accordance with prescriptive standards is permitted.

Typical Causes of Damage

- Pipe movement at penetrations often results in damage to architectural finishes, fire-proofing, and insulation. Failure of joints at or near penetrations may result in leakage causing further damage to these components.
- Where pipes pass through unreinforced masonry walls, the opening may create a point of weakness resulting in crack propagation from the opening. Lightweight partitions or ceilings are also frequently damaged by movement of unrestrained piping. Pipe movement at penetrations may also result in damage to electrical lines in the wall or ceiling space.

DAMAGE EXAMPLES

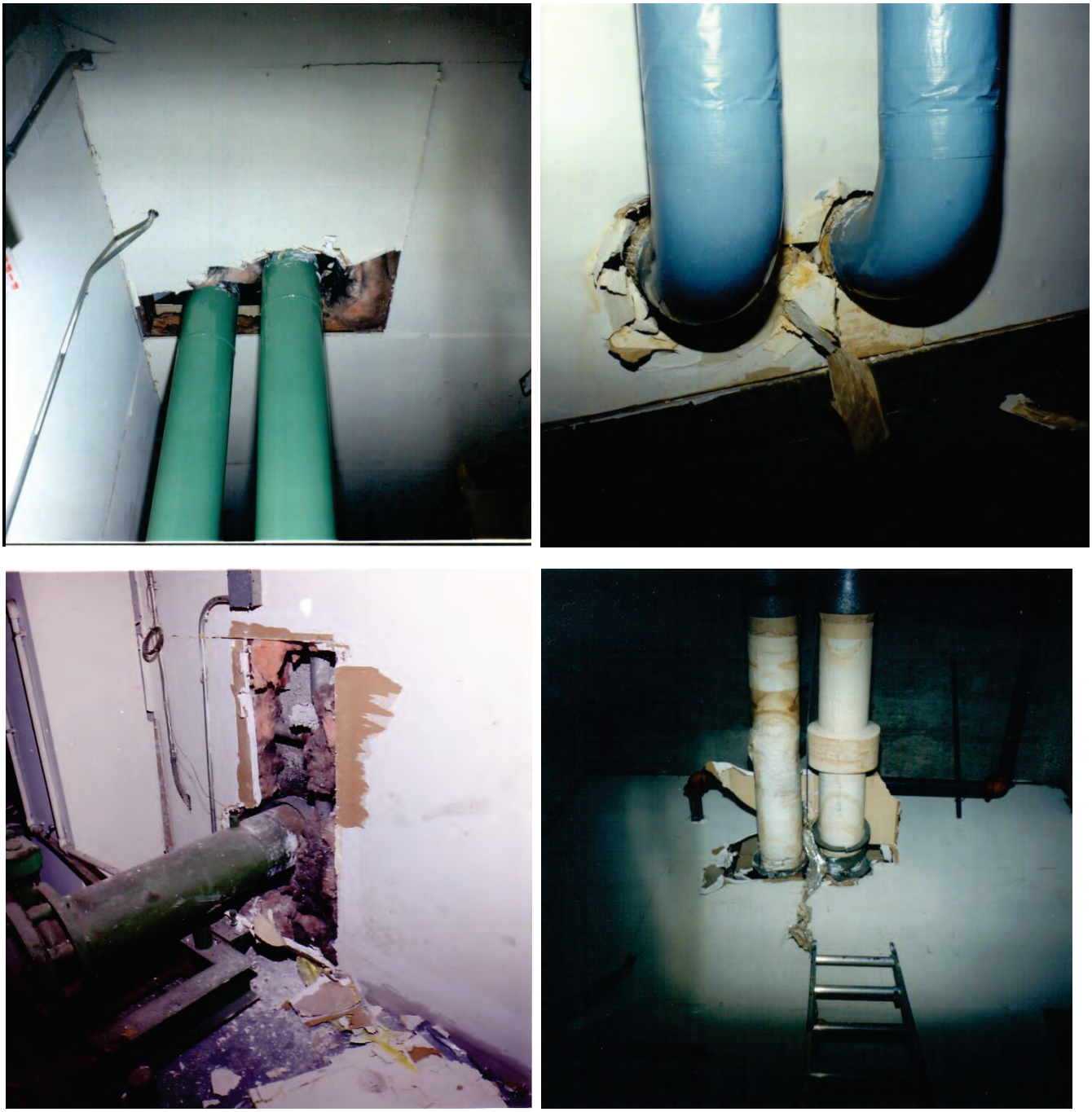


Figure 6.4.3.8-1 Damage to ceilings, gypsum board partitions, fire-proofing, and insulation in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries). Note that the blue piping has joints located in the wall space which leaked, resulting in additional damage.



Figure 6.4.3.8-2 Exterior stucco damage at wall penetration for fire protection piping in the 2001 magnitude-8.4 Peru Earthquake (Photos courtesy of Eduardo Fierro, : BFP Engineers).



Figure 6.4.3.8-3 Wall penetrations for piping and ducts contributed to damage to unreinforced masonry walls at an industrial facility in the 2010 magnitude-7 Haiti Earthquake (Photos courtesy of Eduardo Fierro, BFP Engineers). The piping and ducts were not damaged but the walls cracked and will need to be repaired.

Seismic Mitigation Considerations

- As described above, there are two different approaches for avoiding damage at pipe penetrations. Either the penetration should be designed to be oversized to avoid contact between the pipe and the wall or slab, or the pipe should be restrained at or near the penetration so the pipe and wall or slab are constrained to move together.
- Penetrations should be oversized wherever possible to allow for differential movement of pipe supports and the structural elements they are attached to on either side of the wall, floor, or roof slab. Alternatively, lateral restraints for the piping should be provided close to the penetration to prevent impact between the pipe and the opening. Where piping crosses from one building to another, flexible connections may also be required near the penetration.
- Pipes often fail or leak at joints; pipe joints should be not be located within penetrations where they will leak into a wall cavity or are inaccessible for inspection and repair.
- Penetrations through structural walls, slabs, or framing must be coordinated with a structural engineer; structural walls, slabs, or framing elements may require strengthening around penetrations. For large openings such as a pipe chase, this may involve extra trim steel around the opening or additional framing members beneath a slab. Penetrations in a structural steel girder may require welded reinforcement plates around the opening. For locating penetrations in existing concrete or masonry walls or concrete slabs, care must be taken to locate rebar or post-tensioned tendons prior to drilling holes for pipe penetrations so these elements are not cut.
- Penetrations through nonstructural walls should be coordinated with an architect to ensure that fire-proofing, sound-proofing, weather-proofing, insulation requirements and finishes on either side of the opening are not compromised. Roof penetrations have particular issues related to weather-proofing and corrosion protection; care must be taken to avoid leakage at roof penetrations. Where penetrations pass through weak materials such as unreinforced masonry or lightweight partitions, these elements may require strengthening.
- Detailing at penetrations often involves several layers of material and finishes each of which require attention; penetrations through structural elements may involve both the engineer and the architect. For instance, a penetration through a masonry wall with interior plaster and exterior stucco will require detailing for all three of these materials. The damage shown in Figure 6.4.3.8-2 occurred because although the masonry penetration was oversized and filled with packing, the exterior stucco was placed flush with the pipe resulting in stucco damage during the earthquake.

- Pipe risers that pass through floor and roof penetrations must be detailed so the seismic restraints can also accommodate longitudinal thermal movement of the pipe. If allowance for thermal movement is not included in the design, the seismic restraints may be damaged under operating conditions and fail to perform properly in an earthquake.
- Penetrations in exit corridors needed for emergency egress may warrant special care; similarly, penetrations in boiler rooms or locations with fuel lines or hazardous materials may also warrant special detailing to maintain the fire-proofing of the space in the event of a post-earthquake fire.
- FEMA 414, Installing Seismic Restraints for Duct and Pipe (2004), provides additional precautions regarding the installation of anchor bolts and general guidance on pipe restraints.

MITIGATION EXAMPLES

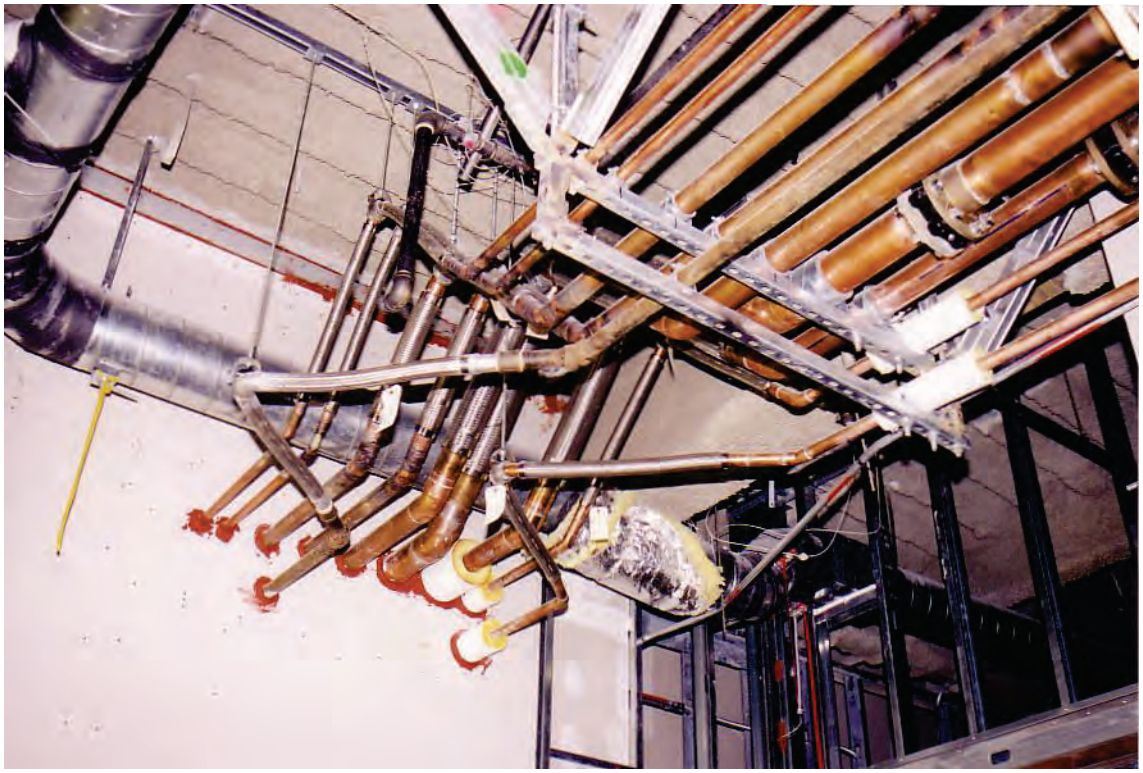


Figure 6.4.3.8-4 Wall penetrations with lateral restraints at trapeze in foreground, flexible couplings with independent vertical supports, and sealant at each wall penetration (Photo courtesy of Mason Industries).



Figure 6.4.3.8-5 Floor penetration with oversized opening and vertical and lateral restraints immediately above floor (Photo courtesy of Mason Industries).



Figure 6.4.3.8-6 Series of pipe penetrations through a full-height CMU partition wall. Note pipe suspended from floor above; partition anchored to floor below and detailed with steel clip angles intended to provide lateral restraint for the wall but allow relative slip between the wall and slab above. The hangers will move with the floor above and the pipe at penetration will move with the wall. Lateral restraints are located immediately above floor (Photo courtesy Cynthia Perry, BFP Engineers).

MITIGATION DETAILS

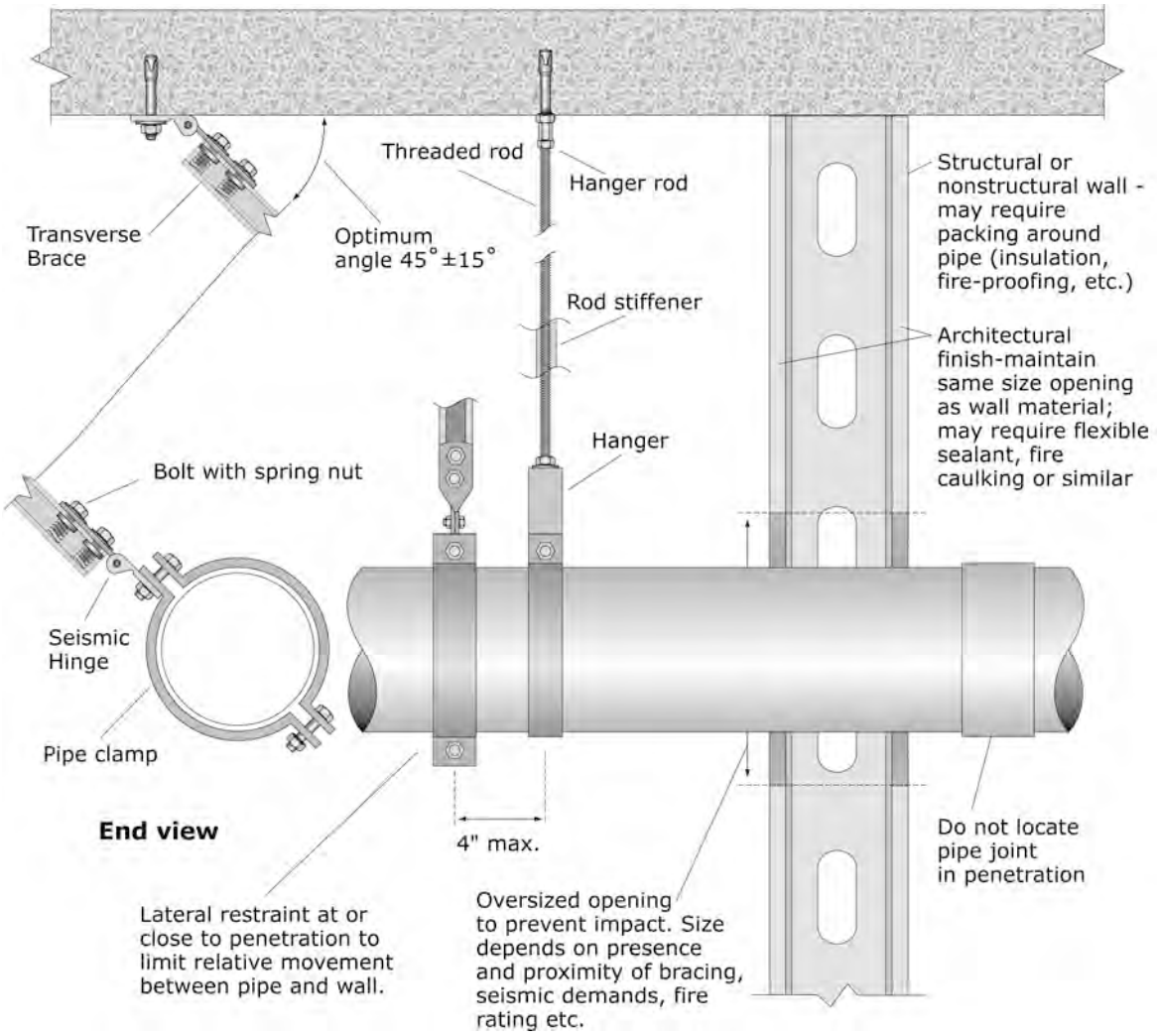


Figure 6.4.3.8-7 Wall penetration (ER).

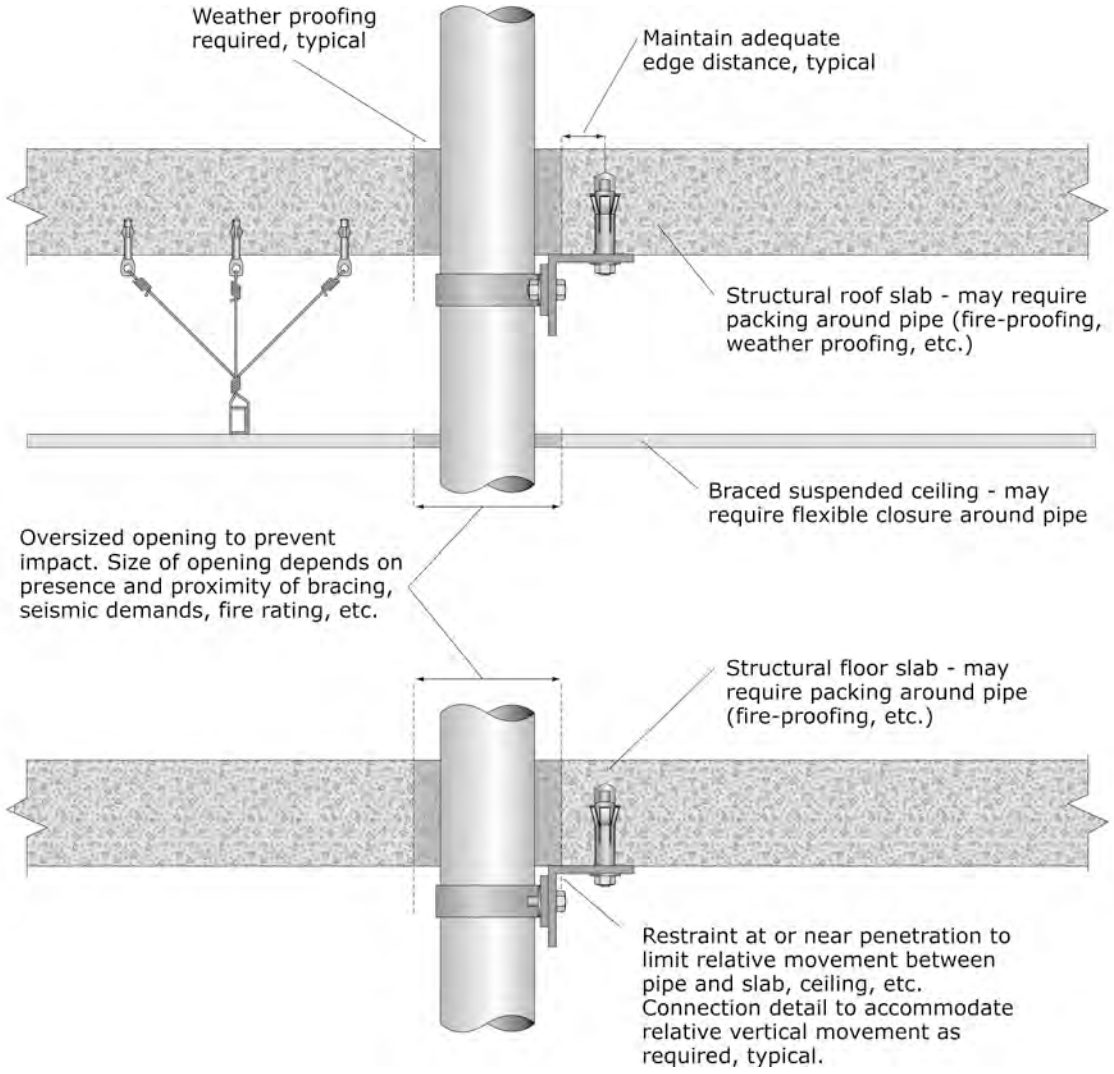


Figure 6.4.3.8-8 Floor or roof penetration (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.4 Fire Protection piping

6.4.4.1 Suspended Fire Protection Piping

This category covers fire protection sprinkler systems and piping. These systems and piping are subject to the requirements in NFPA 13, *Standard Installation of Sprinkler Systems* (NFPA, 20010a). Fire sprinkler systems may include a number of components besides piping, including pumps, tanks, and control panels. Recommendations for these components are found in the appropriate sections in Chapter 6.

Bracing provisions for fire protection piping were introduced in 1947, making it one of the earliest nonstructural standards to consider lateral bracing. NFPA 13 bracing provisions have developed continuously over time, in response to changes in construction practice and lessons learned from earthquakes. As a result, some fire protection piping systems may appear to be braced, even if installed 50 years ago. Unfortunately, older bracing installations may include features that have been shown to be vulnerable in strong ground shaking.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings*, (ASCE, 2010), Section 13.1.3.1 specifies that systems required for life-safety purposes after an earthquake, such as fire protection systems, be classified as designated seismic systems and designed using a component importance factor, I_p, of 1.5. Designated seismic systems may require engineering calculations, equipment certification, special inspection, etc. ASCE/SEI 7-10 specifies that fire protection piping conform to NFPA 13, as follows:

- NFPA 13 provides specific requirements for fire suppression systems and piping. Fire protection piping installations conforming to the 2007 or later editions of NFPA 13 may be considered to comply with the requirements of ASCE/SEI 7-10.
- The 2010 edition of NFPA 13 contains prescriptive details and requirements for many aspects of the piping installation, such as hanger size and spacing, clearances between the system and other structural or nonstructural components, and standard bracing installation details. It also contains a simplified method for doing seismic design, based on the concept of "zone of influence," a method of proportioning forces to bracing

elements that has been in use for decades. Most bracing assemblies for fire protection piping must be listed for a maximum load rating.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies suspended fire protection piping as both force controlled and displacement controlled. ASCE/SEI 41-06 requires compliance with the anchorage provisions of the standard when the performance level is Life Safety or higher. Rehabilitation, if required, is accomplished by prescriptive approaches to support and bracing, in accordance with NFPA 13.

Typical Causes of Damage

- Fire protection piping systems are sensitive to both acceleration and deformation. Vulnerable locations include joints, bends, connections to rigidly mounted equipment and risers subjected to significant relative movement between floors.
- Older bracing installations may include details that have performed poorly in past earthquakes, including the use of non-seismically rated power actuated fasteners (shot pins) or drop-in type concrete expansion anchors in bracing applications, which have proven unreliable under seismic loads. Many sprinkler system failures in the 1994 Northridge Earthquake were due to failure of poorly designed braces and brace connections.
- Sprinkler heads are often damaged due to interactions with ceiling systems, especially those with “hard” finishes such as plaster and metal panels. These interactions may also result in impact damage to the ceiling, failure of the sprinkler head, or failure to joints in the piping, with subsequent water damage. Sprinkler heads and sprinkler drops are also damaged by interactions with structural members and other structural braces where inadequate clearance is provided to avoid impact.
- Older systems may lack lateral restraints on the branch lines, which will make the sprinkler heads more vulnerable to interaction with the ceiling system and adjacent structural members.
- Fluids may leak from damaged joints or broken pipe; property losses and business outages are often attributed to fluid leaks from fire suppression piping. Facilities may need to be evacuated if the fire suppression system is compromised.
- Damage to any part of the fire protection system may compromise its functionality. In addition to the piping, pumps, holding tanks, control panels, control sensors, smoke detection equipment, and fire doors must all be operational for the life-safety systems

to function correctly. If a fire breaks out following an earthquake and the fire suppression system is not functional, significant property losses may result.

DAMAGE EXAMPLES

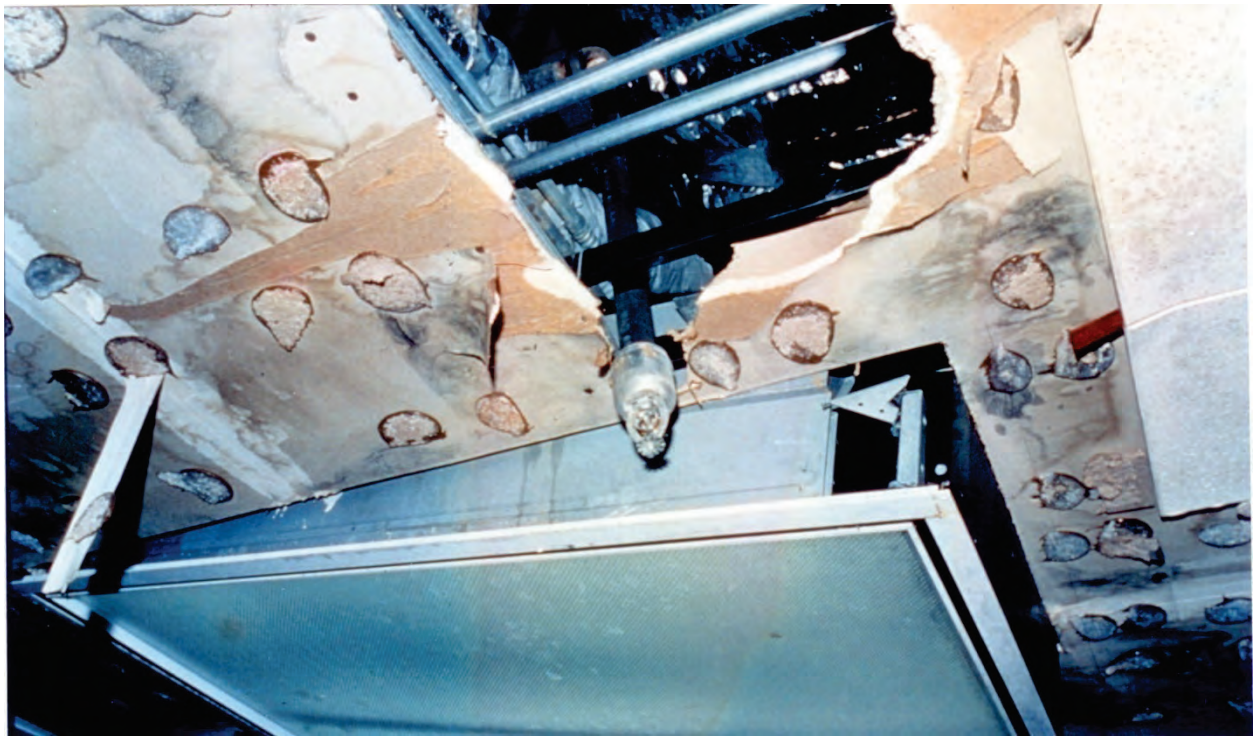


Figure 6.4.4.1-1 Sprinkler pipe ruptured at the elbow joint due to differential motion within the ceiling plenum. Water leakage from broken fire sprinklers and water lines contributed to the decision to close this hospital for several days following the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Robert Reitherman).

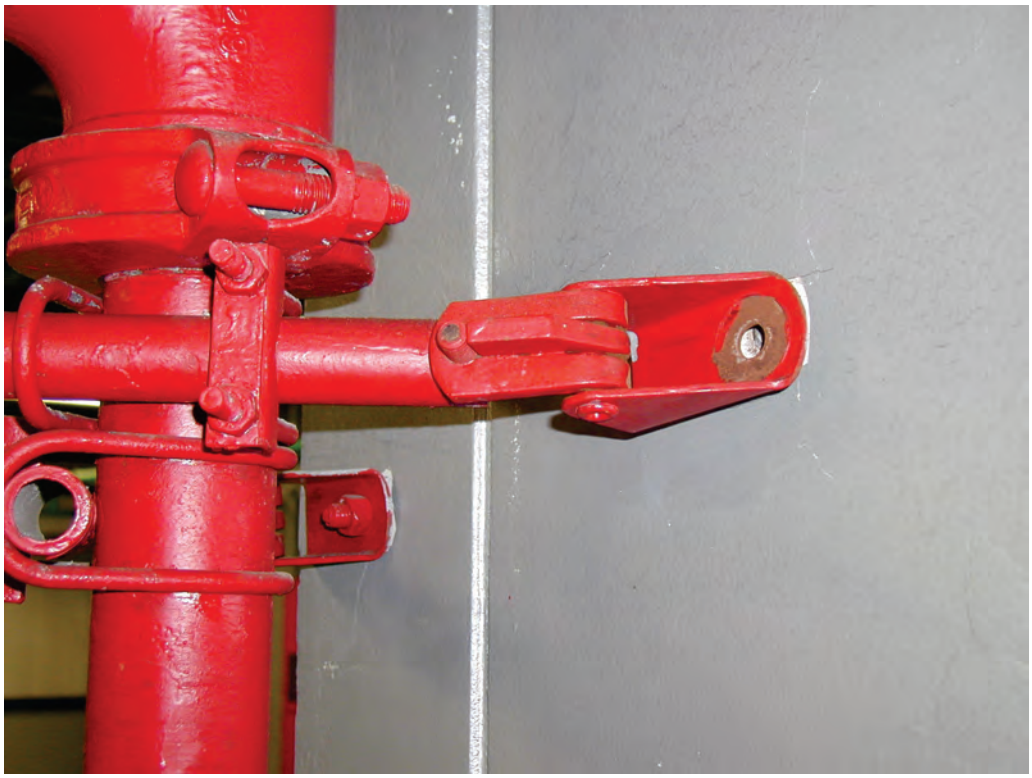


Figure 6.4.4.1-2 Wall-mounted pipe restraint failed due to inadequate connection to structural framing in the 2001 magnitude-8.4 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

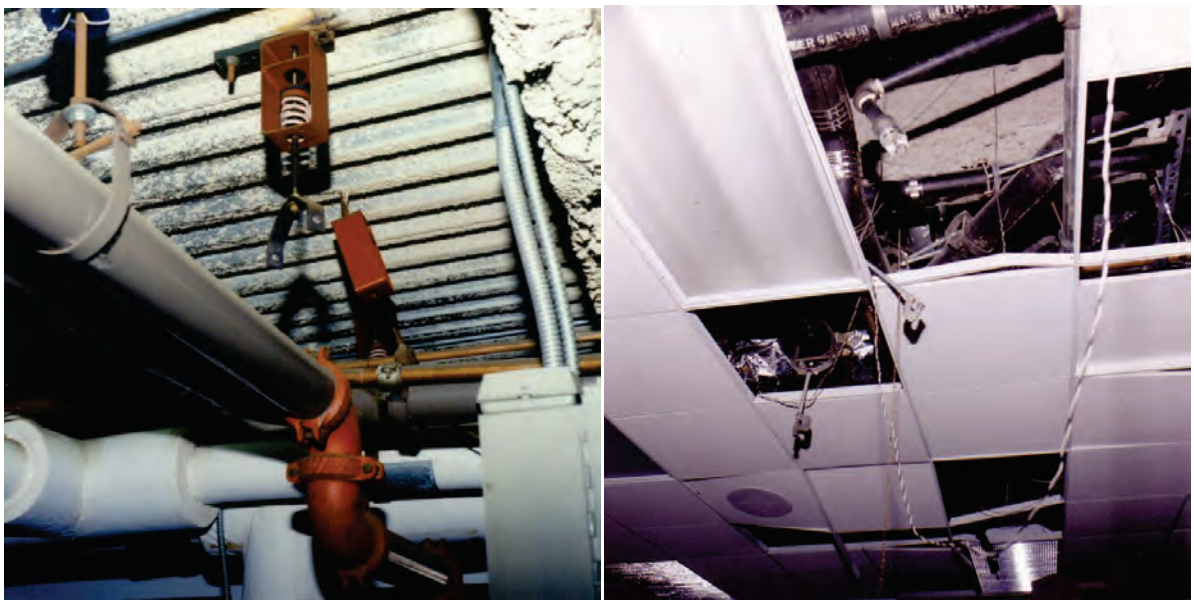


Figure 6.4.4.1-3 Damage to suspended fire protection piping from the 1994 Northridge Earthquake. Failed vibration isolators at left; failed C-clamps without beam clamp restraining straps shown at right (Photos courtesy of Mason Industries).



Figure 6.4.4.1-4 Collapse of water tank at left and broken piping disabled the fire protection system at this power plant in Port-au-Prince and led to the temporary plant closure in the 2010 magnitude-7 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.4.1-5 Unanchored holding tank slid on concrete pad, breaking fire protection piping and disabling the fire protection system in the 2010 Haiti Earthquake. In this case, the piping was well anchored but the tank was unrestrained (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.4.1-6 Damage to industrial fire protection piping located on jetty in 2001 Peru Earthquake. Longitudinal slip at U-bolt shown at left; this U-bolt still intact but other U-bolts broke and fell off the jetty. Failure of joint coupling and crushing of pipe shown at right (Photo courtesy Eduardo Fierro, BFP Engineers).

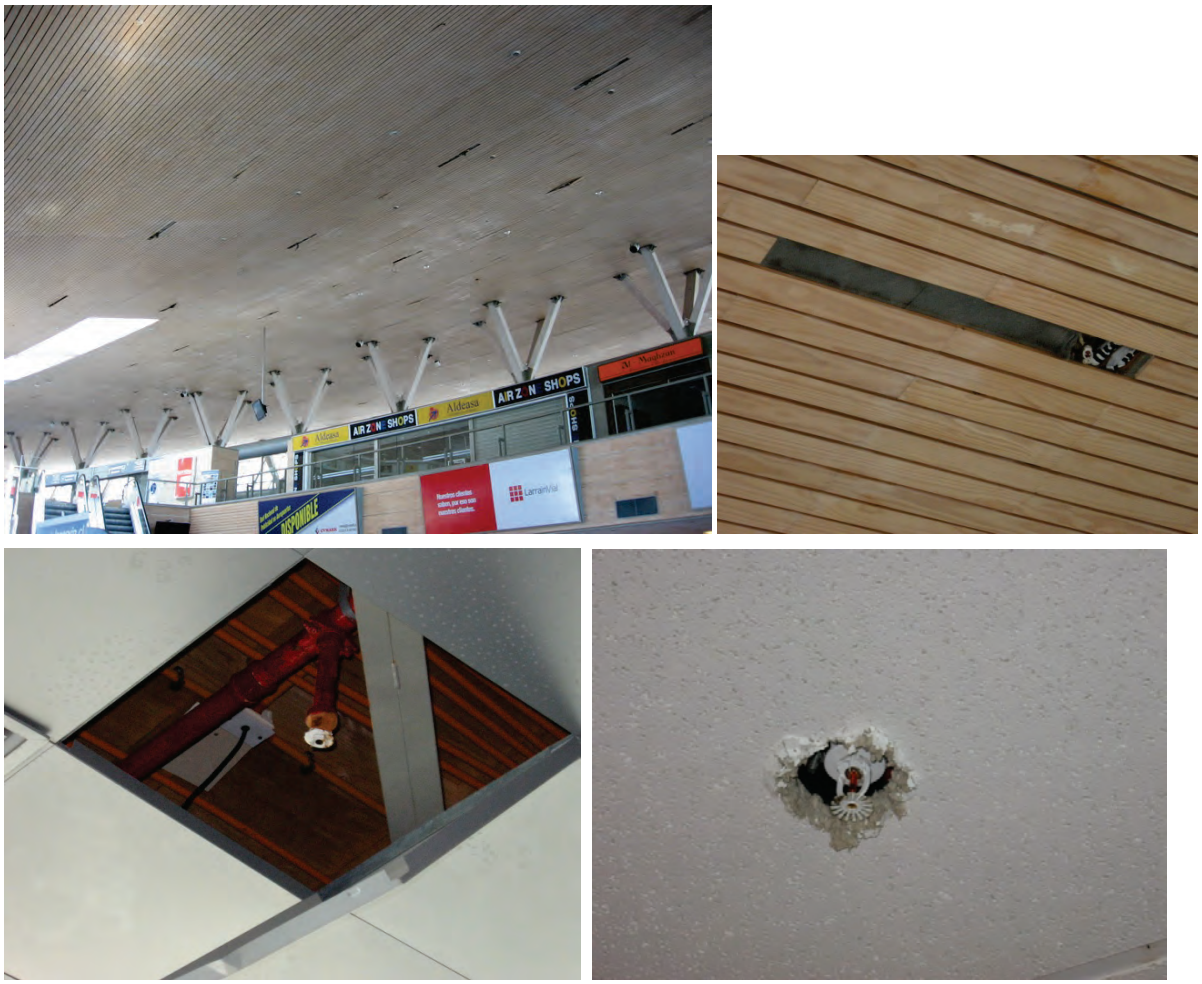


Figure 6.4.4.1-7 Conflicts between the sprinkler heads and several types of ceiling finishes resulted in damage to the ceilings, sprinkler heads and subsequent water damage at the Concepción airport in the 2010 magnitude-8.8 Chile Earthquake (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

Seismic Mitigation Considerations

- Fire suppression systems include many components, all of which must be properly restrained or anchored for the system to function as intended. Pumps, holding tanks, control panels, control sensors, piping and sprinkler heads must all be protected from earthquake damage. In addition to seismic restraints for each component, it is important to check for potential conflicts with other structural and nonstructural elements and for falling hazards.
- Performance of fire protection piping systems that already have some bracing can be improved by addressing the vulnerabilities identified in past earthquakes. Many of these issues have been addressed in the 2010 edition of the NFPA 13 seismic provisions. These include:
    - Limits on the lateral brace spacing on mains and cross-mains to limit bending stresses in the piping, which will reduce the likelihood of leaks.
    - Lateral restraint requirements for branch lines. Laterally restraining the branch lines should reduce the potential for adverse interactions between the sprinkler heads and the ceiling system.
    - The prescriptive allowable fastener load tables have been revised to provide design values consistent with current materials standards. The values in previous editions may be unconservative.
    - The prescriptive values for brace assemblies have been revised. The values in previous editions may be unconservative.
- NFPA 13 Chapter 9 contains many prescriptive bracing details for new installations which may be utilized to retrofit existing systems. As an alternative, seismic restraint details for pressure piping shown in Sections 6.4.3.1 through 6.4.3.8 can be adapted for use with fire protection piping. One significant difference is that components, supports, and seismic restraint hardware for fire protection systems must all be certified (UL listed, FM approved, etc.). This requirement also applies to seismic restraint components for fire protection control panels, pumps, and holding tanks.
- Some proprietary systems are available that reduce the vulnerability of sprinkler heads in suspended ceiling grids. One such system provides flexible sprinkler drops so the sprinkler head can move freely with the ceiling grid (see Figure 6.4.4.1-11); this proprietary system has been shake table tested. Another system is an “integrated” ceiling system where the ceiling grid, acoustical panels, lighting, ducts and air diffusers, and sprinkler piping are all shop assembled in modules; this system alleviates the problem of differential movement of the component parts. These types of solutions

may greatly reduce the seismic vulnerability of sprinkler heads. Check the internet for these and other proprietary systems.

- Two details are included here that are unique to fire protection systems. Figure 6.4.4.1-11 provides one type of detail for a sprinkler drop and Figure 6.4.4.1-12 provides a detail for an end of line restraint required for feeds or cross mains.
- Several engineered seismic bracing systems are commercially available and can be customized for most applications. Check the internet for these proprietary systems and whether they are UL listed, OSHPD approved, FM approved, etc. as required.
- For California schools and essential facilities, DSA Policy 10-01, *Plan Submittal Requirements: Automatic Fire Sprinkler Systems (AFSS)* (California Department of General Services, 2010b), states that as of July 2010, deferred submittals (similar to "design-build" as discussed in Section 5.3.2) for fire protection systems will no longer be accepted. These systems must be submitted as a complete package as part of the initial project submittal.

MITIGATION EXAMPLES



Figure 6.4.4.1-8 There was no damage to the *fire suppression equipment in this control room in the 2001 Peru E*arthquake because the pump and the control panel were well anchored and the piping had flexible connections with adequate sized wall penetration and no overhead falling hazards (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.4.1-9 Transverse and longitudinal restraints on fire protection distribution line (Photo courtesy of Cynthia Perry, BFP Engineers).



Figure 6.4.4.1-10 Flexible hose between sprinkler line and ceiling allowing the sprinkler head to move with the suspended ceiling without causing damage to the sprinkler system (Photo courtesy of Flexhead).

MITIGATION DETAILS

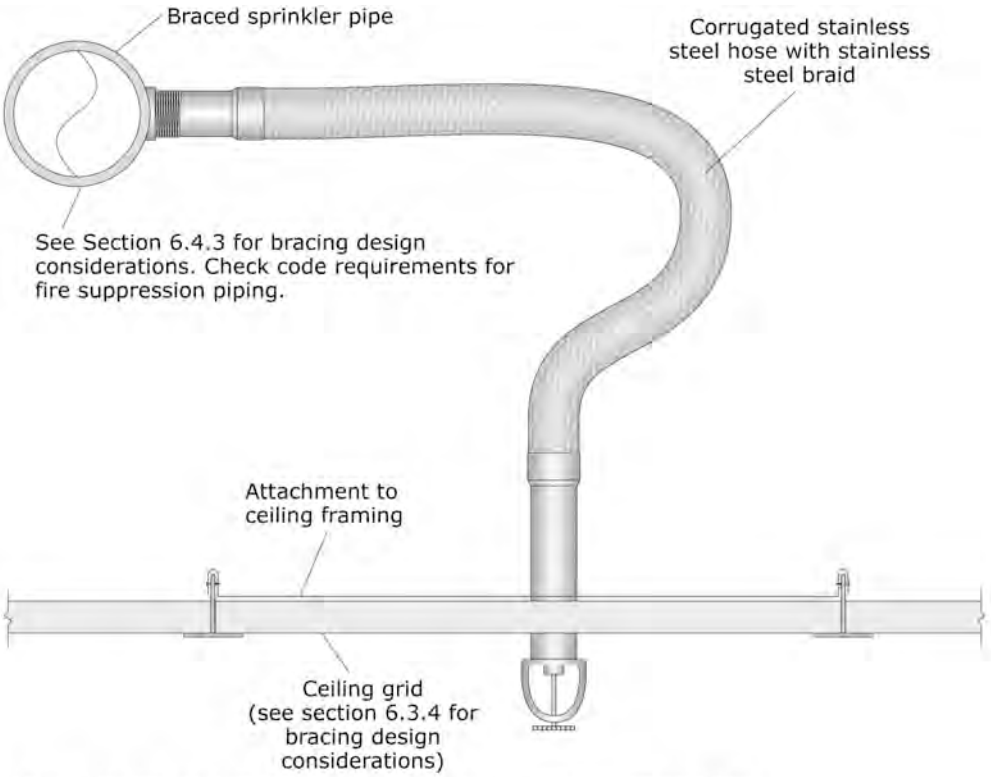


Figure 6.4.4.1-11 Flexible sprinkler drop (ER).

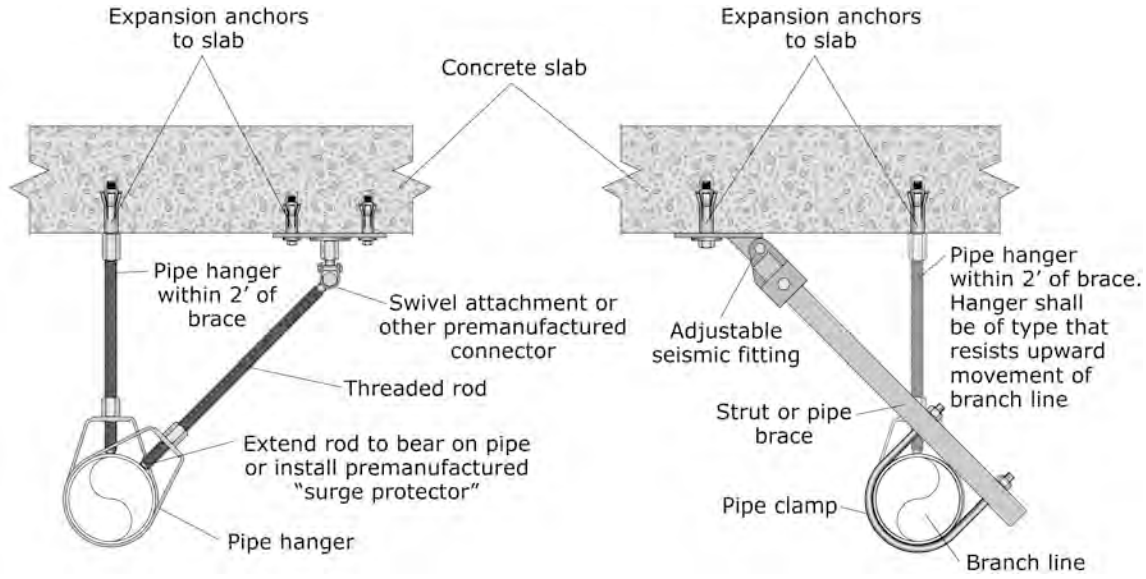


Figure 6.4.4.1-12 End of line restraint (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.5 Fluid Piping, not Fire Protection

6.4.5.1 Hazardous Materials Piping

This category covers fluid piping, other than pressure piping or fire protection piping, that transfers fluids under pressure, by gravity, or that are open to the atmosphere. Specifically, the fluids in this category are hazardous and flammable liquids that would pose an immediate life safety danger due to their inherent properties. Hazardous materials and flammable liquids that would pose an immediate life safety danger if exposed are described in NFPA Standards such as NFPA 49, *Hazardous Chemicals Data*, and NFPA 491, *Hazardous Chemical Reactions,* as listed in the NFPA Fire Protection Guide to Hazardous Materials (NFPA, 2010).

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and other Structures*, (ASCE, 2010), requires the use of a component importance factor, I_p, of 1.5 if the component conveys, supports or contains toxic, highly toxic or explosive substances. The quantities of materials that trigger the requirements are established by the authority having jurisdiction and are based on a determination of the threat to the public if the material is released.

- The piping and supports may be designed using the provisions of ASME B31 *Process Piping* (ASME, 2008) or ASCE/SEI 7-10. If ASME B31 is used, the forces and displacements of ASCE/SEI 7-10 must be used for design.
- In addition to force and displacement design, special certification is required demonstrating that any component containing hazardous materials with an I_p of 1.5 will maintain containment under seismic loading. Thus any component covered by the above descriptions is a "designated seismic system" and, unless it falls under the exemption for mechanical and electrical components in Seismic Design Category B, requires engineering, special certification, or special inspection.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies hazardous material piping systems as both acceleration and deformation sensitive.

- Hazardous material piping systems are subject to the requirements of ASCE/SEI 41-06 when
    - The performance level is Immediate Occupancy or Life Safety in high, moderate, and low seismicity areas.
    - The performance level is Hazards Reduced in high, moderate, and low seismicity areas and the system is close proximity to occupancy such that leakage could cause an immediate life safety threat.
- Acceptance criteria focus on performing drift analysis to determine if the glazing can accommodate the expected story drifts, and the anchorage of the panels under seismic loading. The evaluation approach is similar to that used in ASCE/SEI 7-10.
    - ASCE/SEI 41-06 requires compliance with the anchorage provisions of the standard when the performance level is Life Safety or higher.
    - Rehabilitation may utilize prescriptive standard.

Typical Causes of Damage

- . Vulnerable locations in hazardous fluid piping include joints, bends, connections to rigidly mounted equipment and risers subjected to significant relative movement between floors. These piping systems have failure modes common to all piping systems, but the consequences of failure are more severe.
- Fluids may leak from damaged joints or broken pipe. Hazardous and flammable fluid spills may result in fire, explosion, or evacuation to avoid personal exposure. The risk for injury, property losses and business outages is high.
- Damage to any part of the hazardous piping system may compromise its functionality and connected equipment or systems may be disabled due to piping leaks or failures. For example, many hazardous piping systems are designed with safety systems to reduce the likelihood of leakage such as secondary containment with double walled pipes, automatic shut-off or excess flow valves, leak detection systems, use of non-jointed piping and highly ductile pipe materials, etc. If not properly designed, installed and maintained, any of these secondary or backup systems could also be damaged resulting in hazardous material leaks or loss of functionality.

DAMAGE EXAMPLES



Figure 6.4.5.1-1 Earthquake, liquefaction, and tsunami damage to oil supply lines at the port in Talcahuano in the 2010 magnitude-8.8 Chile Earthquake. The pier in upper photo collapsed over much of its length dragging the pipes down into the water; this caused tension failures in some pipe joints and also resulted in structural damage to the buildings (Photos courtesy of Eduardo Fierro, BFP Engineers).





Figure 6.4.5.1-2 Basement level at power plant in Port-au-Prince flooded with oil and water in the 2010 magnitude-7 Haiti Earthquake creating hazardous conditions for inspection and clean-up (Photos courtesy of Eduardo Fierro, BFP Engineers).





Figure 6.4.5.1-3 Elephant foot damage to inadequately anchored fuel tank in the 2010 Chile Earthquake also resulted in damage to fuel lines. Close-up photo shows failed pipe at welded joint (left) and pipe segment with attached valve (foreground) tore out of the tank wall (Photos courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

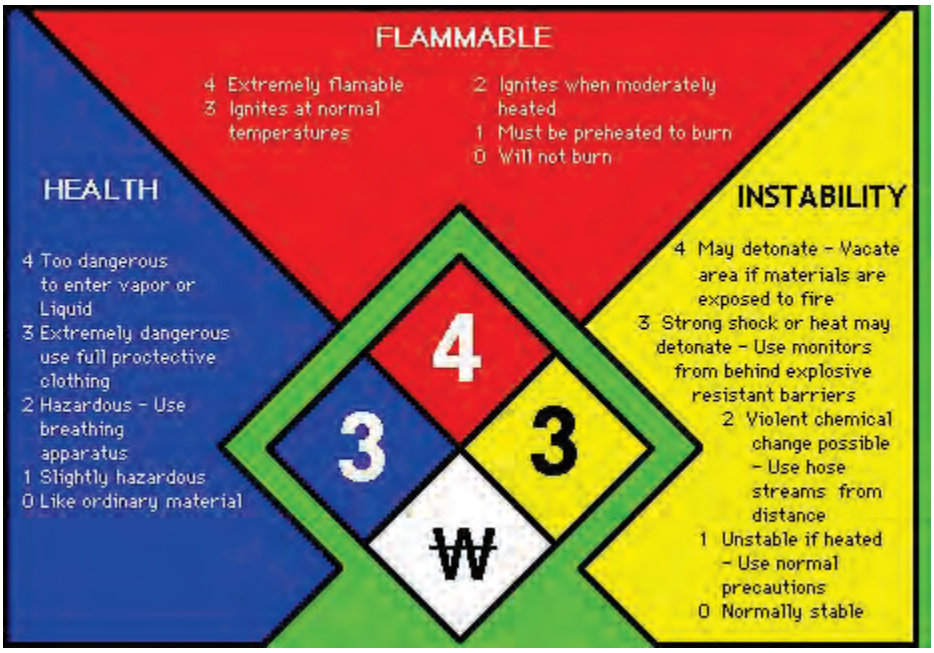
Fuel and natural gas lines are found in many common settings, but this category also covers more hazardous types of piping found in industrial facilities, power plants or hospitals. The national standard for pressure piping, ASME B31.3, *Process Piping* (ASME, 2008), defines hazardous fluid service as "a fluid service in which the potential for personnel exposure is judged to be significant and in which a single exposure to a very small quantity of a toxic fluid, caused by leakage, can produce serious irreversible harm to person on breathing or bodily contact, even when prompt restorative measures are taken."

The International Fire Code (IFC) contains provisions that deal with each type of hazardous material such as corrosives, cryogenics, flammable and combustible liquids, highly toxic materials, organic peroxides, oxidizers, pyrophorics, reactive materials, and water reactive solids and liquids. Independent of any seismic concerns, there are many provisions that apply to piping systems that convey these materials. There may be requirements, such as secondary containment, backup safety systems, emergency shut-off, monitoring or leak detection. NFPA 704, Standard System for the Identification of Hazards of Materials for Emergency Response (NFPA, 2007b) provides a classification and labeling system for hazardous materials as shown in Figure 6.4.5.1-4. The four-part diamond symbol is coded by color and position for type of hazard; the hazards associated with health, flammability and reactivity are further coded by degree of hazard. Use of appropriate hazard labeling for hazardous piping and associated containers or tanks of hazardous materials, as well as buildings housing such materials, is important so that fire fighters, emergency responders, and engineers performing postearthquake inspections will be aware of the hazards present.

- Requirements for seismic shut-off valves, excess flow switches, and excess flow valves for natural gas lines may vary by jurisdiction. While some jurisdictions now require seismic shut-off valves on some types or sizes of gas lines, many utilities do not encourage their use for residential service due to the difficulty in resetting them all following an earthquake. Some jurisdictions have tried to avoid this by requiring excess flow valves instead; check the applicable jurisdiction for specific requirements in your area.
- Seismic restraint details for pressure piping shown in Sections 6.4.3.1 through 6.4.3.8 can be adapted for use with hazardous fluid piping. Nevertheless, additional care is required in the design, installation, inspection, and maintenance of hazardous fluid piping systems. They may require specialized piping analysis, more frequent supports, ductile materials, continuous piping without joints, special welding procedures, special inspections, special purpose pipe clamps to avoid scratching the pipe or to prevent

corrosion, special insulation and consideration of large thermal differentials. Hazardous piping systems often require secondary containment such as double-walled piping. In addition, they may require monitoring, leak detection systems, excess flow switches, excess flow valves or seismic shut-off valves, use of protective sleeved connections, or cushion clamps. There are thousands of possible hazardous chemical streams and dozens of different pipe materials. Design of seismic restraints for these systems is a highly specialized field and may require coordination between the mechanical engineer, hazardous piping expert, and a seismic piping expert. There are currently few references available that deal specifically with the seismic issues related to these hazardous systems.

MITIGATION EXAMPLES



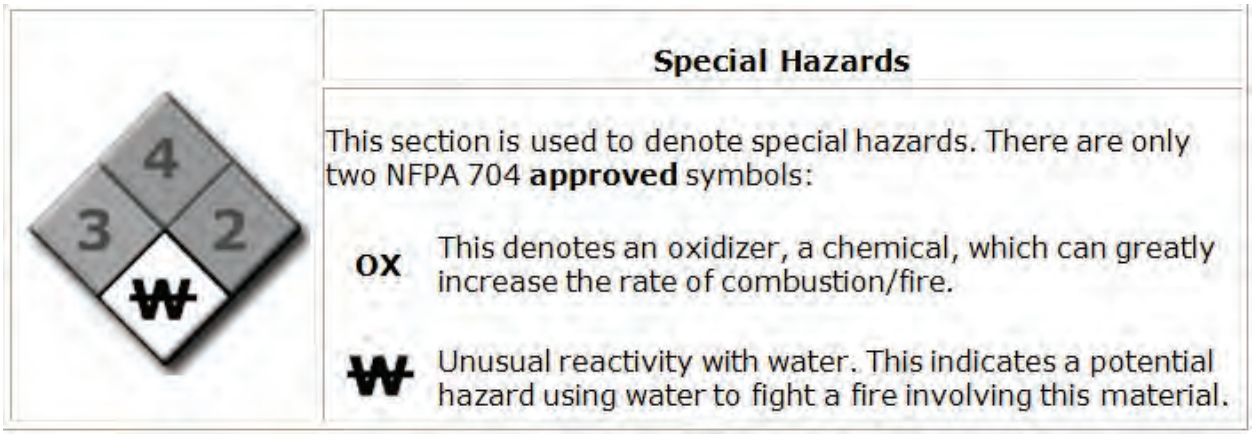


Figure 6.4.5.1-4 Example of NFPA 704 Fire Diamond used to label hazardous substances. The four divisions in the diamond are typically color-coded, with blue indicating level of health hazard, red indicating flammability, yellow (chemical) reactivity, and white containing special codes for unique hazards. Each of health, flammability and reactivity is rated on a scale from 0 (no hazard; normal substance) to 4 (severe risk). This labeling scheme is used in the U.S. but Canada, the European Union, Japan, etc. have different labeling schemes that should be followed for facilities outside the U.S.



Figure 6.4.5.1-5 Two examples of double walled piping used for secondary containment of hazardous fluids. Preassembled double walled pipe with centering devices or spacers separating the inner and outer pipe is available commercially, but as shown here, the outer pipe was installed and leak tested prior to pulling the inner pipe through. Note the yellow color coded labels indicate reactive materials; flow direction also marked prominently (Photos courtesy of Jeffrey Soulages, Intel Corporation).



Figure 6.4.5.1-6 Clockwise from top: a) Sleeved pipe connections where seismic anchorage consists of cushioned pipe clamp attached around outer sleeve and inner pipe not restrained longitudinally. b) Airgas canisters chained and strapped to supports, fitted with flexible hose, stainless steel piping (note blue label), and a row of valves. c) Label on tank shows example of European ADR danger labeling scheme. d) Excess flow valve for large gas tank (Photos courtesy of Jeffrey Soulages, Intel Corporation).



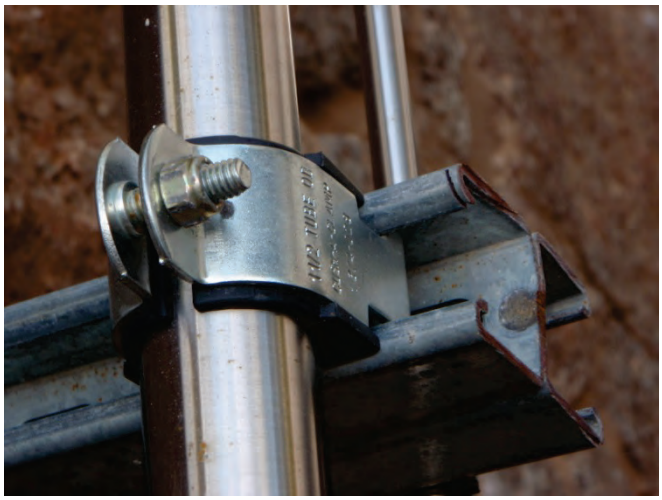


Figure 6.4.5.1-7 Process nitrogen piping outside engineering building on the UC Berkeley campus; strut clamp has rubber fittings to protect the stainless steel piping (Photos courtesy of Cynthia Perry, BFP Engineers).



Figure 6.4.5.1-8 Two examples of seismic shut-off valves in San Francisco Bay Area. Top photo at Marine Mammal Center; lower photo at six unit apartment building in Oakland (Photos courtesy of Cynthia Perry, BFP Engineers).

MITIGATION DETAILS

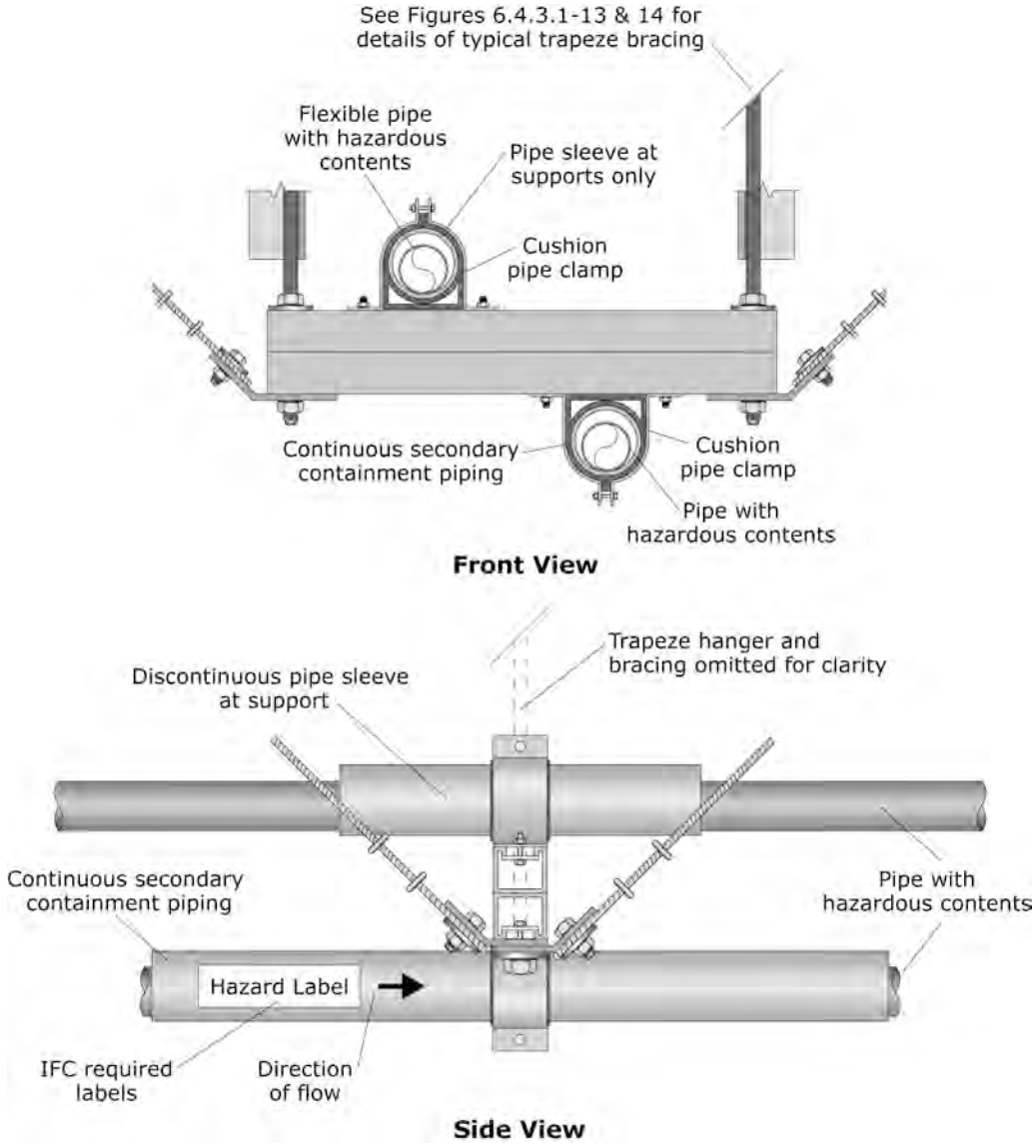


Figure 6.4.5.1-9 Hazardous piping examples (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.5 Fluid Piping, not Fire Protection

6.4.5.2 Nonhazardous Materials Piping

This category covers fluid piping, other than pressure piping or fire protection piping, that transfers fluids under pressure, by gravity, or that are open to the atmosphere. Pressure piping covers piping where the internal pressure is in excess of 15 psf; this category covers piping with pressures lower than 15 psf. The fluids in this category include drainage and ventilation piping, hot, cold, and chilled water piping; and piping carrying other nonhazardous liquids. These fluids, in case of line rupture, would cause property damage, but pose no immediate life safety danger. Like any other piping, failure of the pipes or pipe supports could results in falling hazards.

Provisions

BUILDING CODE PROVISIONS

Piping systems, including their supports, are designed using the provisions of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The principal objective is to prevent the system from falling. Depending on the configuration of the piping, it may also be sensitive to building displacements if it is connected to multiple levels in the same structure, or is supported by adjacent structures.

- ASCE/SEI 7-10 exempts piping from seismic bracing requirements in Seismic Design Category C if $I_p = 1.0$.
- ASCE/SEI 7-10 requires seismic design of piping in Seismic Design Categories D, E, and F that weighs more than 5 pounds per linear foot.
- Unbraced piping attached to in-line equipment must be provided with flexibility adequate to accommodate seismic relative displacements.
- ASCE/SEI 7-10 contains a number of bracing exemptions for suspended piping based on the pipe size and support conditions:
    - Trapeze assemblies are used to support piping whereby no single pipe exceeds the certain size limits and the total weight of the piping supported by the trapeze assemblies is less than 10 lb/ft.
    - Suspended piping where the hangers are less than 12 inches long. Rod hangers must be detailed to prevent bending of the rod.

- High-deformability or limited deformability piping (such as steel and copper pipe) where the pipe diameter is small (anywhere from 1- to 3-inch diameter depending on the building location and occupancy). Provisions must be made to accommodate anticipated movement (such as by providing flexible connections, as shown in Section 6.4.3.3) and to avoid impact with other structural or nonstructural components or to protect the piping in the event of such impact. Allowable stresses are provided in ASCE/SEI 7-10 for suspended pressure piping.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies suspended pressure piping as force controlled, meaning that the principal objective is to prevent piping from falling. Where piping runs between floors or crosses seismic joints it as also deformation controlled. Piping must meet the force and deformation requirements of the standard when the performance level is Immediate Occupancy, and the pipes are 2 inches or more in diameter and suspended more than 12 inches from the structure.

Typical Causes of Damage

- Nonhazardous fluid piping is sensitive to both acceleration and deformation. Vulnerable locations include joints, bends, connections to rigidly mounted equipment and risers subjected to significant relative movement between floors. These piping systems have failure modes common to all piping systems.
- Fluids may leak from damaged joints or broken pipe; water leakage has been a major source of damage in past earthquakes.
- Damage to any part of the piping system may compromise its functionality and connected equipment or systems may be disabled due to piping leaks or failures.

DAMAGE EXAMPLES



Figure 6.4.5.2-1 Broken copper hot water piping for at the San Carlos Hospital in the 2010 Chile Earthquake. Piping failure caused by movement of inadequately braced boiler shown at left (Photos courtesy of Gilberto Mosqueda, SUNY Buffalo).



Figure 6.4.5.2-2 Broken copper piping for hot water supply in residential building in the 2010 Chile Earthquake. Trapeze shown not laterally braced but hangers appear to be less than 12″ in length and may not have required lateral restraints per ASCE 7-10 (Photo courtesy of Gokhan Pekcan).



Figure 6.4.5.2-3 Photos displaying resilience of piping systems; this building suffered a partial structural collapse along one side in the 2010 Chile Earthquake. The only broken pipe (shown at lower right) was along the collapsed side; the other piping had broken pipe supports in some locations but the joints remained largely intact, even with these very large deformations (Photos courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- Seismic restraint details for pressure piping shown in Sections 6.4.3.1 through 6.4.3.8 can be adapted for use with fluid piping. The same types of suspended, wall-, floor-, or roof-mounted details also apply to these types of piping.
- Insulation must be coordinated with pipe supports; the presence of insulation or a protective sleeve between the pipe and the pipe strap or clamp may allow the pipe to slip longitudinally.
- Note that where a pipe carries water in a facility that uses magnesium, it should be treated the same as hazardous material piping due to the potentially violent reaction between some forms of magnesium and water.

MITIGATION EXAMPLES

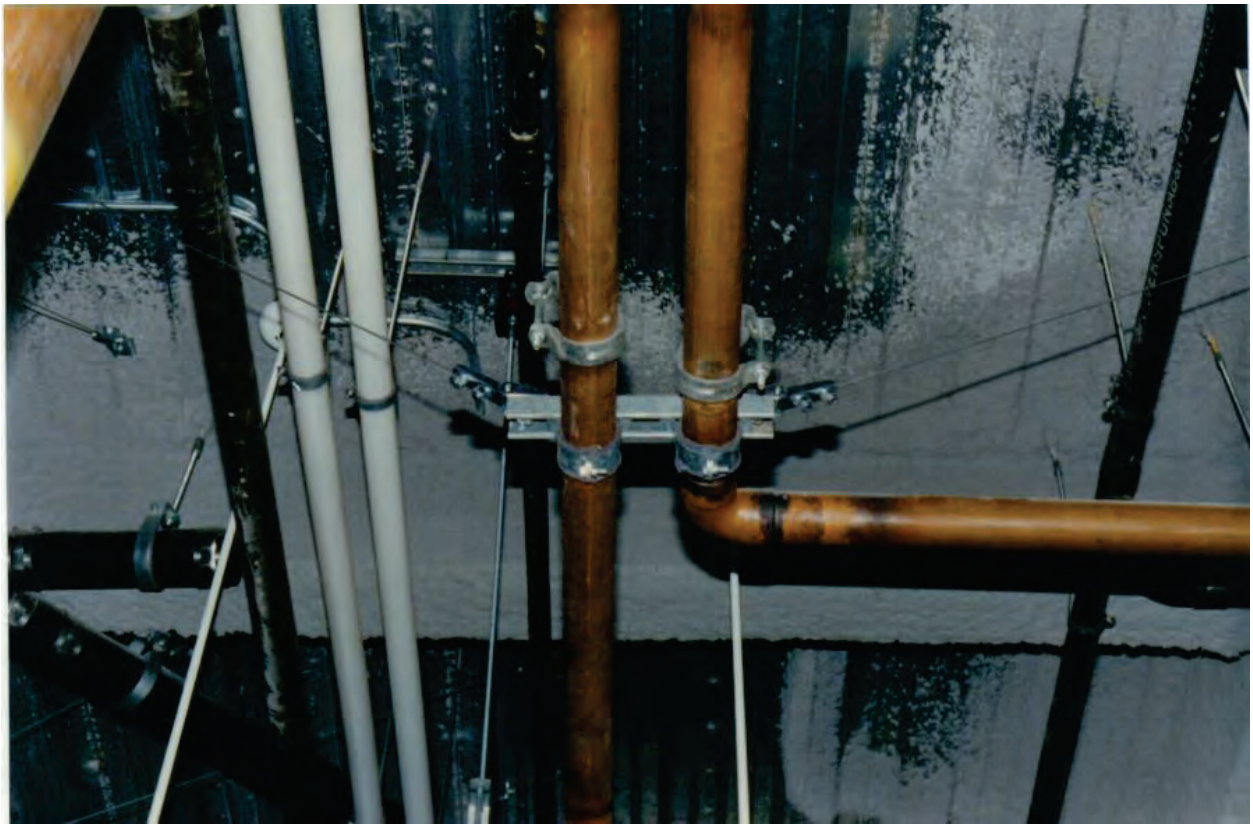


Figure 6.4.5.2-4 Cable bracing used to restrain overhead copper piping (Photo courtesy of Mason Industries).



Figure 6.4.5.2-5 Poor example of sanitary sewer pipe support installed in San Francisco Bay Area in 2010; strut clamp has inadequate edge distance to end of strut and could slip off the end (Photo courtesy of Cynthia Perry, BFP Engineers).



Figure 6.4.5.2-6 Piping installation in garage of mixed commercial/residential building San Francisco Bay Area completed in 2010. Note piping and trapeze supports do not have lateral restraints as all hangers were kept under 12″ in length; only the sprinkler lines were laterally restrained. (Photo courtesy of Cynthia Perry, BFP Engineers).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.6 Ductwork

6.4.6.1 Suspended Ductwork

This category covers suspended HVAC ducts; see Section 6.4.1.5 for suspended HVAC equipment.

Provisions

BUILDING CODE PROVISIONS

Ductwork, including its supports, is designed using the provisions of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The principal objective is to prevent the duct system from falling. Depending on the configuration of the ductwork, it may also be sensitive to building displacements if it is connected to multiple levels in the same structure, or is supported by adjacent structures.

- ASCE/SEI 7-10 exempts ductwork from seismic bracing requirements in Seismic Design Category C if $I_p = 1.0$.
- ASCE/SEI 7-10 requires seismic design for all ductwork in Seismic Design Categories D, E, and F that weighs more than 5 pounds per linear foot.
- Unbraced piping attached to equipment in-line with the ductwork must be provided with flexibility adequate to accommodate seismic relative displacements.
- ASCE/SEI 7-10 contains a number of bracing exemptions for ductwork that does not carry toxic or flammable gases or is used for smoke control. Ductwork is exempt if:
    - Trapeze assemblies are used to support ductwork and the total weight of the ductwork supported by trapeze assemblies is less than 10 lb/ft.
    - The ductwork is supported by hangers and each hanger in the duct run is 12 inches or less in length from the duct support point to the supporting structure. Rod hangers must be detailed to prevent bending of the rod.
    - Design for the seismic forces and relative displacements are not be required where provisions are made to avoid impact with larger ducts or mechanical components or to protect the ducts in the event of such impact, and HVAC ducts have a cross sectional area of less than 6 square feet, or weigh less than 17 lb/ft.
- HVAC duct systems fabricated and installed in accordance with approved bracing standards meet the lateral bracing requirements ASCE/SEI 7-10.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies ductwork as force controlled, meaning that the principal objective is to prevent the ductwork from falling. Where ductwork runs between floors or crosses seismic joints it as also deformation controlled. Ductwork must meet the force and deformation requirements of the standard when:

- The performance level is Immediate Occupancy,
- The performance level is Life Safety in regions of high or moderate seismicity, and:
    - The ductwork conveys hazardous materials, or
    - The ducts are 6 square feet or more in area, or
    - The ducts are suspended more than 12 inches from the structure.

Prescriptive standards for seismic bracing may be used for ductwork meeting the life safety and immediate occupancy performance objectives.

Typical Causes of Damage

- Unbraced ducts may swing and impact other items. They may become damaged at restraints or "hard spots" along the duct path such as at connections of braced in-line equipment, at connections to floor-mounted equipment, or at wall or slab penetrations. Inadequately supported ducts may come loose from the HVAC equipment or diffusers to which they are connected and fall.
- Ducts may be damaged by differential movement such as at building separations.

DAMAGE EXAMPLES



Figure 6.4.6.1-1 Unbraced ducts separated at bend in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries).

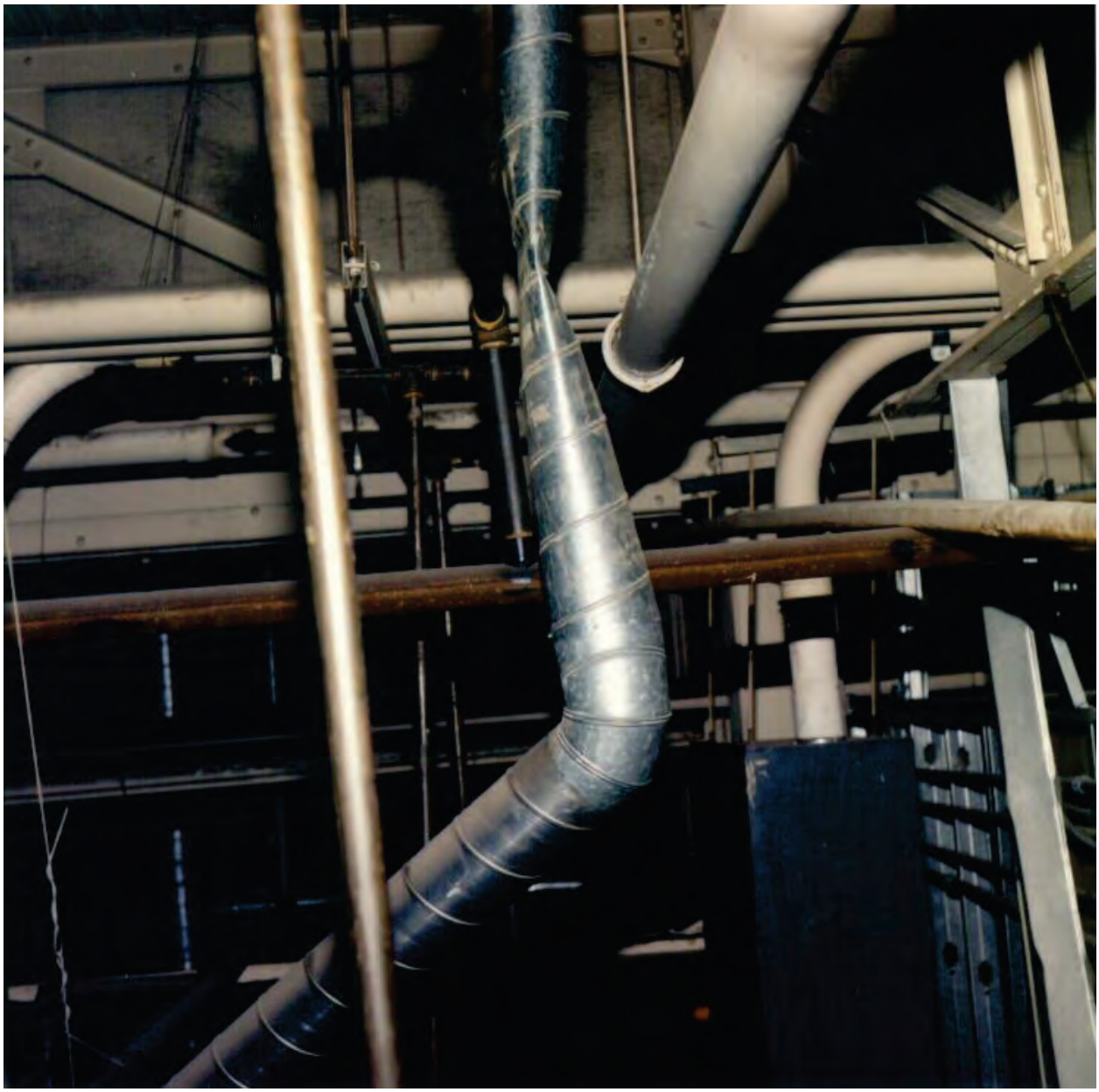


Figure 6.4.6.1-2 Unbraced duct damaged by impact with piping in 1994 Northridge Earthquake (Photo courtesy of Mason Industries).

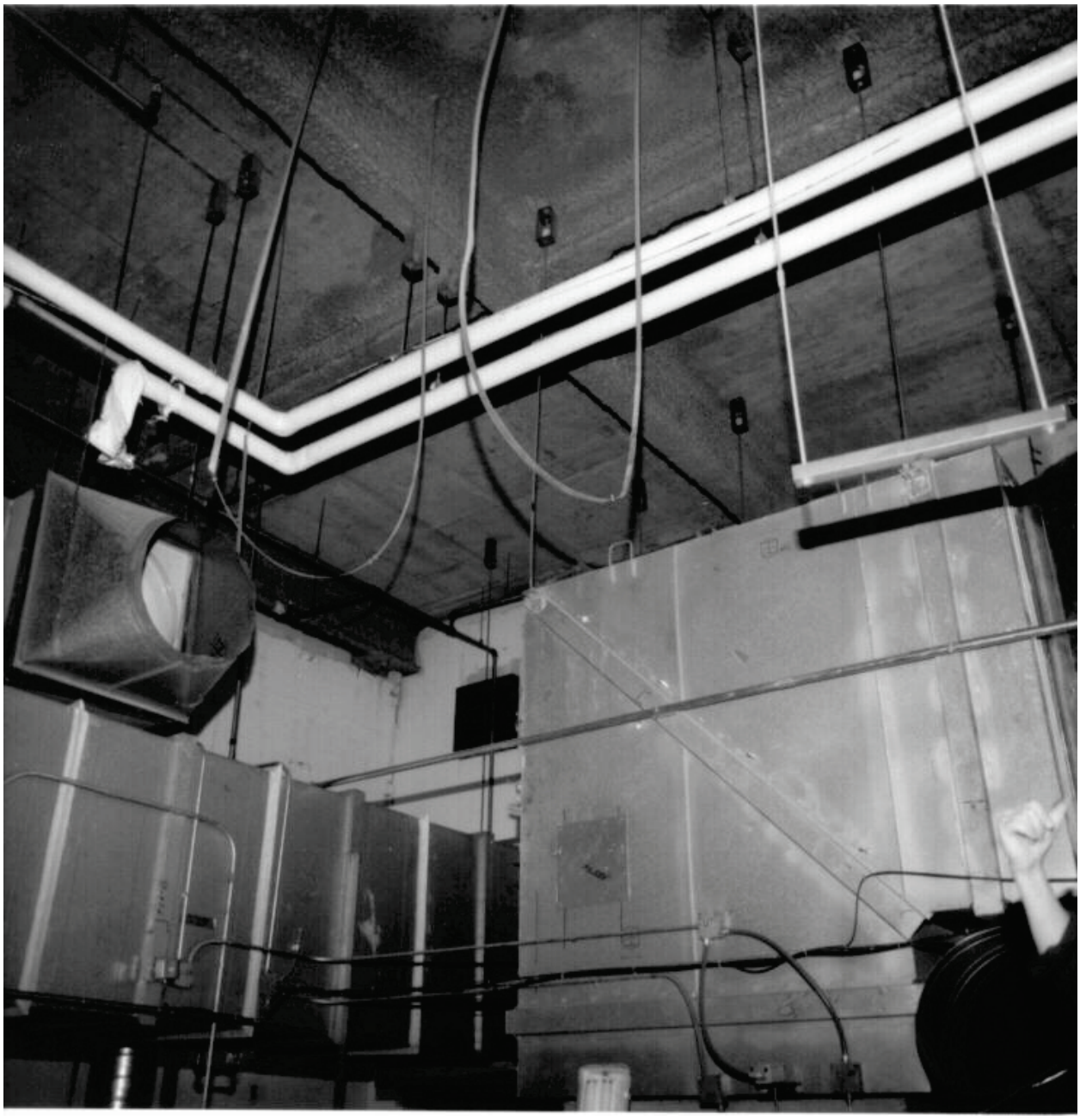


Figure 6.4.6.1-3 Collapsed unbraced ducts and hangers dangling from floor above in the 1994 Northridge Earthquake (Photo courtesy of Mason Industries).

Seismic Mitigation Considerations

- Details shown here are for suspended ducts. Ducts may also be floor-, wall- or roof-mounted, may cross building separations, or may be located in vertical chases. Refer to FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for attachment details, for other conditions and general information about installation.

- Ductwork required for HVAC systems in hospitals or other essential facilities may be classified as designated seismic systems with a component importance factor of 1.5. Such designated seismic systems may require engineering calculations, equipment certification, and additional inspections. Check ASCE 7-10 and the jurisdiction for specific requirements.

MITIGATION EXAMPLES



Figure 6.4.6.1-4 Rectangular duct supported by steel shapes with cable braces (Photo courtesy of Mason Industries).



Figure 6.4.6.1-5 Floor-mounted rectangular duct supported on braced support stand built up from steel angles (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.4.6.1-6 Roof-mounted rectangular duct supported on braced support stand built up from steel channels (Photo courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

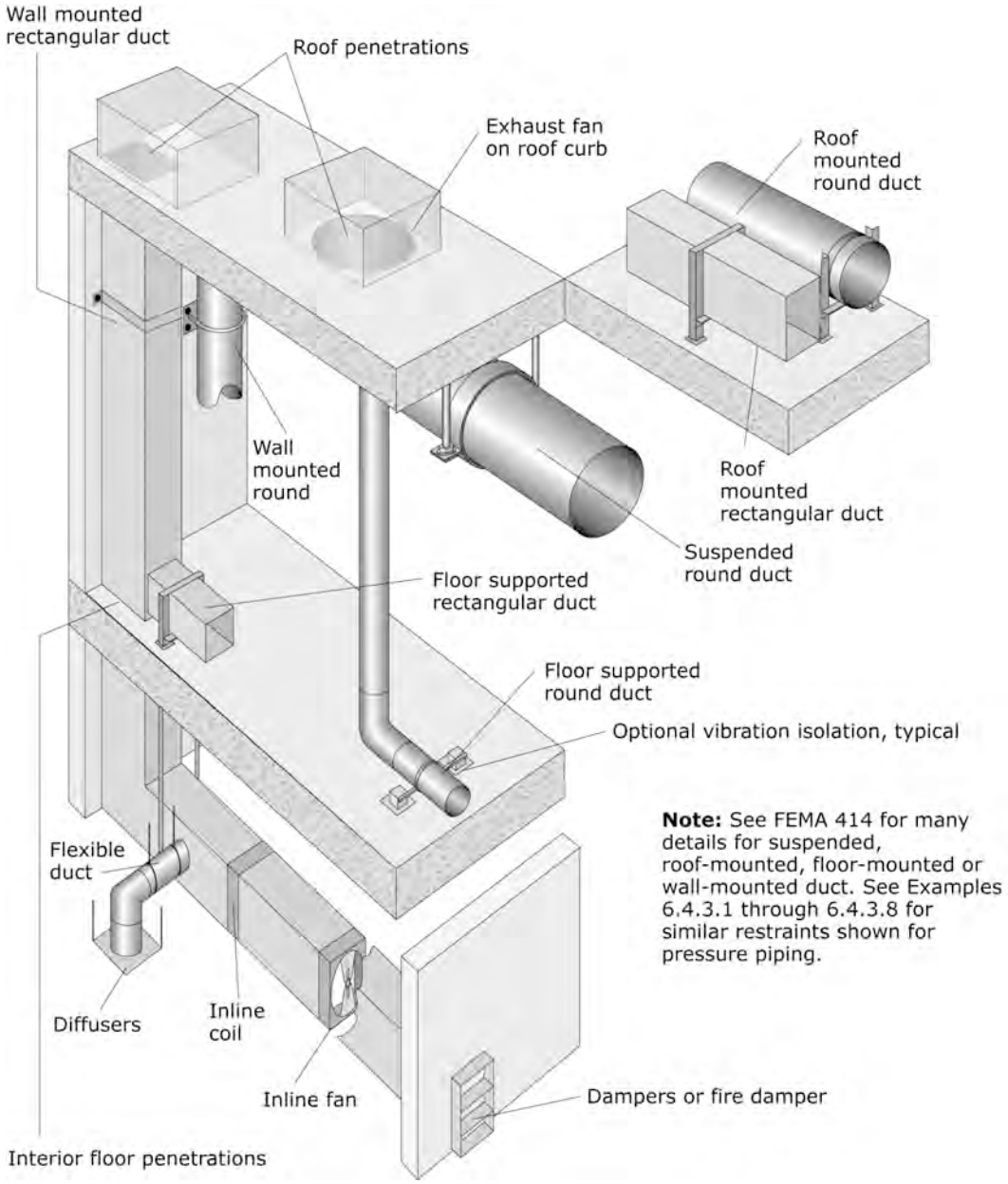


Figure 6.4.6.1-7 Overview of ductwork restraints (ER).

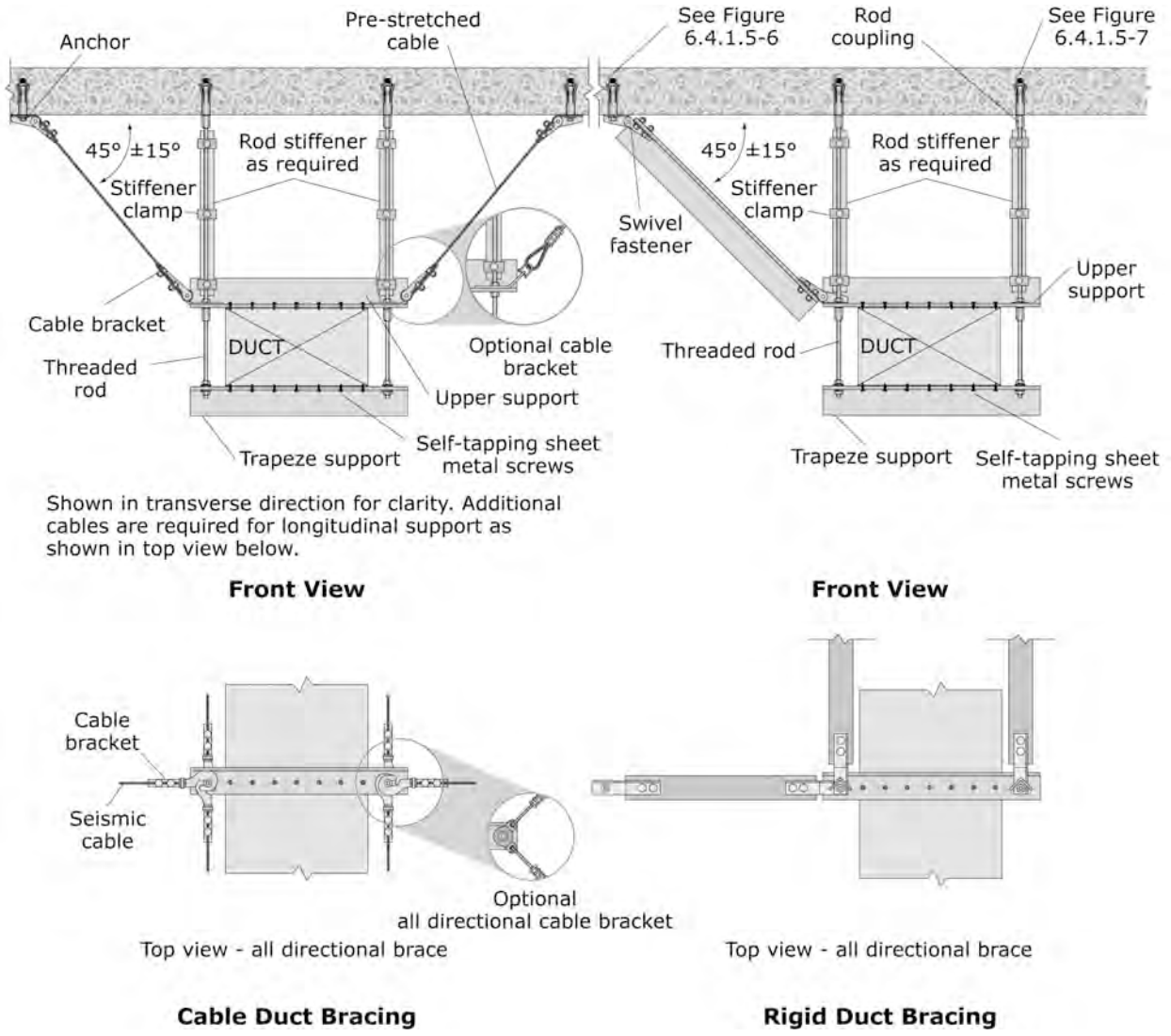


Figure 6.4.6.1-8 Suspended ductwork (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.6 Ductwork

6.4.6.2 Air Diffusers

This category covers suspended air diffusers or mechanical registers, typically part of a suspended ceiling system.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13 requires that appurtenances to ductwork such as dampers, louvers, and diffusers be positively attached with mechanical fasteners. For air diffusers mounted in suspended acoustic lay-in tile ceiling systems, ASTME E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010) requires that ceiling mounted air terminals or other services weighing less than 20 lb (9 kg) be positively attached to the ceiling suspension main runners or cross runners that have the same carrying capacity as the main runners.

RETROFIT STANDARD PROVISIONS

Suspended HVAC equipment in-line with ductwork, including air diffusers, are classified as force-controlled by ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007). ASCE 41-06 requires compliance with the anchorage provisions of the standard when:

- The performance level is Immediate Occupancy.
- The performance level is Life Safety in high seismicity areas, if
  - The item weighs over 20 pounds and is mounted over 4 feet above the floor.
- The recommended evaluation procedure is to use a prescriptive approach, such as provisions in ASCE/SEI 7-10 Section 13.6.7.

Typical Causes of Damage

- Air diffusers may pose a falling hazard if they are not supported independent of the ceiling. The diffuser may separate from the attached duct and fail to operate as intended.

DAMAGE EXAMPLES



Figure 6.4.6.2-1 Air diffusers fell to the floor; ducts hanging through ceiling grid as a result of the 1994 Northridge Earthquake (FEMA 74, 1994).



Figure 6.4.6.2-2 HVAC diffuser attached to the structure with four vertical hangers; ceiling system was damaged beyond repair in the 2001 Peru Earthquake but none of the diffusers or lights fell. Ceiling was demolished prior to photo (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- Requirements for ceiling mounted services in suspended acoustic ceilings are covered in ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010). Air diffusers and other ceiling-mounted services weighing less than 20 lb must have positive attachment to the ceiling grid. In addition to positive attachment to the grid, services weighing between 20 lb and 56 lb must have two 12 gauge safety wires connected to the structure above or to the ceiling hanger wires to prevent them from falling. Two diagonally opposite vertical safety wires can keep them from posing a risk to occupants below. Services weighing above 56 lb must be supported directly from the structure above by approved hangers; in some cases this can be accomplished with 4 taut 12 gauge wires, one located at each corner of the service. While ASTM E580 does

not require safety wires for items weighing less than 20 lb, use of at least one wire may be good practice considering the number of diffusers that have come down in recent earthquakes.

- Only intermediate duty or heavy duty grid may be used to support suspended acoustic ceilings with lights and mechanical services attached. For Seismic Design Category D, E & F, only heavy duty grid may be used. See Section 6.3.4.1 for additional ceiling requirements. For an existing unbraced ceiling, the addition of four diagonal wire braces at each corner of diffusers will limit horizontal movement of the diffuser and prevent impact with other suspended items. Diffuser restraints should be coordinated with the lateral restraints for the ceiling grid and may require engineering expertise.
- Do not brace diffusers to ducts, piping, or other nonstructural items.

MITIGATION DETAILS

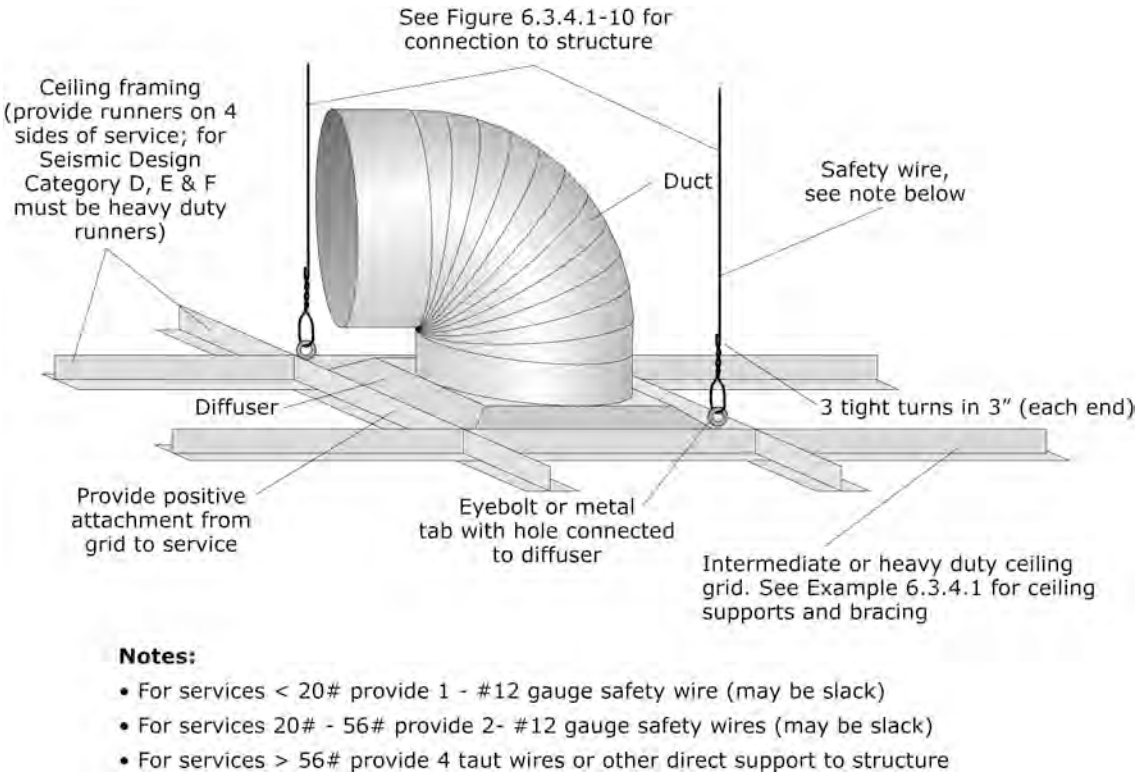


Figure 6.4.6.2-3 Ceiling-mounted diffuser (NE, ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.7 Electrical and Communications Equipment

6.4.7.1 Control Panels, Motor Control Centers, and Switchgear

This category includes tall, narrow floor-mounted electrical items in sheet metal cabinets such as electrical control panels, motor control centers, switchgear, and substations.

Provisions

BUILDING CODE PROVISIONS

Electrical control panels, motor control centers, switchgear, and substations are designed using the provisions of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The principal objective is to prevent the components from sliding or toppling. These components may also be sensitive to building displacements if they are both anchored to the floor and braced to the floor above.

- ASCE/SEI 7-10 requires anchorage design for all equipment in Seismic Design Categories D, E, and F if the equipment weighs over 400 pounds. Lighter components may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage design requirements must still be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Exempt items must also be provided with flexible connections between the equipment and associated raceways, bus ducts, or conduits if there is a potential for damaging differential movement between the equipment and connected components.
- Electrical component supports and their attachment to the component must be designed for the appropriate forces and displacements. Supports include braces, frames, skirts, legs, pedestals, and snubbers, as well as elements forged or cast as a part of the mechanical or electrical component. There are prescriptive requirements for reinforcing the cabinets around anchor points.
- The seismic design must consider the loads imposed on the components by attached utility or service lines that are attached to separate structures.
- Control panels, motor control centers, switchgear, and substations with slideout components must have a latching mechanism to hold the components in place.

- The design of the component cabinet must comply with the applicable National Electrical Manufacturers Association (NEMA) standards.
- If cutouts are made in the lower panels of the cabinet that were not made by the manufacturer, the effects of the cutouts on the strength of the cabinet should be specifically evaluated.
- Attachments for additional external items not provided by the manufacturer that weigh more than 100 lb should be evaluated.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies electrical equipment, including panel boards, motor control centers, and switch gear as force controlled. These components are subject to the provisions of the standard when the performance level is Immediate Occupancy. The requirements also apply when the performance level is Life Safety in high and moderate seismicity areas, and the equipment is over 6 feet in height and weighs more than 20 pounds. When applicable, electrical equipment meeting any of the following criteria must comply with the requirements of ASCE/SEI 41-06:

- The item weighs more than 400 pounds.
- The item is unanchored, weighs over 100 pounds and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 when design loads are applied.
- The item weighs over 20 pounds and is mounted over 4 feet above the floor.
- Building operation equipment.

Acceptance criteria for electrical equipment focus on providing adequate anchorage for seismic forces. Prescriptive anchorage and bracing provisions may be used for smaller equipment.

Typical Causes of Damage

- Overturning or sliding due to lack of anchorage or inadequate anchorage.
- Loss of function due to failure of internal components caused by inertial forces.
- Damaged electrical equipment may cause electrical hazards and fire hazards.

DAMAGE EXAMPLE



Figure 6.4.7.1-1 Overturned equipment in the 1985 magnitude-8 Mexico Earthquake, note absence of anchorage of equipment base to floor (Photo courtesy of Degenkolb Engineers).



Figure 6.4.7.1-2 Unanchored electrical cabinets overturned in a paper products plant during the 1999 magnitude-7.4 Izmit, Turkey earthquake (Photo courtesy of NISEE Izmit Collection, No. IZT-682, photograph by Halil Sezen).



Figure 6.4.7.1-3 Damage to unanchored electrical cabinets at power plant in Port-au-Prince in the 2010 magnitude-7 Haiti Earthquake (Photos courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- Working around electrical equipment can be extremely hazardous. Read the Electrical Danger Warning and Guidelines in Section 6.6.8 of this document before proceeding with any work.
- Many of these components can be supplied with shop welded brackets or predrilled holes for base or wall anchorage. For any new equipment, request items that can be supplied with seismic anchorage provisions by the manufacturer.
- When tall units are anchored to the floor, flexible connections between the equipment and raceways, bus ducts, or conduits that are braced to the level above will limit damage due to story drift.
- See Section 6.4.1.1 for additional base anchorage details. Refer to FEMA 413 *Installing Seismic Restraints for Electrical Equipment* (2004) for general information on seismic anchorage of electrical equipment.

MITIGATION EXAMPLES



Figure 6.4.7.1-9 Anchorage for electrical cabinets. Anchorage to wall at top of cabinets is also present but not visible (Photo courtesy of Maryann Phipps, Estructure).

p



Figure 6.4.7.1-10 Detail of cabinet base anchorage (Photo courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

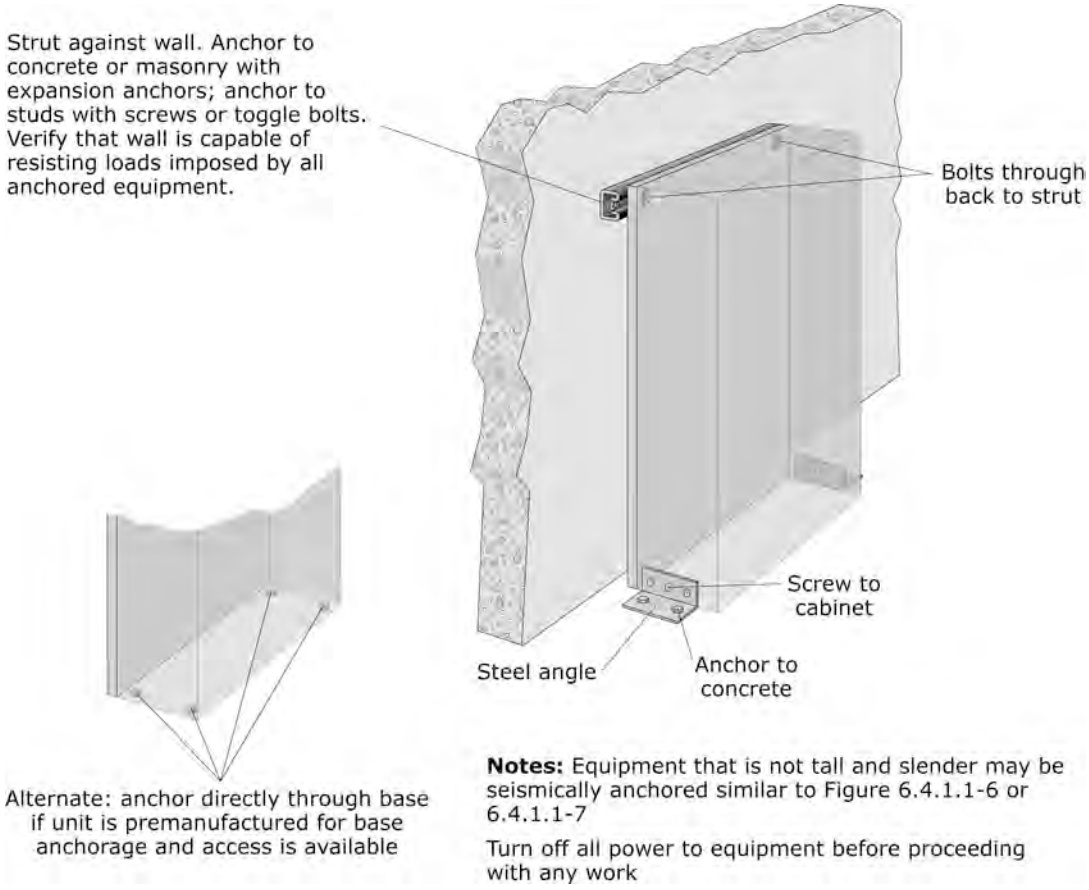


Figure 6.4.7.1-11 Electrical control panels, motor controls centers, or switchgear, (ER).

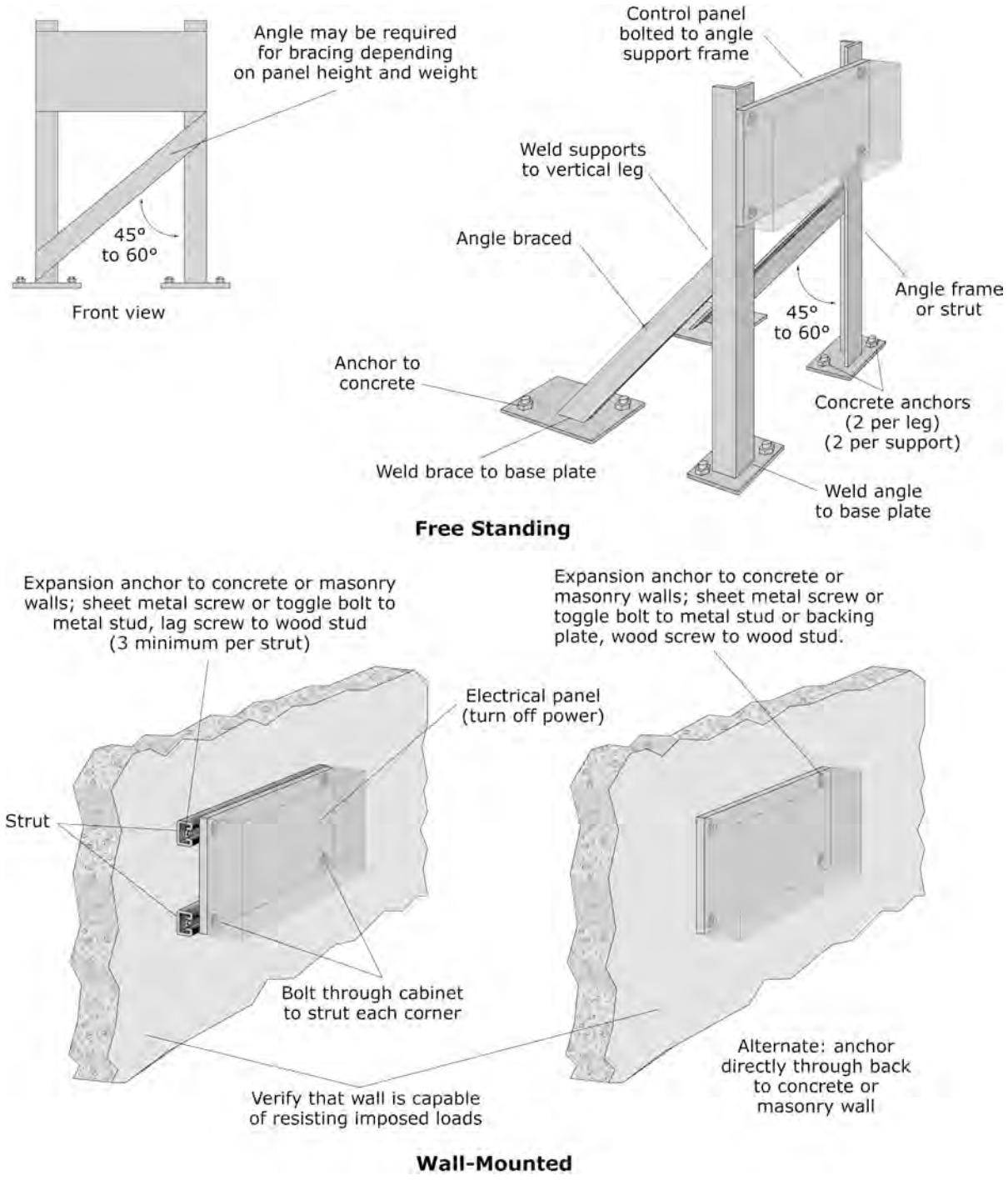


Figure 6.4.7.1-12 Free-standing and wall-mounted electrical control panels, motor controls centers, or switchgear (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.7 Electrical and Communications Equipment

6.4.7.2 Emergency Generators

Emergency generators are essential for postearthquake operations for many types of facilities. These range from small residential size generators to large systems required to maintain hospital or other essential operations. Emergency generators are often mounted on vibration isolators.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for emergency generators are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The principal objective is to prevent the component from sliding or overturning.

- If the emergency generator is required to function for life safety purposes, ASCE/SEI 7-10 classifies them as *Designated Seismic Systems*, with an Importance Factor $I_p = 1.5$. It may also require seismic qualification (shake table testing) to verify that the generator will function following and earthquake.
- Generators are often mounted on vibration isolators. The seismic design force for vibration isolated equipment is doubled if the "air gap" (the distance between the equipment support frame and the restraint) is greater than 0.25 inches.
- When checking the adequacy of an emergency generator for seismic forces, the load path from the generator, through any supporting framing to the ground or structural slab must be evaluated. For example, some emergency generators are "packaged: units," where all of the necessary components (prime mover, generator, radiator, fuel tank, etc.) are mounted on a skid or frame. Another common approach is to mount the generator on top of the fuel tank. In either case, a load path of adequate strength and stiffness must be confirmed. Supporting elements, especially fuel tanks used as supports, may require reinforcement to withstand the seismic loads.

REHABILITATION CODE PROVISIONS

In ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) emergency generators are not covered in Section 11, Architectural, Mechanical, and Electrical Components

as a separate item. The closest requirements are those for electrical and communications equipment, Section 11.10.7. Electrical and communications equipment are subject to the provisions of the standard when the performance level is Immediate Occupancy. The requirements also apply when the performance level is Life Safety in high and moderate seismicity areas, and the equipment is over 6 feet in height and weighs more than 20 pounds. Regardless of these provisions, it is prudent to apply the nonstructural evaluation and retrofit requirements for all occupancies and performance levels due to the essential nature of emergency generators.

Acceptance criteria for electrical equipment focus on providing adequate anchorage for seismic forces.

Typical Causes of Damage

- Emergency generators may slide, tilt, or overturn. Internal elements may be damaged by inertial forces.
- Unanchored or poorly reinforced housekeeping pads may fail, resulting in excessive movement of the supported equipment.
- Vibration isolators can fail causing excessive generator movement.
- Failure of the emergency power generating system may be caused by the failure of any of the component parts including generator, fuel tank, fuel line, batteries and battery racks.

Seismic Mitigation Considerations

- Working around electrical equipment can be extremely hazardous. Read the Electrical Danger Warning and Guidelines in Section 6.6.8 of this document before proceeding with any work.
- Many equipment items can be supplied with a structural steel base, shop welded brackets, or predrilled holes for base anchorage. For any new equipment, request items that can be supplied with seismic anchorageprovisions.
- For equipment mounted on a free-standing concrete pad, make sure pad is large enough to resist seismic overturning of generator.
- Check the anchorage for all the component parts of the emergency power generation system; failure of any one of them could compromise the postearthquake performance of the system. Provide flexible connections for the fuel line, exhaust ducting and any other connected utility.

- See Section 6.4.1.1 for additional base anchorage details. Refer to FEMA 413 *Installing Seismic Restraints for Electrical Equipment* (2004) for general information on seismic anchorage of electrical equipment.

MITIGATION EXAMPLES



Figure 6.4.7.2-1 Emergency generator is anchored to a concrete inertia base. The inertia base is mounted on spring isolators and restrained by steel angle snubbers on all sides (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.4.7.2-2 Emergency generator with skid mount on housekeeping pad; shear lugs added following the 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

MITIGATION DETAILS

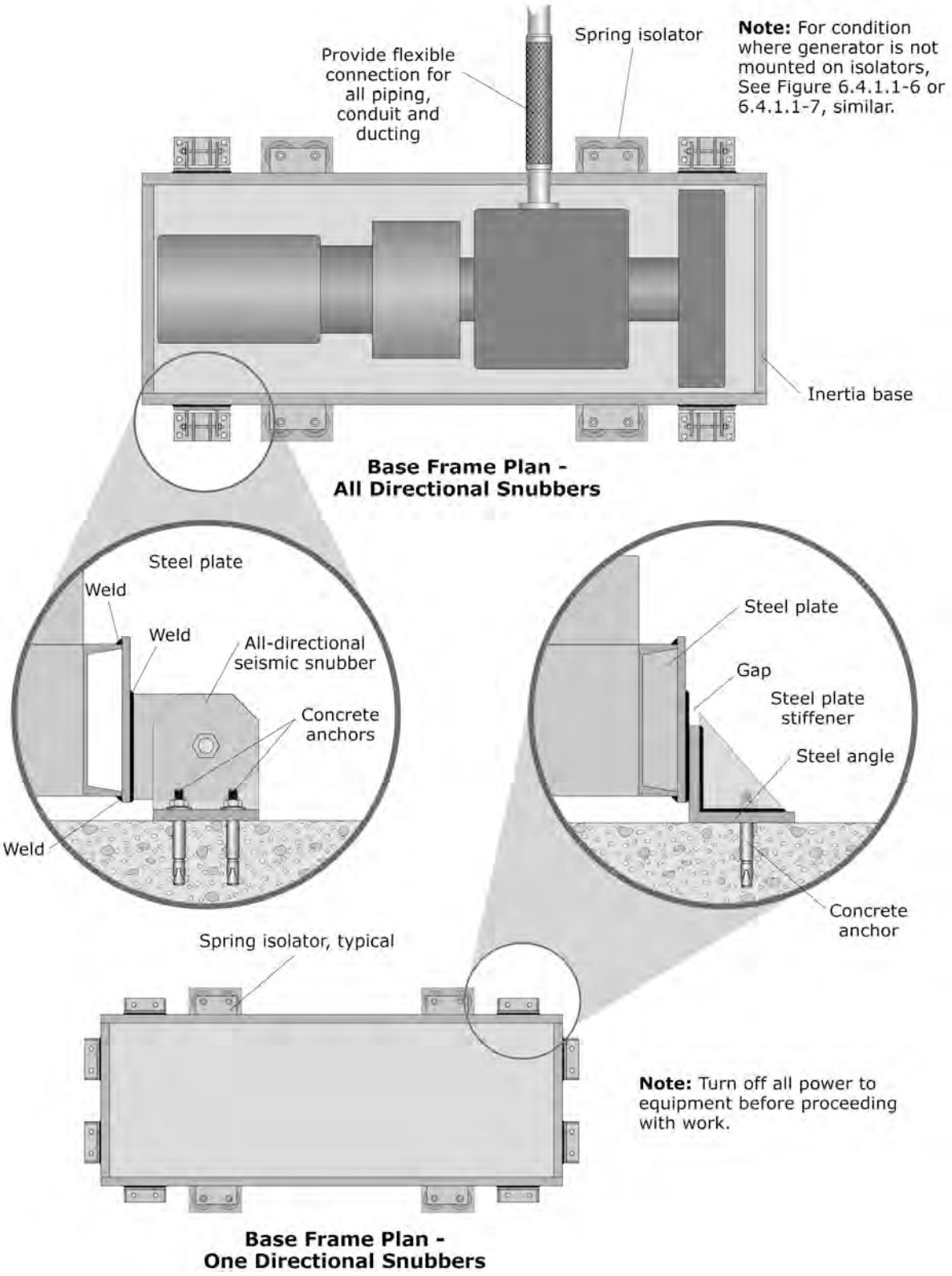


Figure 6.4.7.2-3 Emergency generator (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.7 Electrical and Communications Equipment

6.4.7.3 Transformers

Transformers may be dry-type or liquid filled; mounted on a floor, wall or roof; and installed with or without vibration isolation.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for transformers are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The principal objective is to prevent the component from sliding or overturning. They may be floor mounted, wall mounted, or suspended from the level above.

- ASCE/SEI 7-10 requires anchorage design for all equipment in Seismic Design Categories D, E, and F if the equipment weighs over 400 pounds. Lighter components may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage design requirements must still be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Exempt items must also be provided with flexible connections between the equipment and associated raceways, bus ducts, or conduits if there is a potential for damaging differential movement between the equipment and connected components.
- Internal coils of dry type transformers should be positively attached to their supporting substructure within the transformer enclosure.
- Electrical component supports and their attachment to the component must be designed for the appropriate forces and displacements. Supports include braces, frames, skirts, legs, pedestals, and snubbers, as well as elements forged or cast as a part of the mechanical or electrical component.
- The seismic design must consider the loads imposed on the components by attached utility or service lines that are attached to separate structures.
- Attachments for additional external items not provided by the manufacturer that weigh more than 100 lb should be evaluated.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies electrical equipment, including transformers, as force controlled. These components are subject to the provisions of the standard when the performance level is Immediate Occupancy. The requirements also apply when the performance level is Life Safety in high and moderate seismicity areas, and the equipment is over 6 feet in height and weighs more than 20 pounds. When applicable, electrical equipment meeting any of the following criteria must comply with the requirements of ASCE/SEI 41-06:

- The item weighs more than 400 pounds,
- The item is unanchored, weighs over 100 pounds and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 when design loads are applied.
- The item weighs over 20 pounds and is mounted over 4 feet above the floor.
- Building operation equipment.

Acceptance criteria for electrical equipment focus on providing adequate anchorage for seismic forces.

Typical Causes of Damage

- Transformers may slide, tilt, overturn, or fall. Vibration isolation hardware may be damaged.
- Internal elements may be damaged by inertial forces.
- Damaged electrical equipment may be cause electrical hazards and fire hazards. Transformer damage may result in power outages and business interruption.

DAMAGE EXAMPLES



Figure 6.4.7.3-1 Rail mounted transformer slipped off rails at power plant in Port-au-Prince in the 2010 magnitude-7 Haiti Earthquake; only one of six identical transformers was damaged (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- Working around electrical equipment can be extremely hazardous. Read the Electrical Danger Warning and Guidelines in Section 6.6.8 of this document before proceeding with any work.
- This type of equipment can be supplied with a structural steel base, shop welded brackets, or predrilled holes for base anchorage. For any new equipment, request items that can be supplied with seismic anchorage provisions.
- See Section 6.4.1.1 for additional base anchorage details. Refer to FEMA 413 *Installing Seismic Restraints for Electrical Equipment* (2004) for additional mounting configurations such as wall- and roof-mounting, or vibration isolation as well as general information on the seismic anchorage of electrical equipment.



Figure 6.4.7.3-2 Typical electrical distribution dry type transformer. Note the use of manufacturer supplied anchor locations on base channels. Post earthquake photo from the 2010 Haiti M 7.0 Earthquake (photos courtesy of Philip J. Caldwell).



Figure 6.4.7.3-3 High ampacity power busway routing power from generator paralleling switchgear to facility. Note use of lateral restraints in addition to gravity hanger. Supplied uninterrupted power to critical facility during the 2010 M 7.0 Haiti earthquake. (photos courtesy of Philip J. Caldwell)



Figure 6.4.7.3-4 Outdoor low voltage switchgear supplying incoming utility power to critical facility. Note equipment frame seismic anchorage load path is bolted at both equipment frame and pad with a continuous rigid load path. Post earthquake photo from the 2010 M 7.0 Haiti earthquake. (photos courtesy of Philip J. Caldwell)



Figure 6.4.7.3-5 Outdoor liquid type electrical power transformer which converts incoming medium voltage to 480 volt utilization voltage for critical facility. Note use of manufacturer supplied diagonal elements on cooling fin assembly to minimize dynamic loading on liquid filled fin assembly which contains numerous welded connections. Post earthquake photo from the 2010 M 7.0 Haiti Earthquake (photos courtesy of Philip J. Caldwell).



Figure 6.4.7.3-6 Battery room for central network cell phone carrier after 2010 M 7.0 Haiti Earthquake. Three-story building which contained the UPS (uninterruptable power supply) and battery room was newly constructed and suffered near collapse structural damage which required structural demolition and replacement. Note that high mass batteries with integral structural system was rigidly anchored and sustained no damage or loss of operation despite building structural system displacing enough to shear support columns. Cellular carrier representative advised that the central network support functionality was maintained during Earthquake (photos courtesy of Philip J. Caldwell).



Figure 6.4.7.3-7 Heat rejection mechanical units which provide cooling for servers in cellular carrier central network facility (left photo). Collapsing security wall during the 2010 M 7.0 Haiti Earthquake crushed these units and resulted cyclical total failure of the cellular network as the servers hit temperature limits, shut down, rebooted and heated up again. System stability was restored by replacing the damaged units with temporary ones (right photo). Example of how the reliability of a critical facility essential system is both dependent upon adequate seismic restraints and a location which is free of structural and nonstructural falling hazards (photos courtesy of Philip J. Caldwell).



Figure 6.4.7.3-8 Example of rugged equipment. Post earthquake photos of two different essential facilities which sustained significant structural damage during the 2010 M 7.0 Haiti Earthquake. Wall mounted electrical power distribution panels were undamaged and remained functional even though the walls they were mounted to were severely damaged during the earthquake (photos courtesy of Philip J. Caldwell).



Figure 6.4.7.3-9 Incoming power switchgear for critical facility anchored through base undamaged by the 2010 Haiti M 7.0 Earthquake. Visual inspection of equipment base channels did not reveal any structural damage or equipment displacement on concrete equipment pad. Similar equipment located nearby which did not have a rigid seismic restraint with a continuous load path shifted on its pad (photos courtesy of Philip J. Caldwell).

MITIGATION DETAILS

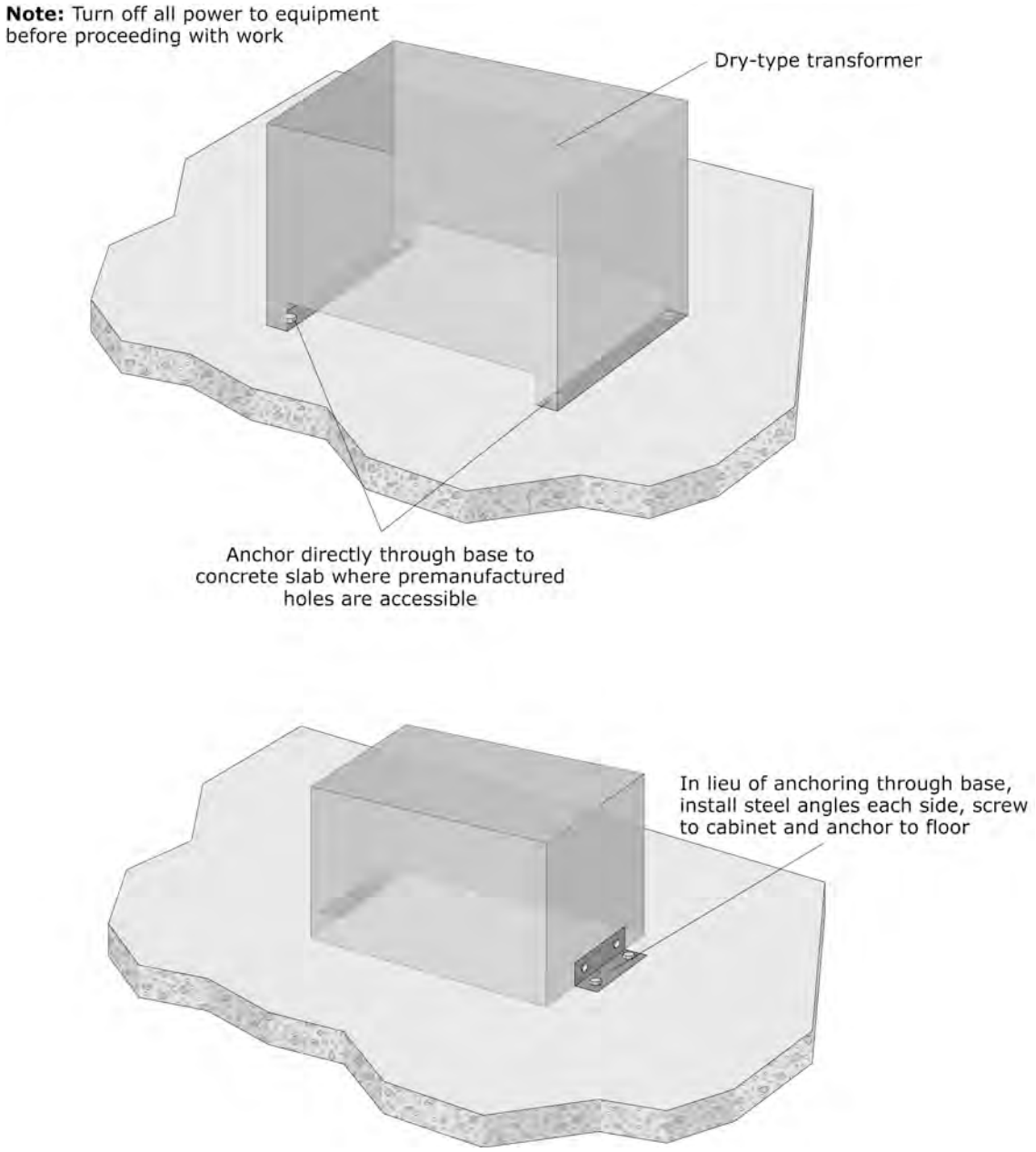


Figure 6.4.7.3-10 Transformer, note that external bracket must bolt directly to the internal frame to which the transformer core and coil assembly is attached (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.7 Electrical and Communications Equipment

6.4.7.4 Batteries and Battery Racks

This category covers batteries and battery racks, often used as part of the emergency generation system. These may be mounted on a concrete floor, raised floor, wall or roof.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for batteries and battery racks are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. The principal objective is to prevent the component from sliding or overturning.

- If the batteries are required to function for life safety purposes, ASCE/SEI 7-10 classifies them as *Designated Seismic Systems*, with an Importance Factor $I_p = 1.5$. This may require additional analysis, testing, and special inspections.
- ASCE/SEI 7-10 requires anchorage design for all equipment in Seismic Design Categories D, E, and F if the equipment weighs over 400 pounds. Lighter components may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage design requirements must still be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Exempt items must also be provided with flexible connections between the equipment and associated raceways, bus ducts, or conduits if there is a potential for damaging differential movement between the equipment and connected components.
- Batteries on racks must have wraparound restraints to ensure that the batteries will not fall from the rack. Spacers should be used between restraints and cells to prevent damage to cases.
- All elements of battery racks must be evaluated for sufficient lateral load capacity, including braces, frames, legs, pedestals, restraints, and snubbers.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies electrical equipment, including batteries and battery racks, as force controlled. These components are

subject to the provisions of the standard when the performance level is Immediate Occupancy. The requirements also apply when the performance level is Life Safety in high and moderate seismicity areas, and the equipment is over 6 feet in height and weighs more than 20 pounds. When applicable, batteries and battery racks meeting any of the following criteria must comply with the requirements of ASCE/SEI 41-06:

- The item weighs more than 400 pounds.
- The item is unanchored, weighs over 100 pounds and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 when design loads are applied.
- The item weighs over 20 pounds and is mounted over 4 feet above the floor.

Acceptance criteria for batteries and battery racks focus on providing adequate anchorage for seismic forces.

Typical Causes of Damage

- The racks may slide or overturn and batteries may slip or fall from the rack. Failure of the batteries may compromise the emergency power generation system or other functions that rely on backup battery power.

DAMAGE EXAMPLES

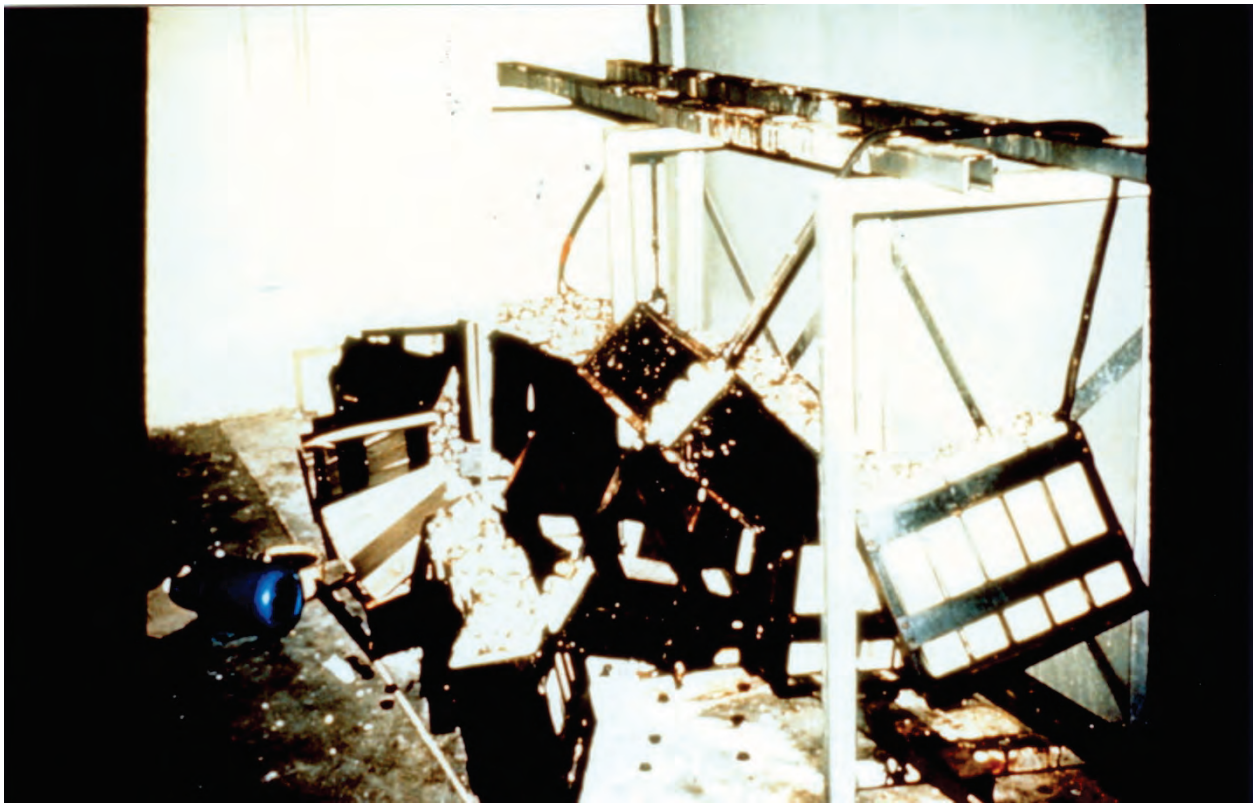


Figure 6.4.7.4-1 Earthquake Damage in the 1971 magnitude-6.6 San Fernando Earthquake (Photo courtesy of John F. Meehan).

Seismic Mitigation Considerations

- Seismic resistant battery racks are available from a number of vendors; these may be directly bolted to the floor or wall. Check the internet for available products.
- For existing battery racks, check that the batteries are secured to the rack and that the rack is properly braced and anchored.

MITIGATION EXAMPLES



Figure 6.4.7.4-2 Anchored battery racks (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.7.4-3 Batteries anchored with equipment skid (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.7.4-4 Battery rack that performed well in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

MITIGATION DETAILS

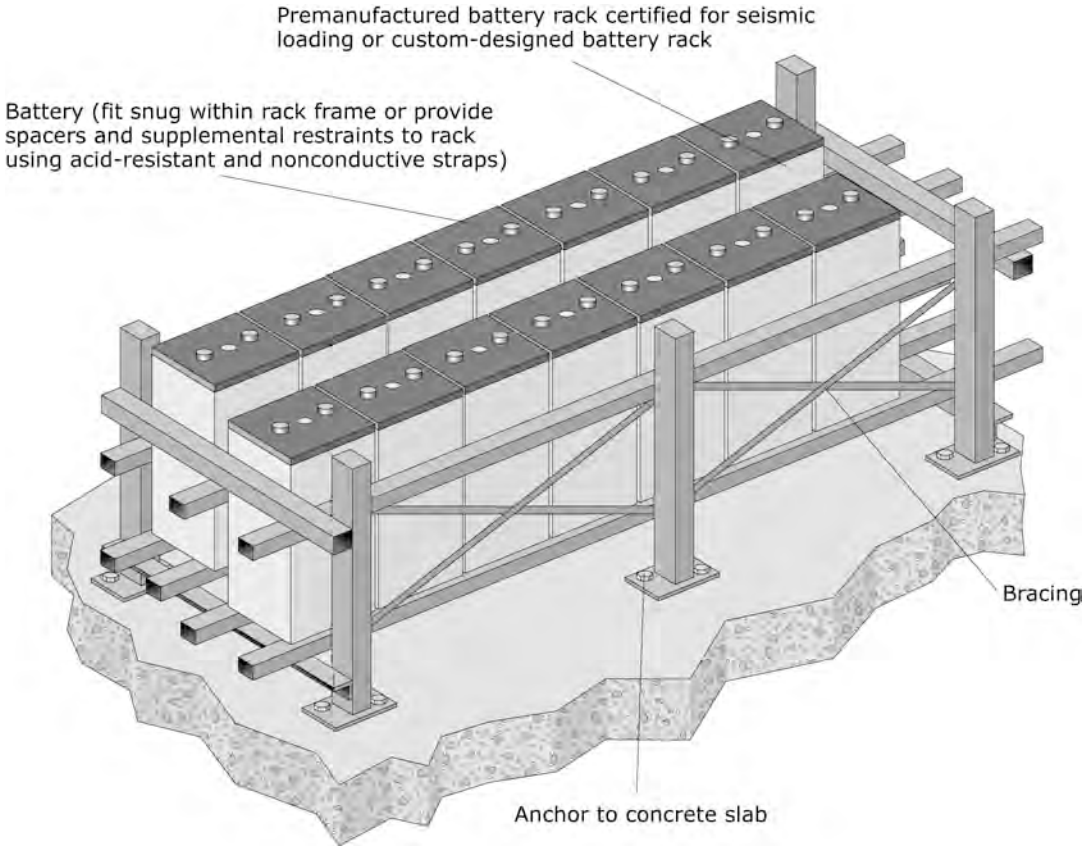


Figure 6.4.7.4-5 Batteries and rack (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.7 Electrical And Communications Equipment

6.4.7.5 Photovoltaic (PV) Power Systems

This category covers photovoltaic (PV) power systems and solar car charging stations, commonly mounted on roofs or on separate freestanding racks.

Provisions

BUILDING CODE PROVISIONS

While not explicitly covered in ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), PV power systems are subject to the seismic requirements for nonstructural components. If mounted on a building, the provisions of Chapter 13 for nonstructural components apply. PV power systems mounted on racks at grade are subject to the provisions of Chapter 15, Nonbuilding Structures. The principal objective is to prevent the component from sliding or overturning.

- ASCE/SEI 7-10 requires anchorage design for all equipment in Seismic Design Categories D, E, and F if the equipment weighs over 400 pounds. Lighter components may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage design requirements must still be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Exempt items must also be provided with flexible connections between the equipment and associated raceways, bus ducts, or conduits.
- Ballasted PV systems use friction due to the weight of the system to resist lateral loads. These systems must use an alternative analysis approach, since ASCE/SEI 7-10 requires that component attachments be bolted, welded, or otherwise positively fastened without consideration of frictional resistance produced by the effects of gravity. The alternative analysis should account for the coefficient of friction between the PV system and the supporting structure, the slope of the supporting structure, and the tendency of the PV panels to slide in the direction of the roof slope during shaking. Seismic performance depends on providing adequate distance between the PV system and the edge of the supports, so that the panels do not slide off, and in providing flexible connections to electrical system to accommodate the expected displacements.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2006) does not expressly cover PV systems, but they may be classified as electrical equipment, that is both force and displacement controlled. PV systems are subject to the provisions of the standard when the performance level is Immediate Occupancy. They requirements also apply when the performance level is Life Safety in high and moderate seismicity areas, and the equipment is over 6 feet in height and weighs more than 20 pounds. When applicable, PV systems meeting any of the following criteria must comply with the requirements of ASCE/SEI 41-06:

- The items weighs more than 400 pounds,
- The item is unanchored, weighs over 100 pounds and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 when design loads are applied.
- The item weighs over 20 pounds and is mounted over 4 feet above the floor or roof.

Refer to the notes on Building Code Provisions (above) for acceptance criteria.

Typical Causes of Damage

As the installation of these fixtures on U.S. rooftops is relatively new, there are few documented examples of earthquake damage to date. This is in part due to the fact that since panels tend to be very light, the most severe design loading for roof-mounted photovoltaic panels is typically wind. Nevertheless, if these have not been properly designed to meet seismic loading, the panels may become dislodged and fall from the racks or fall off of pitched roofs or piping may be damaged, resulting in leakage. Wiring may also become dislodged and disable the systems.

Seismic Mitigation Considerations

- Solar power is a rapidly changing field; these products and systems are evolving. Where existing photovoltaic systems may weigh between 2.5 to 3.0 pounds per square foot and consist of glass covered modules that are roof mounted on aluminum or galvanized steel track, newer products include lighter panels without glass, solar roof tiles that interlock with standard S-shaped clay or concrete roofing tiles, or peel and stick panels which weigh under 2 pounds per square foot that may be applied directly to the roof surface. Several of these newer systems are integrated with the roofing materials and may not require special seismic consideration as long as the additional weight is accounted for. Ballasted photovoltaic systems are also available that do not require

anchorage or penetration of the roofing membrane. Check the internet for proprietary systems.

- Photovoltaic panels supported on framing systems are typically flush mounted or tilt mounted. These systems typically have anodized aluminum or galvanized steel track channels mounted to brackets or standoffs which are mounted to roof framing or structural supports. The panels or modules are then screwed directly to the track, typically four per panel. For installation on a wood framed roof, the system layout works best when the track is mounted perpendicular to the rafters; blocking may be required between the rafters where the track is mounted parallel to the rafters. Care must be taken to see that the roof penetrations are well sealed so the photovoltaic power system does not cause roof leaks. Friction fittings should not be used to resist seismic loading; positive connections should be provided between all the component parts.
- Photovoltaic power systems may be installed on top of carports for charging electric cars. Before mounting an expensive solar system on top, it must be ensured that the carport or patio structures have been designed for seismic loading.
- The State of California has published DSA IR 16-8 *Solar Photovoltaic and Thermal Systems Acceptance Requirements* (California Department of General Services, 2010a) to address requirements for California schools. This document describes solar systems supported on framing systems and foundations, ballast panel systems, and adhered panel systems.
- Installation guidelines are available on the internet for proprietary flush mount kits and tilt up kits. For example, UniRac, Inc. has installation manuals for two proprietary systems called SolarMount and Clicksys (see http://unirac.com/mounting-solutions). These installation manuals have wind and snow load tables with wind loading from 90 mph to 170 mph. Although there is no explicit mention of seismic provisions, the detailing will be adequate if designed sufficiently for wind. A review of the tabulated wind design loads shows these systems are engineered for 10 psf to over 100 psf uplift; thus a well engineered wind design for a photovoltaic system typically weighing less than 3 psf should not require additional seismic detailing. Another company, Professional Solar Products (http://www.prosolar.com/prosolar-new/pages/installation-guides-subpage2.htm) has hardware with installation guides for tilt up kits designed for 30 psf or 100 mph winds.
- Like any components exposed to the weather, components and connectors for photovoltaic systems should be corrosion resistant materials such as stainless steel or

anodized aluminum. Where roof penetrations are required, these should have appropriate flashing and caulking to prevent leakage.

MITIGATION EXAMPLES

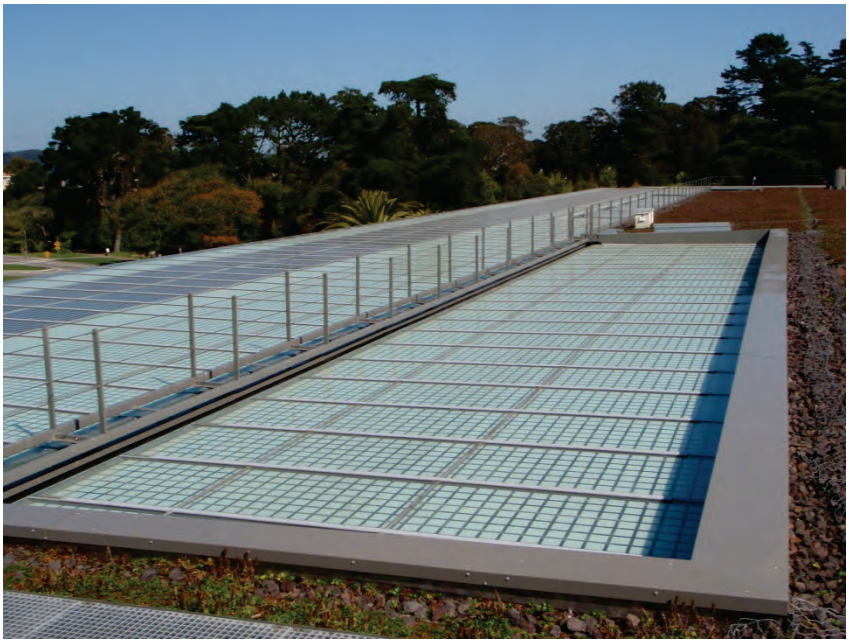




Figure 6.4.7.5-1 60,000 photovoltaic cells are incorporated into the glass canopy surrounding the Academy of Science, San Francisco, California (Photos courtesy of Cynthia Perry, BFP Engineers). The photovoltaic system provides 10% of the electricity needed for the facility. Panels must be securely attached to resist wind loads but also because these cantilevered members may be subject to vertical as well as horizontal seismic forces.



Figure 6.4.7.5-2 Ground mounted photovoltaic system that also provides shade to injured animals at the Marine Mammal Center in Sausalito, California (Photo courtesy of Cynthia Perry, BFP Engineers). Each solar panel is screwed to the strut at four locations; two rows of struts are bolted to 6 steel tubes which are anchored at the base with four bolts apiece.



Figure 6.4.7.5-3 Residential photovoltaic system in Berkeley, California mounted over the transition between two different roof slopes (Photos courtesy of Heber Santos). Short standoff used on tar and gravel flat portion (upper left); aluminum flashing and mounting bracket used on sloped portion with composition tile roofing (upper right). The profile of one type of proprietary mounting track is seen at lower left.



Figure 6.4.7.5-4 Flush mount photovoltaic system on barrel shaped roof of gymnasium at Head-Royce School, Oakland, California (Photo courtesy of Cynthia Perry, BFP Engineers).

MITIGATION DETAILS

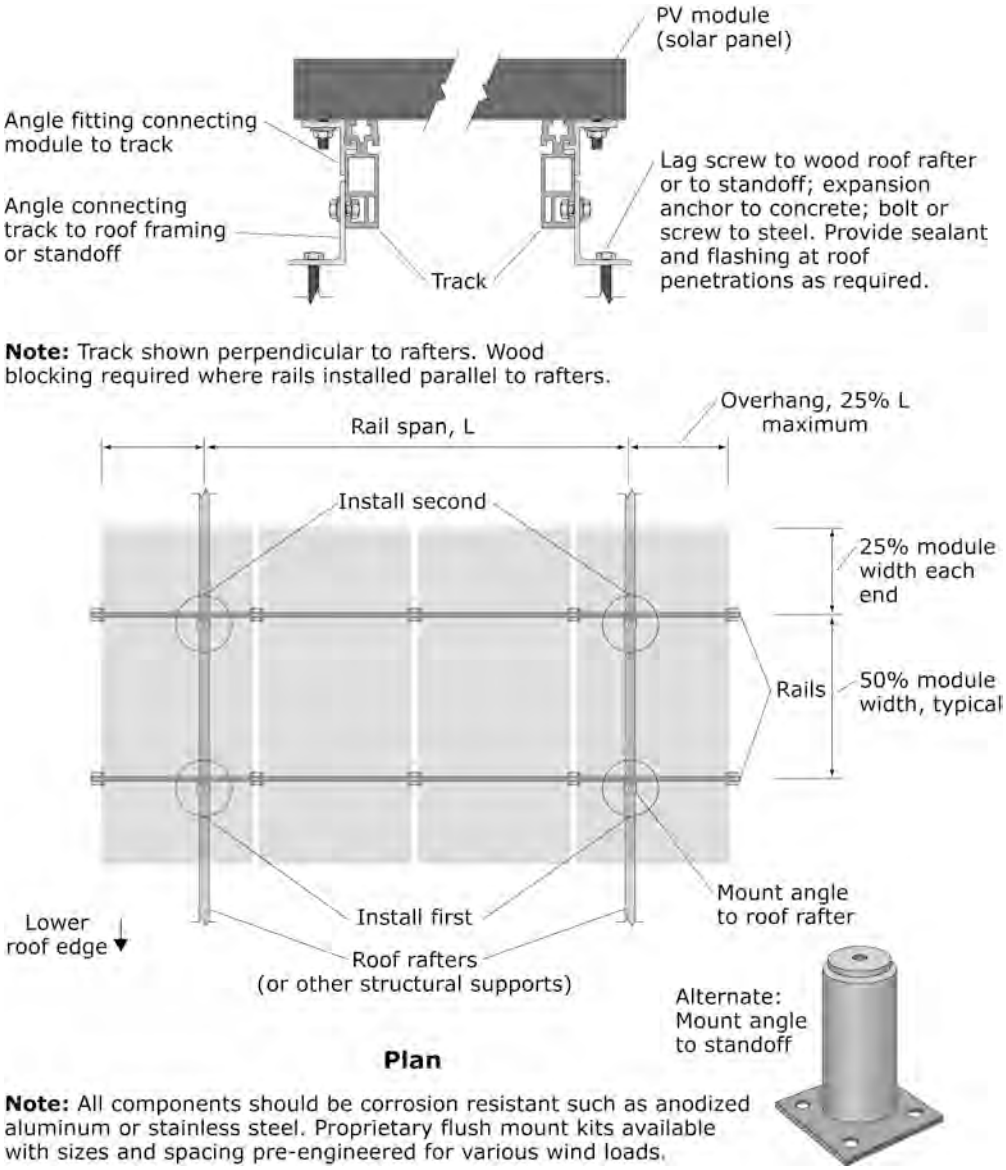
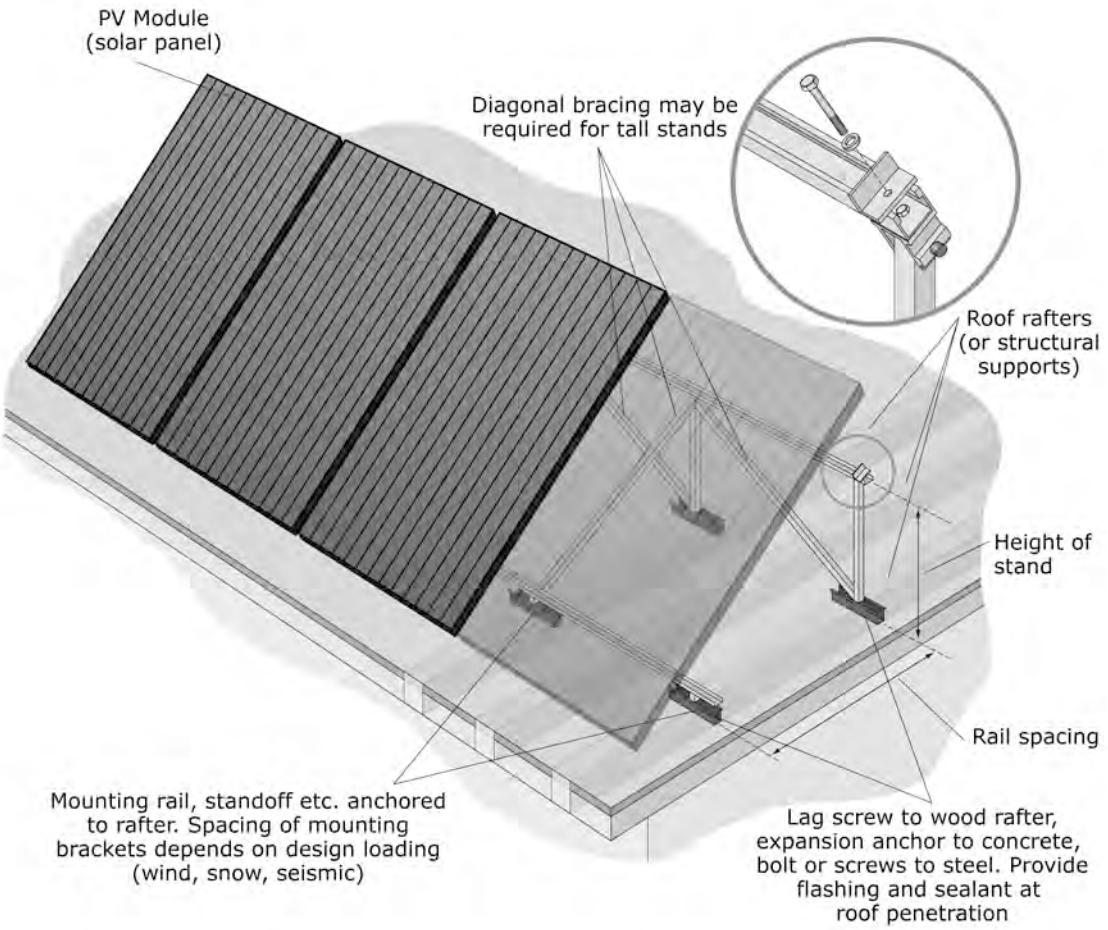


Figure 6.4.7.5-5 Typical details for flush-mounted photovoltaic power modules (ER).



Note: All components should be corrosion resistant such as anodized aluminum or stainless steel. Proprietary tilt-up kits available with sizes and spacing pre-engineered for various wind loads.

Figure 6.4.7.5-6 Typical tilt up details for anchored photovoltaic power modules (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.7 Electrical and Communications Equipment

6.4.7.6 Communications Antennae

This category covers communications antennae, often referred to as satellite dishes, which may be mounted in a variety of ways. Circular antennae used for residential or small commercial applications are typically supported by a single mast that may be mounted on a wall, roof, chimney, eaves, balcony, or freestanding at the ground. Non-penetrating roof mounts that typically rely on ballast are also available.

Provisions

BUILDING CODE PROVISIONS

Communications antennae are designed using the provisions of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13 when supported by a structure, and Chapter 15, Nonbuilding Structures, if the antennae is supported at grade. The principal objective is to prevent the component from sliding or toppling.

- ASCE/SEI 7-10 requires anchorage design for all equipment in Seismic Design Categories D, E, and F if the equipment weighs over 400 pounds. Lighter components may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage design requirements must still be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Exempt items must also be provided with flexible connections between the equipment and associated raceways, bus ducts, or conduits.
- Electrical component supports and their attachment to the component must be designed for the appropriate forces and displacements. Design of dish antennae should consider the effects of both wind and seismic loading.
- The design of the antenna depends on whether it is braced above or below its' center of gravity.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies communications equipment as force-controlled. There are no specific provisions for antennas. Communications equipment is subject to the provisions of the standard when the performance

level is Immediate Occupancy. The requirements also apply when the performance level is Life Safety in high and moderate seismicity areas, and the equipment is over 6 feet in height and weighs more than 20 pounds. When applicable, electrical equipment meeting any of the following criteria must comply with the requirements of ASCE/SEI 41-06:

- The item weighs more than 400 pounds,
- The item is unanchored, weighs over 100 pounds and is subject to overturning. These items may be exempt if they have a factor of safety greater than 1.5 when design loads are applied.
- The item weighs over 20 pounds and is mounted over 4 feet above the floor.
- Building operation equipment.

Acceptance criteria for communication equipment focus on providing adequate anchorage for seismic forces. Prescriptive anchorage and bracing provisions may be used for smaller components.

Typical Causes of Damage

- While TV antennae have been mounted on roofs for many decades, the appearance of circular antennae on U.S. rooftops is relatively new, and to date, earthquake damage has not been documented. This is in part due to the fact that since antennae tend to be very light, the most severe design loading for circular antennae is typically wind. Nevertheless, if antennae have not been mounted to meet seismic loading, they could become dislodged and either the dish or the mast or both could fall.
- Damage to the antennae could disable critical communications systems or television access that may be needed following an earthquake.

DAMAGE EXAMPLES



Figure 6.4.7.6-1 Most antenna are designed for wind and able to resist seismic loading. In spite of the collapse of the first story of this residential building complex, the roof-mounted antennae appear intact in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.7.6-2 Antennae retrieved from roof of adjacent collapsed wing of the Hôpital Saint-François de Sales in the 2010 magnitude-7 Haiti Earthquake (not known if antenna suffered earthquake damage; photo courtesy of Ayhan Irfanoglu, Purdue University). Hospital communications depend on the functionality of antennae such as this.

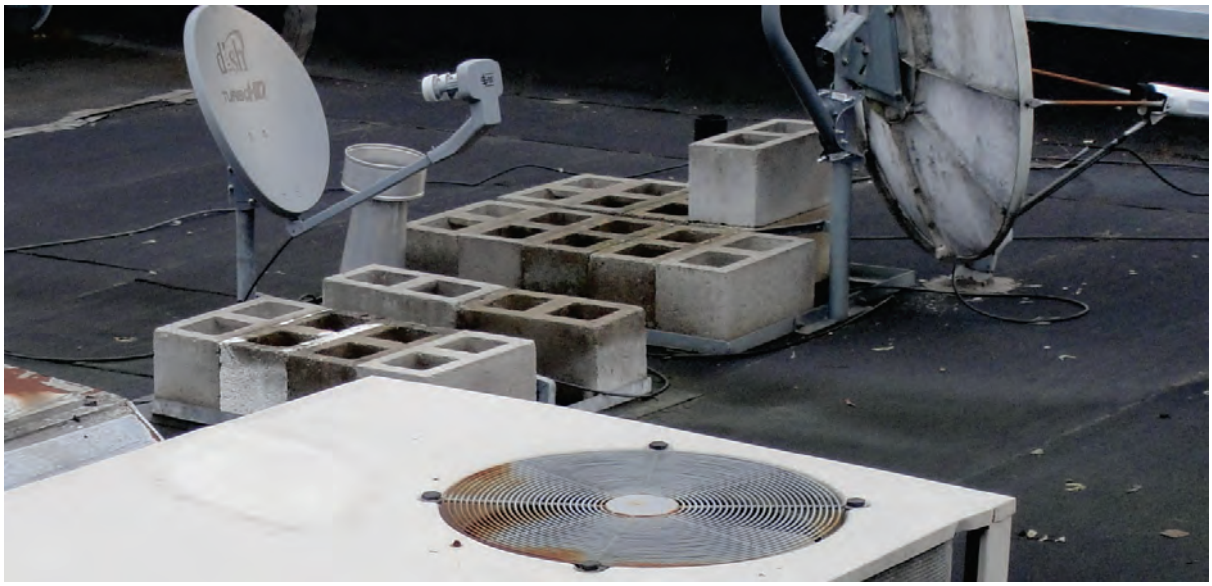


Figure 6.4.7.6-3 Damage or movement of ballasted antennae was not observed on this rooftop in the 2010 magnitude-6.5 Eureka Earthquake (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.4.7.6-4 The antenna with guy wires remained upright atop a collapsed building in the 2010 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Even though some of the guy wires went slack, the antenna did not fall into the street.

Seismic Mitigation Considerations

- The Federal Communications Commission (FCC) issues regulations for Over-the-Air Reception Devices to preempt restrictions on the size, mast height, or location of direct-to-home satellite dishes. For instance, Title 47 (Section 1.200) of Code of Federal Regulations which codifies the FCC regulations covers dishes less than 1 meter in diameter with a mast height less than 12 feet above the roofline. In addition, tenant or homeowner association agreements may have restrictions on the size or placement of antennae; check for local code or association requirements.
- The antenna mast may be mounted in a variety of ways, for example to wood or metal stud walls, concrete or solid masonry walls (cells filled with concrete), hollow masonry block walls, freestanding poles, or to roof rafters or a concrete roof slab. Schematic details for installing the mast mounting bracket to a stud or concrete walls are shown in Figure 6.4.7.6-5.
- Some mounting kits available on the internet provide hardware for strapping the antenna to a residential chimney. As unreinforced masonry chimneys are highly prone to earthquake damage as described in Section 6.3.7.1, antenna should not be mounted to unreinforced masonry chimneys. If the chimney is adequately reinforced, chimney mount details may be used for lightweight antennae.
- Hardware and kits for non-penetrating ballasted mounts are also available for purchase. These kits often use standard sized concrete blocks for ballast. Use of multiple concrete blocks for ballast may be heavy enough to trigger the requirement for the equipment to have engineered anchorage. While these ballasted systems can reasonably be used in areas of low seismicity, they could potentially slide and damage roofing or wiring in areas of high seismicity.
- Large or tall antennae need to be properly engineered for both wind and seismic loading. Tower antennae may be anchored with guy wires, or mounted to a specially designed frame. Positive attachments from the antenna to the supporting structure should be provided and one should check with the manufacturer to see if the antenna itself has been designed or tested for seismic loading since seismic forces at the roof elevation are typically much higher than at ground level.
- Communications equipment used for essential facilities may need to be shake table tested and certified. Shake tables operated by the Pacific Earthquake Engineering Research Center (PEER) at UC Berkeley, MCEER at SUNY Buffalo, and others both perform testing of telecommunications network equipment in accordance with *NEBS Requirements: Physical Protection* (NEBS, 2006), protocol to certify that the internal parts and electronic components can withstand seismic shaking.

- As with any items mounted with exterior exposure, components and connectors should be corrosion resistant and roof or wall penetrations should receive flashing and sealant as appropriate.
- Extreme caution must be exercised when working in the proximity of any satellite dish antenna used to uplink internet, broadcast or other communications services. Because the dish is used to greatly focus the beam of microwave radio frequency energy a serious radio frequency (RF) exposure hazard may be present. Never position yourself in front of an uplink dish unless the transmitter has all sources of power removed and the appropriate lock out procedures are in practice.
- Always consult a qualified communications expert knowledgeable about the RF exposure hazard present in the vicinity of all antennas used for all form of radio transmission and obtain a detailed description of what the RF exposure guidelines are for each. For more information refer to FCC OET Bulletin 65 (FCC, 1997).

MITIGATION EXAMPLES



Figure 6.4.7.6-5 Antenna mast mounted to concrete wall surface at top floor of building (Photo courtesy of (Photo courtesy of Maryann Phipps, Estructure). Note that two wall brackets are used to resist moments produced by wind or seismic forces. This antenna is larger than most standard residential versions.



Figure 6.4.7.6-6 Antenna mast mounted to wood stud wall using blocking to clear eves (Photo courtesy of Cynthia Perry, BFP Engineers).

MITIGATION DETAILS

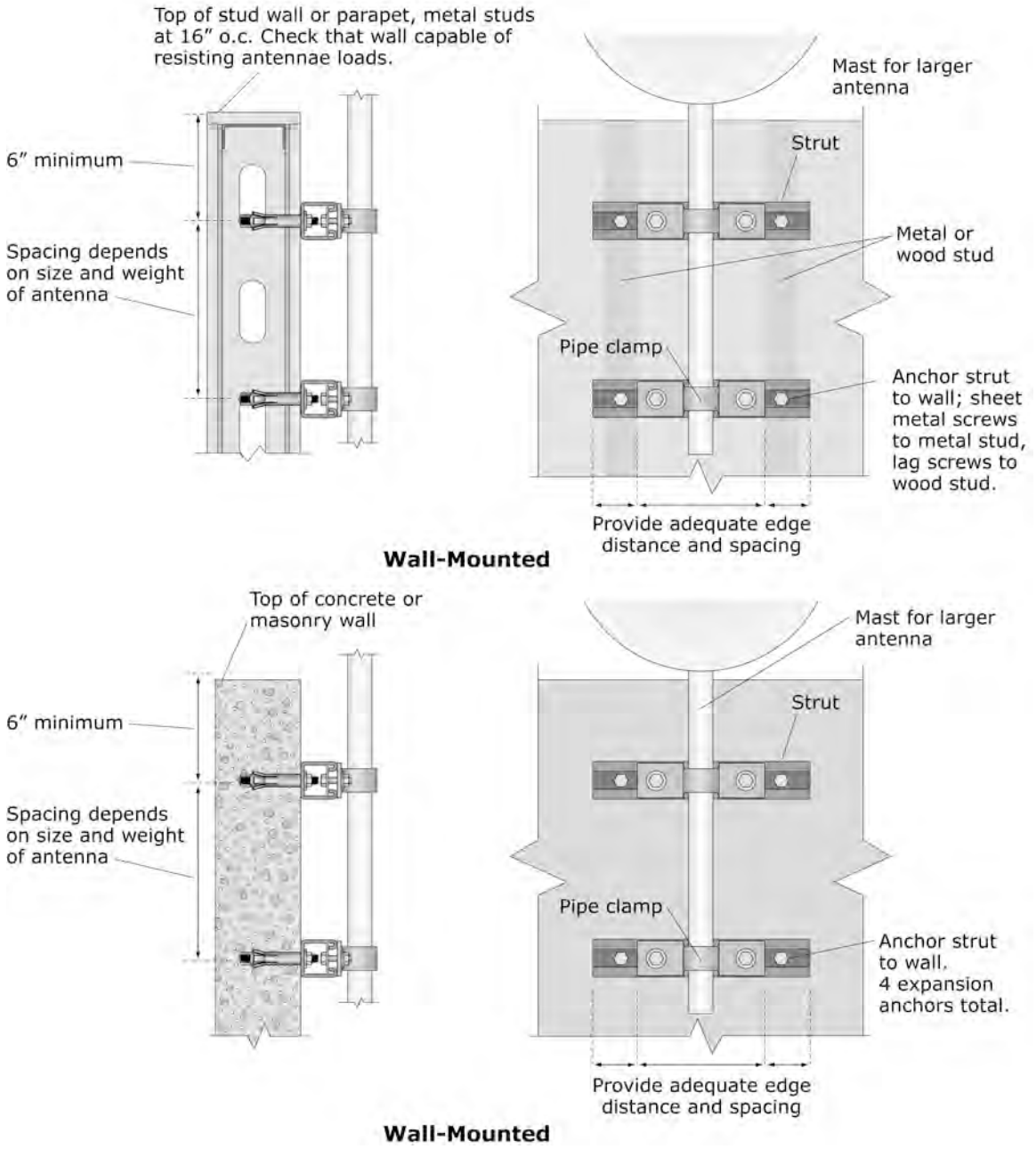


Figure 6.4.7.6-7 Details for wall-mounted communications antenna (ER).

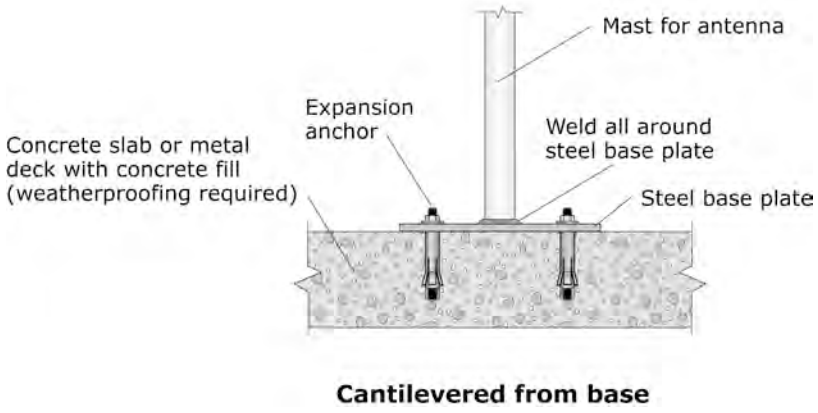


Figure 6.4.7.6-8 Details for roof/slab mounted communications antenna (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.8 Electrical and Communications Distribution Equipment

6.4.8.1 Electrical Raceways, Conduit, and Cable Trays

This category covers electrical raceways, conduit, cable trays, and bus ducts. These items may be suspended from above or be floor-, chase-, wall- or roof-mounted.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for electrical raceways, conduit, cable trays, and bus ducts are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures,* (ASCE, 2010), Chapter 13. The principal objective for suspended and wall-mounted systems is to prevent them from falling. Depending on the configuration of the system, it may also be sensitive to building displacements if it is connected to multiple levels in the same structure, or is supported by adjacent structures.

- ASCE/SEI 7-10 exempts electrical raceways, conduit, cable trays, and bus ducts from seismic bracing requirements in Seismic Design Category C if $I_p = 1.0$.
- ASCE/SEI 7-10 requires seismic design for all distribution systems in Seismic Design Categories D, E, and F that weighs more than 5 pounds per linear foot, except as noted below.
- Unbraced electrical raceways, conduit, cable trays, and bus ducts attached to in-line equipment must be provided with flexibility adequate to accommodate seismic relative displacements.
- Conduit greater than 2.5 inches (64 mm) trade size and attached to panels, cabinets or other equipment subject to seismic relative displacement, must be provided with flexible connections or designed for seismic forces and seismic relative displacements.
- Design for the seismic forces is not required for raceways where trapeze assemblies are used to support raceways and the total weight of the raceway supported by trapeze assemblies is less than 10 lb/ft.
- The raceways that are supported by hangers where each hanger in the raceway run is 12 inches or less in length from the raceway support point to the supporting structure are also exempt from bracing requirements. The rod hangers used must be equipped with swivels to prevent inelastic bending in the rod.

- Design for seismic forces is not required for conduit, regardless of the value of I_p, where the conduit is less than 2.5 inches trade size.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies electrical and communication distribution components as force controlled, meaning that the principal objective is to prevent the systems from falling. Where the system runs between floors or crosses seismic joints it as also deformation controlled. Electrical and communication distribution components are subject to the provisions of the standard when:

- The performance level is Immediate Occupancy.
- The requirements also apply when the performance level is Life Safety in high and moderate seismicity areas, the systems form part of an emergency lighting, power, and/or communications system.

When applicable, electrical and communication distribution components must meet the force and deformation requirements of the standard. Rehabilitation may utilize prescriptive standards, such as *Seismic Restraint Manual: Guidelines for Mechanical Systems* (SMACNA, 2009) or *A Practical Guide to Seismic Restraint* (ASHRAE, 2012).□

Typical Causes of Damage

- Items may swing and impact structural or other nonstructural elements; they may fall and create electrical hazards.
- Vulnerable locations include seismic separations; wall, floor, or roof penetrations; and attachments to rigidly mounted equipment.

DAMAGE EXAMPLES



Figure 6.4.8.1-1 Unbraced suspended piping and conduit (Photo courtesy of Wiss, Janney, Elstner Associates).

Seismic Mitigation Considerations

- Working around electrical equipment can be extremely hazardous. Read the Electrical Danger Warning and Guidelines in Section 6.6.8 of this document before proceeding with any work.
- Individual conduit is usually braced using the same design approach and details as piping. The weight of the conduit plus the conductors is approximately the same as water-filled pipe of similar diameter.
- Two trapeze anchorage details are shown. See Section 6.4.3.1 for additional pipe anchorage details; the same type of bracing is typically used for electrical distribution lines. Refer to FEMA 413 *Installing Seismic Restraints for Electrical Equipment* (2004) for general information on seismic anchorage of electrical equipment and to FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004) for many different anchorage configurations for raceways, conduit and cable trays.
- Several engineered seismic bracing systems are available and can be customized for most applications. This is particularly useful for large scale projects or essential applications.

MITIGATION EXAMPLES



Figure 6.4.8.1-2 Rigid strut bracing provides restraint against earthquake forces perpendicular to the piping. Similar bracing is required in the direction parallel to the conduit (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.4.8.1-3 Rigid strut bracing for trapeze supporting electrical conduit; conduit attached to trapeze with conduit clamp that provides lateral and longitudinal restraint (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.4.8.1-4 Lateral and longitudinal rigid strut bracing for trapeze supporting electrical raceways (Photo courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

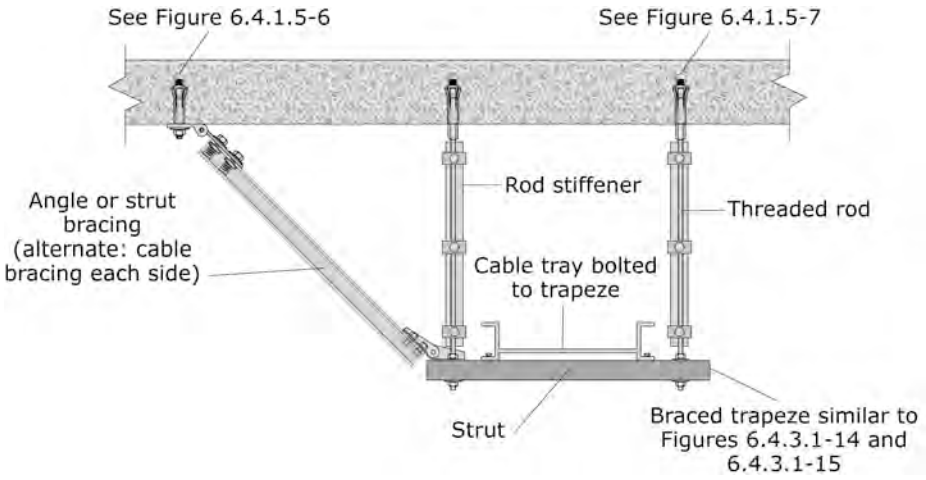


Figure 6.4.8.1-5 Cable tray on braced trapeze (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.8 Electrical and Communications Distribution Equipment

6.4.8.2 Electrical Distribution Panels

This category includes electrical distribution panels, either recessed or surface-mounted. Wall-mounted electrical panels have generally performed well in past earthquakes, in part due to their weight (typically less than 200 pounds), the ductility of the sheet metal cabinets, and the strength of the interconnected conduit which can serve as unintended bracing.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for electrical distribution panels are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13. The principal objective is to prevent the component from falling.

- ASCE/SEI 7-10 requires anchorage for all equipment in Seismic Design Categories D, E, and F for all equipment weighing over 400 pounds, and items weighing over 20 pounds that are mounted over 4 feet above the floor. Lighter items may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. They must also be provided with flexible connections between the equipment and associated conduit, if relative motion between the panel and the conduit is possible.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies electrical equipment, including panel boards, as force controlled. These components are subject to the provisions of the standard when the performance level is Immediate Occupancy. The requirements also apply when the performance level is Life Safety in high and moderate seismicity areas, and the equipment is over 6 feet in height and weighs more than 20 pounds. When applicable, electrical equipment meeting any of the following criteria must comply with the requirements of ASCE/SEI 41-06:

- The item weighs more than 400 pounds,

- The item weighs over 20 pounds and is mounted over 4 feet above the floor.
- Building operation equipment.

Acceptance criteria for electrical equipment focus on providing adequate anchorage for seismic forces.

Typical Causes of Damage

- Panels may become dislodged and fall.
- Damage to distribution panels and the attached lines may create electrical hazards and fire hazards.

DAMAGE EXAMPLES

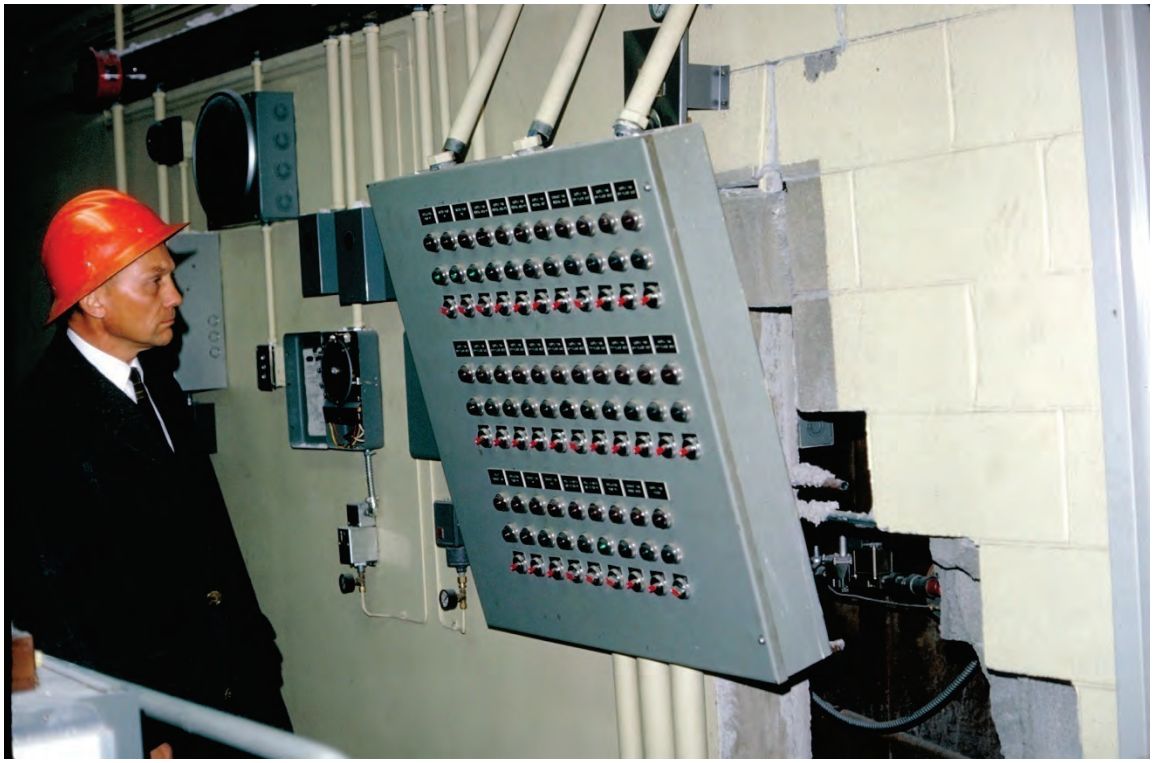


Figure 6.4.8.2-1 Dislodged panel board due to failure of hollow concrete block partition wall in the 1964 magnitude-9.2 Anchorage, Alaska earthquake (Photo courtesy of PEER Steinbrugge Collection, No. S2144).

Seismic Mitigation Considerations

- Working around electrical equipment can be extremely hazardous. Read the Electrical Danger Warning and Guidelines in Section 6.6.8 of this document before proceeding with any work.
- This type of equipment can be supplied with shop welded brackets or predrilled holes for wall anchorage. For any new equipment, request items that can be supplied with seismic anchorage details.
- See Section 6.4.7.1 for additional details. The wall mount detail shown is for a concrete wall; refer to FEMA 413 *Installing Seismic Restraints for Electrical Equipment* (2004) for additional information about anchoring to masonry or drywall and for general information on seismic anchorage of electrical equipment.

MITIGATION EXAMPLES



Figure 6.4.8.2-2 Wall anchorage for electrical panel; standard strut anchored to wall studs and panel anchored to strut (Photo courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

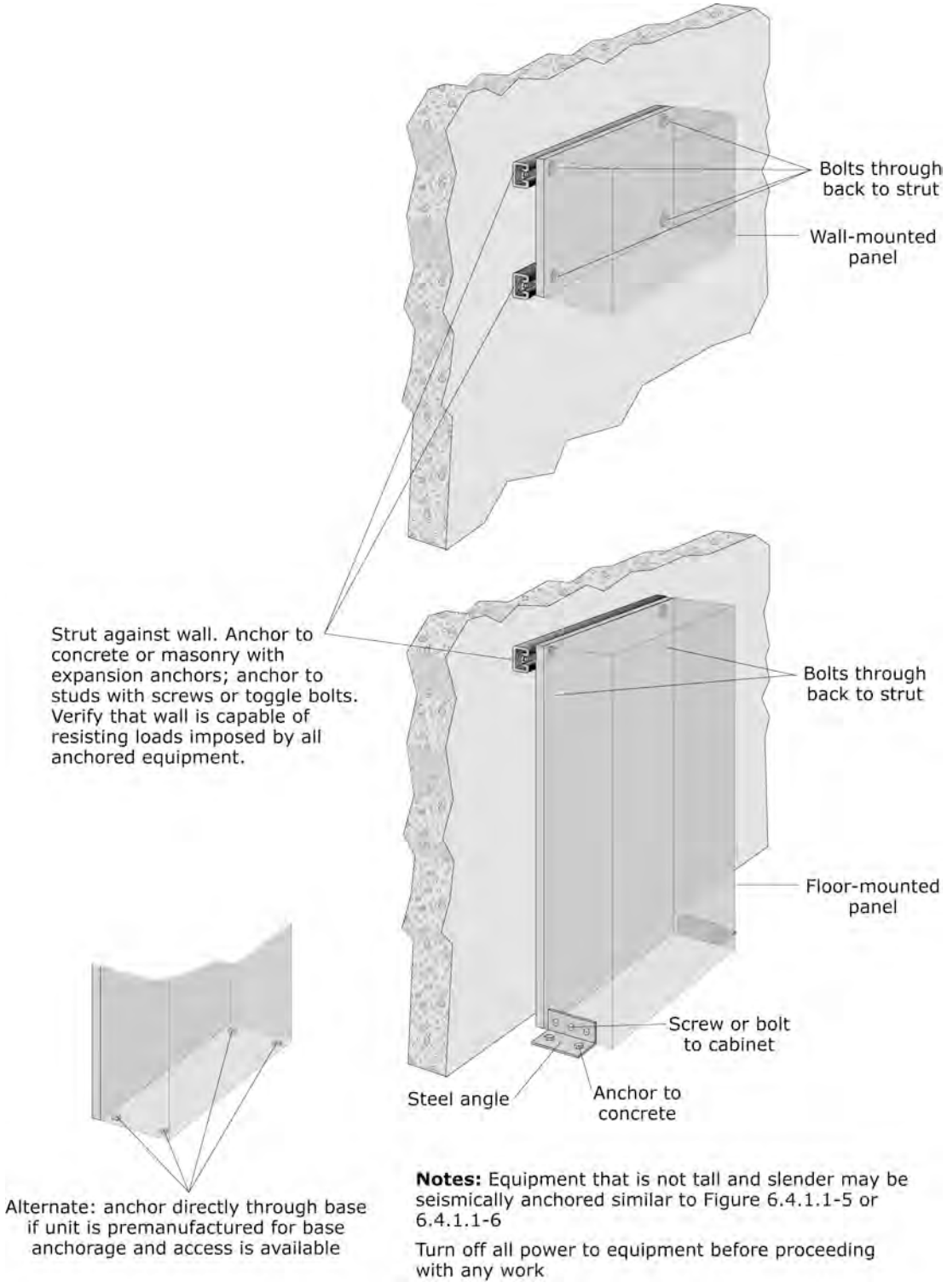


Figure 6.4.8.2-3 Free-standing electrical distribution panel (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.9 Light Fixtures

6.4.9.1 Recessed Light Fixtures

This category covers recessed light fixtures that are part of a suspended ceiling grid. These may be lay-in fixtures in a suspended acoustic tile ceiling or recessed fixtures in other types of suspended ceilings such as gypsum board, plaster, or metal panels. Overhead light fixtures in a finished ceiling have often been damaged in past earthquakes; the fixtures may become dislodged from the ceiling or ceiling grid and fall unless they are tied to the grid and have independent support to the structure above.

Provisions

BUILDING CODE PROVISIONS

Recessed light fixtures are an integral part of suspend ceiling systems, and their support is covered by the standards for suspended acoustical tile ceilings. Requirements for recessed fixtures in suspended acoustic tile ceilings in ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), are by reference to ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010).

ASCE/SEI 7-10 specifies that systems required for life safety purposes after an earthquake be classified as designated seismic systems and designed using a component importance factor, I_p, of 1.5. Ceiling systems and light fixtures classified a designated seismic systems may require engineering calculations or special inspection.

The requirements depend on the Seismic Design Category of the structure.

- In Seismic Design Category C:
  - Lighting fixtures that weigh less than 56 pounds must be positively attached to the ceiling grid as specified in the electrical code, with a minimum of two attachment devices. The attachment devices must be capable of resisting 100% of the fixture weight in any direction.
  - Lighting fixtures weighing less than 10 pounds that are supported by the ceiling grid must have a safety wire attached to the fixture and the structure above.

  - Lighting fixtures weighing between 10 and 56 pounds that are supported by the ceiling grid must have two safety wires attached to the fixture and the structure above.
  - Lighting fixtures that weigh more than 56 pounds must be supported directly from the structure.

- In Seismic Design Categories D, E, and F:
  - Light fixture attachments and safety wires must conform to the requirements for Seismic Design Category C.
  - An intermediate duty or heavy duty ceiling grid is required for ceilings carrying light fixtures.
  - Where the load carrying capacity of the cross runners is less than 16 lb/ft, supplementary hanger wires may be required for the ceiling grid.
  - The requirements for safety wires on fixtures are identical to Seismic Design Category C.
  - Lighting fixtures weighing more than 56 pounds must be supported directly from the structure above by approved hangers. If the ceiling bracing can provide lateral restraint for such fixtures, they should be positively attached to the ceiling grid but must still be but supported with not less than four taut #12 wires.

- ASTM E580 Section 5.3 contains prescriptive requirements for attachment of light fixtures: Fixtures must be positively attached to the suspended ceiling system by mechanical means. The attachment device shall have the capacity of supporting 100 % of the lighting fixture weight acting in any direction. A minimum of two attachment devices are required for each fixture.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies light fixtures into one of four types. Recessed light fixtures are classified as "Category 1" or "Category 3," depending on the type of ceiling they are installed in. ASCE/SEI 41-06 provides prescriptive acceptance criteria for the life safety and immediate occupancy nonstructural performance levels. Fixtures not meeting the criteria must be seismically retrofit.

Evaluation for the presence of adequate attachment is required for all performance levels and in high, moderate, and low seismicity areas.

Typical Causes of Damage

- Recessed fixtures supported by a suspended ceiling without independent safety wires to the structure above can become dislodged and fall. Fixtures with proper safety wires may fall from the grid and dangle from the safety wire but will not threaten occupants.
- Unless secured to a properly braced ceiling grid, relative movement between the light fixture and the ceiling may damage the ceiling finishes, ceiling grid, wiring, or the light fixture. Heavy fixtures that are hung independently but not laterally braced may swing independent of the ceiling and damage the ceiling system.
- Unsecured lenses and bulbs may fall independent of the fixture and cause damage below.
- Most observed damage to recessed light fixtures in the U.S. has involved fixtures in suspended acoustic tile ceilings which do not have much inherent in-plane stiffness; damage to fixtures in gypsum board ceilings has been less common.

DAMAGE EXAMPLES



Figure 6.4.9.1-1 Numerous fluorescent fixtures dangling from electrical conduit; installed without safety wires in unbraced suspended acoustical ceiling and damaged in the 2010 magnitude-7 Haiti Earthquake. Loose bulbs, lenses, ceiling panels, diffusers and ducts also on the floor (Photo courtesy of Ayhan Irfanoglu, Purdue University).



Figure 6.4.9.1-2 Overhead lights with four vertical hangers to the structure. Unbraced acoustic ceiling system was damaged beyond repair in the 2001 magnitude-8.4 Peru Earthquake but none of the diffusers or lights fell because they had independent supports. Ceiling was demolished prior to photo (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.9.1-3 Light fixture without adequate independent support dangling along one edge from ceiling grid, damaged in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Degenkolb Engineers).



Figure 6.4.9.1-4 Light fixture without independent support dangling from conduit as a result of the 1994 Northridge Earthquake (Photo courtesy of Degenkolb Engineers).

Seismic Mitigation Considerations

- Requirements for recessed lighting fixtures may vary depending on requirements for the type of ceiling in which they are located. Recessed light fixtures may be found in any type of ceiling system. Requirements for suspended acoustic ceilings and suspended gypsum board ceilings are discussed below.
- For acoustic tile ceilings, California schools require safety wires or independent vertical support for each light fixture, positive attachment from the light fixtures to the ceiling grid, and bracing for the ceiling grid that is adequate to resist the lateral loading from the ceiling, lights, and diffusers. DSA IR 25-5 *Metal Suspension Systems for Lay-in Panel Ceilings* (California Department of General Services, 2009c) provides details for lights in suspended acoustic ceiling grids. The requirements in DSA IR 25-5 differ slightly from ASTM E580: California schools require two safety wires on all fixtures under 56 pounds; require all 4 ft x 4 ft fixtures have a slack #12 safety wire at each corner, even if the fixture weight is less than 56 lb; and for fixtures weighing more than 56 lb, require they be independently supported by not less than four taut #12 wires, and that these wires be capable of supporting four times the weight of the fixture.
- Per ASCE 7-10, certain types of suspended ceilings with screw-attached gypsum board built at one level do not require special seismic details; these ceilings also do not require safety wires for light fixtures (see Section 6.3.4.3 for a discussion of exempt ceilings). The weight of recessed light fixtures in suspended gypsum board ceilings must be supported by main runners, supplementary framing supported by the main runners, or directly by the structure above. Neither the ceiling finish material nor the cross furring should be used to support light fixtures. The fixture should be positively attached with screws or other approved connectors to the ceiling grid. Requirements for California schools are in DSA IR 25-*3 Drywall Ceiling Suspension Conventional Construction-One Layer* (California Department of General Services, 2005b). For suspended gypsum ceilings built at multiple levels, or other types of heavy ceilings, seismic detailing and safety wires for lighting may be required; check applicable code provisions.
- International Code Council Evaluation Service has published AC184, *Acceptance Criteria for Attachment Devices for Recessed Lighting Fixtures (Luminaries) in Suspended Ceiling Systems* (ICC-ES, 2006), with information on attachments of light fixtures to suspended ceiling grids. The website located at http://www.agi-seismic.com/code/ac184.html# provides footage of lighting fixture failures where the lights are attached only with tie wires. A discussion of issues related to the code design provisions and the requirement for positive attachments is also provided. In some instances, where approved seismic

fixture clamps (SFC) are used to anchor the lighting to a properly braced ceiling grid, the independent tie wires are not required.

- For existing construction where the ceiling grid is not adequately braced or not strong enough to provide lateral restraint for the lighting, splay wire bracing at each corner of the fixture can be used to provide horizontal restraint. Such bracing would also help prevent swinging lights from damaging the surrounding ceiling. At a minimum, such fixtures should be retrofit with independent safety wires to prevent them from falling.
- Lenses and bulbs may require independent restraints to keep them from falling from the fixture.
- For fire rated ceiling assemblies, only fixtures and attachments with an approved fire rating may be used. Check with the manufacturer for approved systems. Some fixtures may require lead shielding or a fire-rated enclosure; check local code provisions.
- Do not attach lights to ducts, piping, or other nonstructural items in the ceiling plenum.

MITIGATION EXAMPLES



Figure 6.4.9.1-5 Example of light fixture with only one safety wire attached; the Salt Lake City schools require four wires for a fixture of this size and weight and also require tighter turns on the wire (Photo courtesy of Salt Lake City School District). Investigations in ceiling plenums often reveal missing wires.

MITIGATION DETAILS

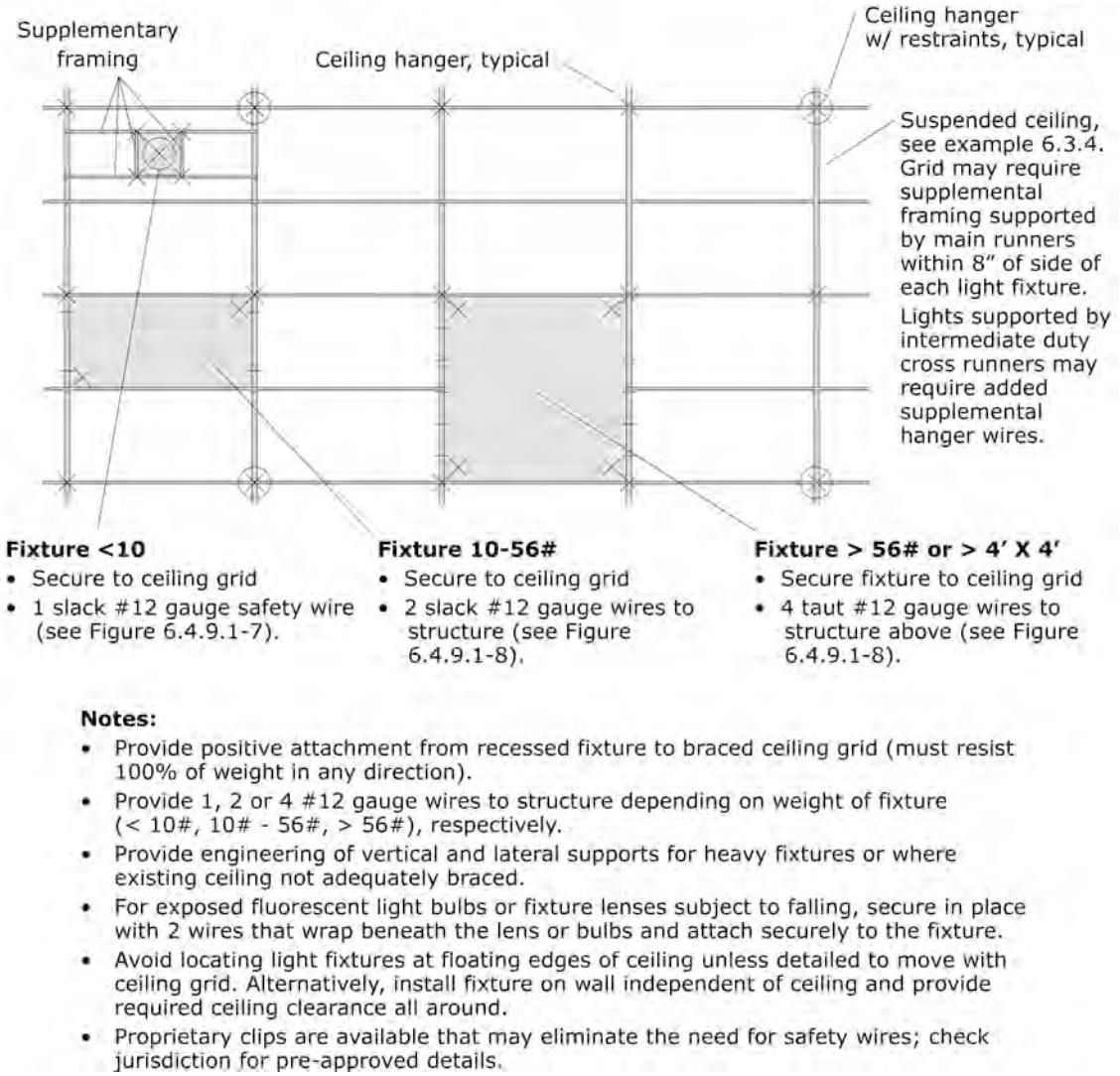


Figure 6.4.9.1-6 Schematic plan of recessed lights in suspended acoustic ceiling (PR).

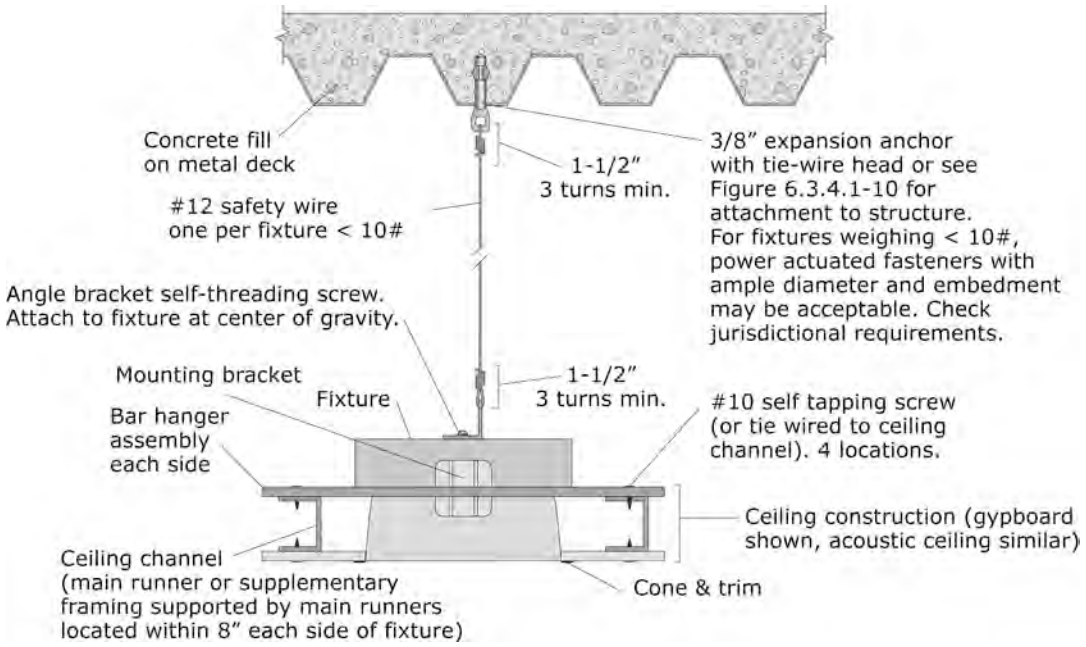


Figure 6.4.9.1-7 Recessed light fixture in suspended ceiling (fixture weight < 10 pounds) (PR).

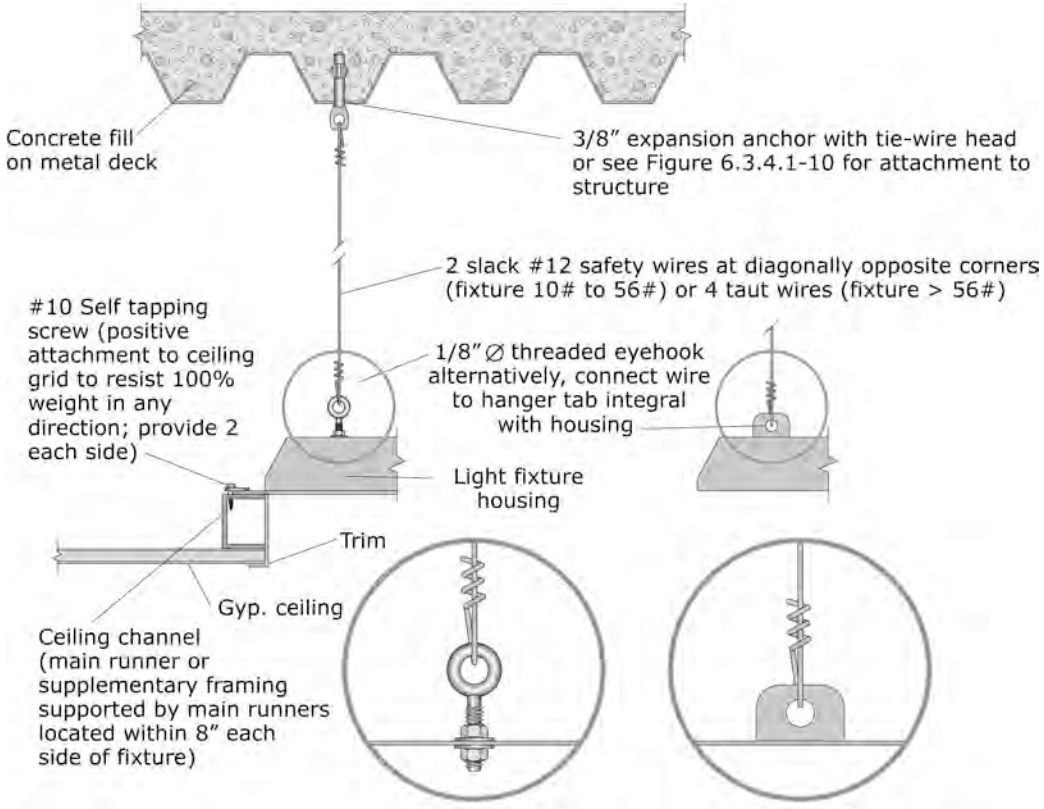


Figure 6.4.9.1-8 Recessed light fixture in suspended ceiling (fixture weight 10 to 56 pounds) (PR).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.9 Light Fixtures

6.4.9.2 Surface-Mounted lighting

This category covers surface-mounted light fixtures that are overhead in a finished ceiling. The term surface-mounted refers to a range of conditions; in some cases the fixture and housing are entirely below the ceiling surface, in other cases part of the housing is recessed above the bottom of the ceiling. Overhead fixtures may also be surface-mounted on a wall. Damage to overhead lighting has occurred frequently in past earthquakes; the fixtures become dislodged from the ceiling or ceiling grid and fall unless they are tied to the grid or have independent support to the structure above.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) does not have specific seismic requirements for surface mounted light fixtures. For the purposes of design, the same design procedures used for suspended ceilings may be used.

ASCE/SEI 7-10 specifies that systems required for life-safety purposes after an earthquake be classified as designated seismic systems and designed using a component importance factor, I_p, of 1.5. Ceiling systems and light fixtures classified a designated seismic systems may require engineering calculations, or special inspection.

When supported by ceiling systems other than suspended lay-in types, surface-mounted light fixtures must conform to the anchorage requirements of ASCE/SEI 7-10. The anchorage of surface mounted light fixtures weighing less than 20 pounds need not be designed, provided that the importance factor for the fixtures is equal to 1.0 (not part of an essential system), the fixture is positively attached to the structure, and that flexible connections are provided between the fixture and conduit if there is a potential for damaging differential movement.

When surface-mounted fixtures are supported by suspended lay-in ceilings, the provisions of ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010) apply. The requirements for support of the fixtures depend on the Seismic Design Category of the structure.

- In Seismic Design Category C:
  - Lighting fixtures that weigh less than 56 pounds must be positively attached to the ceiling grid as specified in the electrical code, with a minimum of two attachment devices. The attachment devices must be capable of resisting 100% of the fixture weight in any direction.
  - Lighting fixtures weighing less than 10 pounds that are supported by the ceiling grid must have a safety wire attached to the fixture and the structure above.
  - Lighting fixtures weighing between10 and 56 pounds that are supported by the ceiling grid must have two safety wires attached to the fixture and the structure above.
  - Lighting fixtures that weigh more than 56 pounds must be supported directly from the structure.

- In Seismic Design Categories D, E, and F:
  - Light fixture attachments and safety wires must conform to the requirements for Seismic Design Category C.
  - An intermediate duty or heavy duty ceiling grid is required for ceilings carrying light fixtures.
  - Where the load carrying capacity of the cross runners is less than 16 lb/ft, supplementary hanger wires may be required for the ceiling grid.
  - Lighting fixtures weighing less than 10 pounds require one safety wire connected from the fixture housing to the structure above. The wire may be slack.
  - Lighting fixtures weighing 10 to 56 pounds require two safety wires at diagonally opposite corners connected from the fixture housing (not the detachable end plates) to the structure above. The wires may be slack.
  - Fixtures weighing more than 56 pounds must be supported directly from the structure above by approved hangers. If the ceiling bracing can provide lateral restraint for such fixtures, they should be positively attached to the ceiling grid but must still be supported with not less than four taut #12 wires.

- ASTM E580 Section 5.3 contains prescriptive requirements for attachment of surface-mounted light fixtures:
  - Surface-mounted lighting fixtures must be attached to the ceiling system with a positive clamping device that completely surrounds the supporting members. Safety wires have to be attached between the clamping device and the adjacent ceiling hanger or to the structure above.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies light fixtures into one of four types. Surface-mounted light fixtures are classified as "Category 2" or "Category 3," depending on the type of ceiling they are installed in. ASCE/SEI 41-06 provides prescriptive acceptance criteria for the life safety and immediate occupancy nonstructural performance levels. Fixtures not meeting the criteria must be retrofitted.

Evaluation for the presence of adequate attachment is required for all performance levels and in high, moderate, and low seismicity areas.

Typical Causes of Damage

- Surface lighting that is not equipped with independent safety wires may fall to the floor. Lighting with proper safety wires may fall from the ceiling and dangle from the safety wires but will not pose a safety risk to occupants.
- Unless secured to a properly braced ceiling grid, relative movement between the light fixture and the ceiling may damage the ceiling finishes, ceiling grid, wiring, or the light fixture.
- Unsecured lenses and bulbs may become dislodged and fall to the floor even where the fixture is restrained. This may occur with both ceiling and wall mounted surface lighting.
- Most observed damage to light fixtures in the U.S. has involved fixtures in suspended acoustic tile ceilings which do not have much inherent in-plane stiffness; damage to fixtures mounted in or on gypsum board ceilings has been less common.

DAMAGE EXAMPLES



Figure 6.4.9.2-1 Numerous failures of ceilings and lights were observed at the Concepción airport in the 2010 magnitude-8.8 Chile Earthquake. Photo shows surface-mounted fixture on wall that remained in place but the lens fell and the bulbs were dislodged (Photo courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).



Figure 6.4.9.2-2 Overhead surface-mounted fixture anchored to underside of concrete slab damaged in the 2010 Chile Earthquake. Back of fixture housing remained anchored to the concrete slab above and the bulbs remained in place but the lens and sides of housing fell indicating that internal connections in the fixture were inadequate (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

Seismic Mitigation Considerations

- Retrofit of surface-mounted light fixtures is generally performed by following the prescriptive requirements for new construction. The key considerations include attachment to the ceiling suspension system with positive clamping devices that completely surround the supporting members. Safety wires are required between the clamping device and the adjacent ceiling hanger or to the structure above. The weight of the fixture shall not exceed the design carrying capacity of the supporting members. One, two, or four safety wires are required from the fixture housing to the structure above.
- For suspended acoustic ceilings, ASTM E580 has other requirements related to the grid itself. Intermediate or heavy duty ceiling grid is required where lights will be supported and supplementary ceiling framing and supplementary hanger wires may be required adjacent to fixtures. Lateral restraint for lighting is assumed to be provided by the ceiling grid so the design of the grid must account for the overall weight of all the attached lighting and mechanical registers. See Section 6.3.4 for additional information regarding ceilings.
- Per ASCE 7-10, certain types of suspended ceilings with screw-attached gypsum board built at one level do not require special seismic details; these ceilings also do not require safety wires for light fixtures (see Section 6.3.4.3). The weight of surface-mounted fixtures must be supported by main runners, supplementary framing supported by the main runners, or directly by the structure above. Neither the ceiling finish material nor the cross furring should be used to support light fixtures. The fixture should be positively attached with screws or other approved connectors to the ceiling grid. Requirements for California schools are in DSA IR 25-3 *Drywall Ceiling Suspension Conventional Construction-One Layer* (California Department of General Services, 2005b) and read "Surface-mounted fixtures shall be attached to a main runner with a positive clamping device made of material with a minimum of 14 gage. Rotational spring clamps do not comply." For suspended gypsum ceilings built at multiple levels, or other types of heavy ceilings, seismic detailing and safety wires may be required; check applicable code provisions.
- International Code Council Evaluation Service has published Acceptance Criteria AC184 (ICC-ES, 2006) with information on attachments of light fixtures to suspended ceiling grids. The website located at http://www.agi-seismic.com/code/ac184.html provides footage of lighting fixture failures where the lights are attached only with tie wires. A discussion of issues related to the code design provisions and the requirement for positive attachments is also provided. In some instances, where approved seismic

fixture clamps are used to anchor the lighting to a properly braced ceiling grid, independent tie wires are not required. Check for pre-approved details for such devices in the applicable jurisdiction.

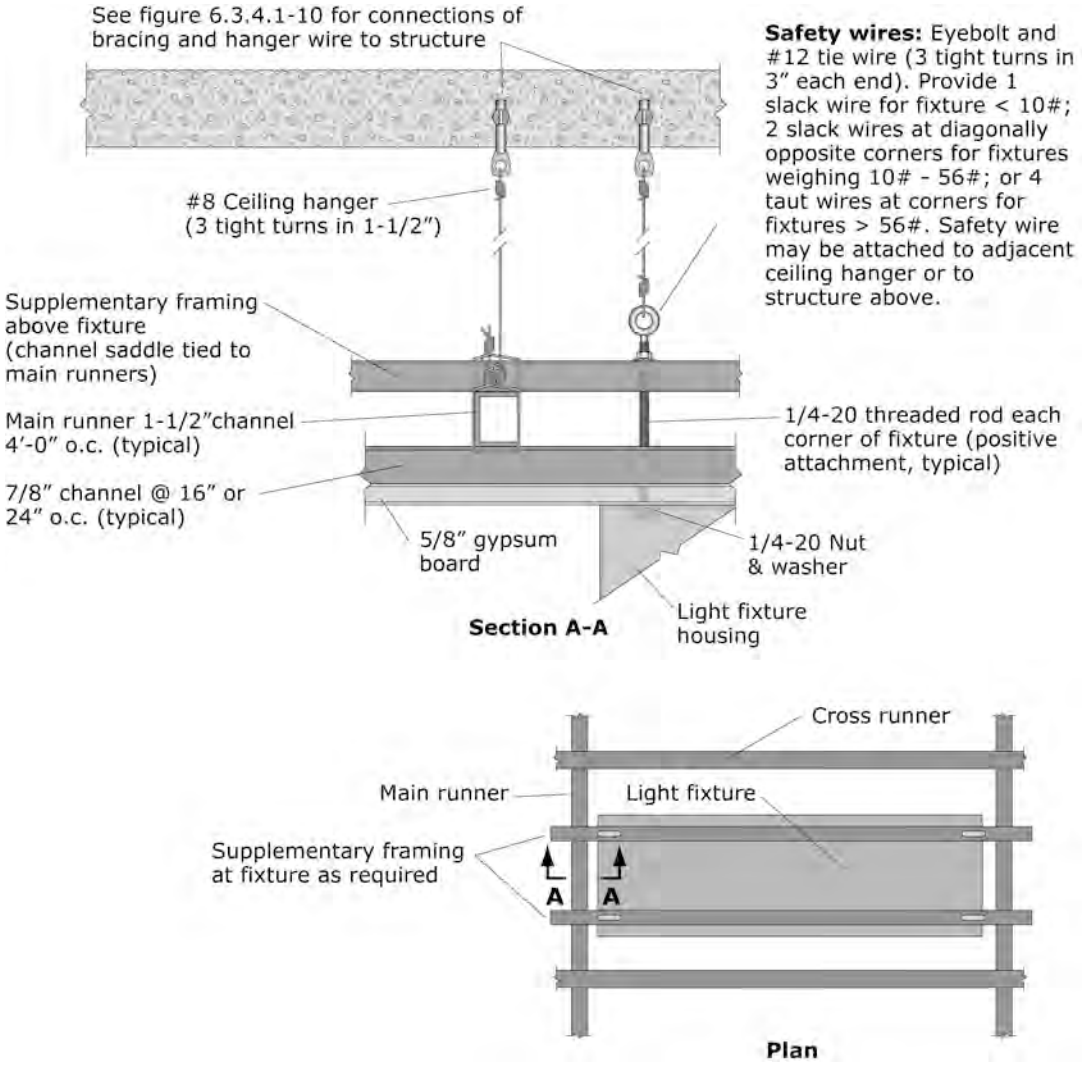
- For surface-mounted fixtures in existing buildings where the ceiling grid is unbraced, such fixtures should be retrofit with safety wires at a minimum to prevent them from falling. Providing independent lateral bracing for the fixture may reduce the potential for the light to damage an existing unbraced ceiling.
- For fire rated ceiling assemblies, only fixtures and attachments with an approved fire rating may be used. Check with the manufacturer for approved systems. Some fixtures may require lead shielding or a fire-rated enclosure; check local code provisions.
- Do not attach lights to ducts, piping, or other nonstructural items in the ceiling plenum.

MITIGATION EXAMPLES



Figure 6.4.9.2-3 Independent vertical support for surface-mounted light fixture in suspended gypsum board ceiling located in California hospital. Eye hook and slack wire from fixture is tied to concrete slab above. The rigid bracing in the photos is attached to the ceiling grid, not the light fixture (Photos courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS



Note: Surface-mounted fixtures shall be attached to ceiling suspension systems with screws or positive clamping devices. Safety wires (1, 2 or 4) are required in suspended acoustic lay-in tile ceilings depending on the size and weight of the fixture; safety wires may be required in other ceiling types as well. Weight of fixture shall not exceed design carrying capacity of the supporting members; supplementary framing and additional hanger wires may be required. Gypsum board ceiling shown in details; although some gypsum ceilings may be exempt from the seismic detailing requirements and may not require the safety wires shown.

Figure 6.4.9.2-4 Surface-mounted fixture below suspended ceiling grid (PR).

6.4 Mechanical, ElectricaL, and Plumbing Components

6.4.9 Light Fixtures

6.4.9.3 Pendant Light Fixtures

This section covers pendant light fixtures, chandeliers, ceiling fans, and other similar suspended items.

Provisions

BUILDING CODE PROVISIONS

ASCE/SEI 7-10, *Minimum Design Loads for Buildings and other Structures*, (ASCE, 2010) contains provisions for components supported by chains or suspended from the structure. The anchorage of pendant light fixtures weighing less than 20 pounds need not be designed, provided that the importance factor $I_p = 1.0$ (not part of an essential system) and the fixture is positively attached to the structure. Flexible connections must be provided between the fixture and conduit.

Larger suspended items need not meet the seismic force requirements of ASCE/SEI 7-10 provided prescriptive conditions are met. The connection to the structure must be designed for vertical and horizontal loads equal to 1.4 times the operating weight, acting simultaneously. The connection to the structure must permit a 360 degree range of motion in the horizontal plane; care must be taken to avoid seismic interactions with adjacent objects when the suspended component swings.

When pendant fixtures are installed with suspended lay-in ceilings, the provisions of ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010) apply. Pendant-hung lighting fixtures must be supported directly from the structure above using no less than number 9-gauge (3.80 mm) wire or an approved alternate support. The ceiling suspension system may not provide any direct support.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies light fixtures into one of four types. Pendant light fixtures are classified as “Category 4”. ASCE/SEI 41-06 provides prescriptive acceptance criteria for Life Safety and Immediate Occupancy nonstructural performance levels. Fixtures not meeting the criteria must be seismically retrofit.

Evaluation for the presence of adequate attachment is required for all performance levels and in high, moderate, and low seismicity areas.

Typical Causes of Damage

- Suspended items can swing and impact building elements or adjacent equipment, resulting in damage to the fixture or damage to the surrounding items. Lenses, bulbs, or decorations may come loose and fall and endanger occupants.
- If the item is not sufficiently well supported, or if the item is connected only to ceiling framing which is damaged in an earthquake, the entire fixture may become dislodged and fall. Where a string of fixtures are attached end to end, the failure of one fixture can overload the supports for the adjacent fixtures leading to progressive collapse.

DAMAGE EXAMPLES



Figure 6.4.9.3-1 Failure of a strip of pendant light fixtures at Dawson Elementary School library as a result of the 1983 magnitude-6.4 Coalinga Earthquake. Note that in this case the support stems failed at the ceiling connection and the stem came down with the lights (Gary McGavin, NGDC, 2009).



Figure 6.4.9.3-2 Failure of pendant light fixtures at Northridge Junior High School as a result of the 1994 Northridge Earthquake. In this example, the support stem failed at the fixture connection and the stem is still attached at the ceiling (Photo courtesy of Gary L. McGavin).



Figure 6.4.9.3-3 Failure of pendant light fixture in the 2010 magnitude-7 Haiti Earthquake; stem of fixture broke and conduit pulled loose (Photos courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- All light fixtures should have positive attachments to the structure to prevent falling hazards. Per ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010), pendant fixtures in suspended ceilings must be supported directly from the structure above by no less than #9 gauge wire or an approved alternate support. The ceiling suspension system shall not provide any direct support and rigid conduit is not permitted for the attachment of fixtures.
- For California schools, DSA IR 25-5, *Metal Suspension System for Lay-in Panel Ceilings* (California Department of General Services, 2009c), requires the following: "Support pendant mounted light fixtures directly from the structure above with hanger wires or cables passing through each pendant hanger and capable of supporting two (2) times the weight of the fixture. A bracing assembly, (see Section 6.3.4.1), is required where the pendant hanger penetrates the ceiling. Special details are required to attach the pendant hanger to the bracing assembly to transmit horizontal force. If the pendant mounted light fixture is directly and independently braced below the ceiling, i.e. aircraft cables to walls, then brace assembly is not required above the ceiling." See DSA IR 16-9, *Pendant Mounted Light Fixtures* (California Department of General Services, 2009a), for additional requirements for pendant mounted fixtures.
- For older installations, provide a safety chain or cable for the fixture and provide restraints for lenses and bulbs that can readily fall from the fixture.
- If the fixture can impact other items and cause failure of an essential component, or if impact can create a falling hazard, then seismic restraints that limit the range of motion of the fixture should be installed.

MITIGATION DETAILS

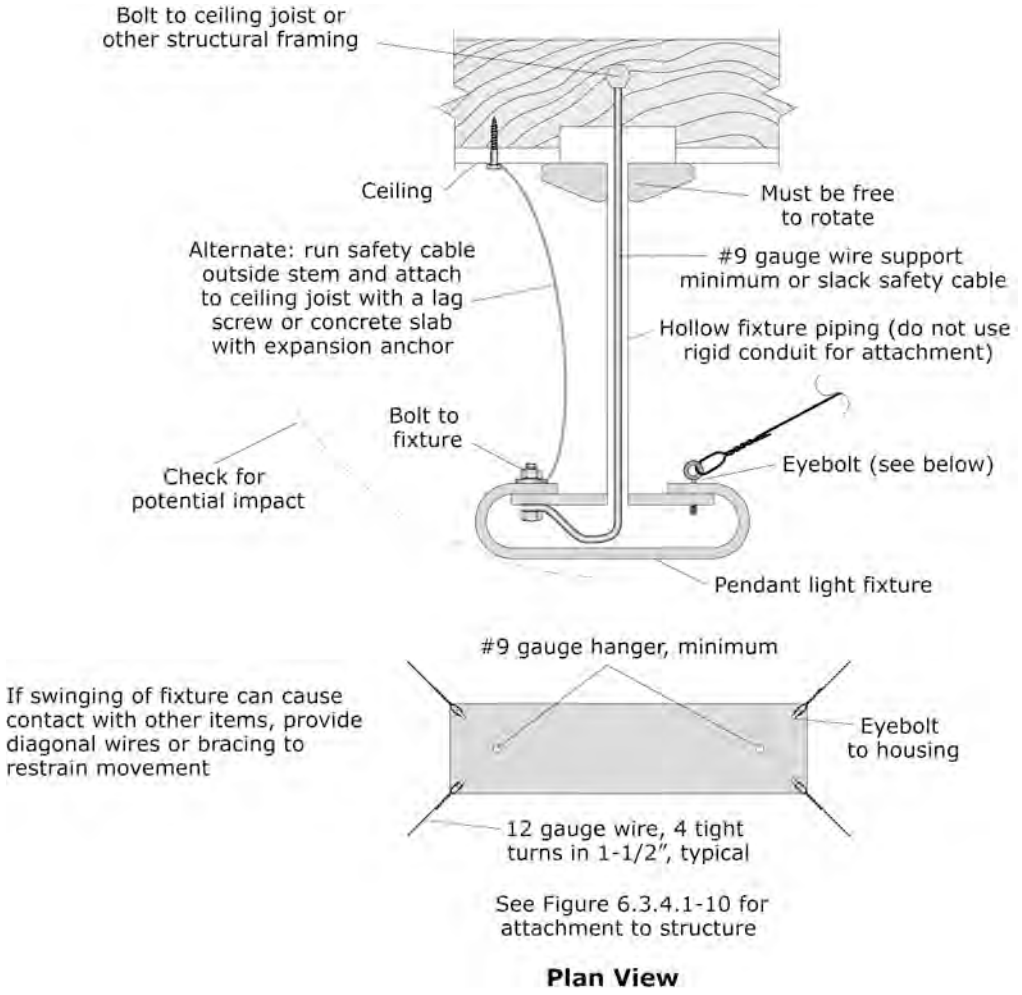


Figure 6.4.9.3-4 Pendant light fixture (NE).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.9 Light Fixtures

6.4.9.4 Heavy Light Fixtures

This category covers heavy or special purpose overhead light fixtures that require engineered support details. This includes fixtures such as hospital operating room lights which also have movable arms. Damage to overhead lighting has occurred frequently in past earthquakes; special purpose lighting has additional issues in that the fixture may have internal joints and movable parts which may not have not been designed for seismic loading.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for heavy light fixtures are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13. The principal objective is to prevent the component from falling. Light fixtures are classified as an electrical component. Unless they are anchored directly to the structure (slab or framing), they require component supports (structural members, frames, braces, anchor plates, etc) that carry gravity and lateral loads to the structure. The design of heavy light fixtures must include the component supports as well as the design of the anchorage of the fixture itself.

- ASCE/SEI 7-10 requires anchorage for items weighing over 20 pounds that are mounted over 4 feet above the floor.
- Heavy light fixtures in essential buildings such as hospitals may be classified as designated seismic systems. Designated seismic systems are designed using a component importance factor, I_p, of 1.5 and may require engineering calculations, equipment certification, and special inspection.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies light fixtures into one of four types. Heavy suspended light fixtures do not fit any of the four types. "Category 4" fixtures are described as "lighting suspended from ceiling or structure by a pendant or chain." Heavy light fixtures are generally supported by a rigid or braced frame component supports, and so do not fit this category. They rarely rely on the ceiling for vertical or lateral support, and so do not fit the other categories.

Analysis of the fixture anchorage and component supports is required, since the prescriptive acceptance criteria for the life safety and immediate occupancy nonstructural performance levels are not generally applicable.

Given the level of risk posed by these components, evaluation for the presence of adequate attachment and support should be performed for all performance levels in high, moderate, and low seismicity areas.

Typical Causes of Damage

- Heavy or special purpose lighting can fail at the attachment to the structure above if not adequately designed and the fixture could fall and injure occupants. Overhead braces may buckle and the fixture will be misaligned or fail to function as intended.
- Fixtures with multiple parts or movable arms may fail at the connections or arm joints; bulbs or lenses may fall.
- Bracing for the light fixture and surrounding ceiling should be coordinated to allow for relative movement. If the ceiling surround has not been designed with appropriate clearance around the fixture, the ceiling may be damaged at the interface with the light.

DAMAGE EXAMPLES



Figure 6.4.9.4-1 Operating room lights undamaged although hospital evacuated due to collapse of adjacent wing in the 2010 magnitude-7 Haiti Earthquake. Fixture anchored to underside of concrete slab (Photo courtesy of Ayhan Irfanoglu, Purdue University).

Seismic Mitigation Considerations

- Per ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010), where the weight of a fixture in a suspended acoustic ceiling is greater than 56 pounds, the fixture must be supported directly from the structure above by approved hangers. Where the fixture is over 56 pounds but light enough so that the lateral restraint for the fixture can be provided by the lateral bracing for the ceiling grid, these fixtures must also be positively attached to the ceiling grid with a minimum of two attachment devices capable of resisting 100% of the fixture weight in any direction. This condition is covered in Sections 6.4.9.1 and 6.4.9.2.
- Lights covered here are those heavier than can be safely supported by the suspended ceiling grid and require independent engineered supports for both vertical and lateral loads. In addition, special purpose lighting with movable parts may require more fixity than provided by the ceiling grid and require independent support and bracing to maintain position and satisfy operational tolerances.
- Note that fixed lighting provides an obstruction for a suspended ceiling system. For suspended acoustic ceilings in Seismic Design Category D, E & F, ASTM E580 requires that the ceiling surrounding such a fixture must be detailed as if it were a perimeter closure that must allow the required clearances by use of suitable closure details; this typically would require a minimum ¾" clearance around the fixture.
- When purchasing heavy light fixtures that have multiple part or movable arms, check with the manufacturer for seismically qualified fixtures. Certified fixtures are required for hospitals or essential facilities that must remain functional following an earthquake per Section 13.2.2.1 of ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010).

MITIGATION EXAMPLES



Figure 6.4.9.4-2 Engineered support and bracing are required for heavy operating room lights. The arms, joints, lenses and bulbs must be capable of resisting seismic forces. Hospital fixtures require certification. Photo also shows surface mounted fluorescent fixtures in a suspended gypsum board ceiling; each of these requires independent safety wires to the structure above; see Section 6.4.9.2 (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.4.9.4-3 Engineered support and bracing for operating room lights located in California hospital. Steel plate has predrilled holes to receive fixture attachments (Photo courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

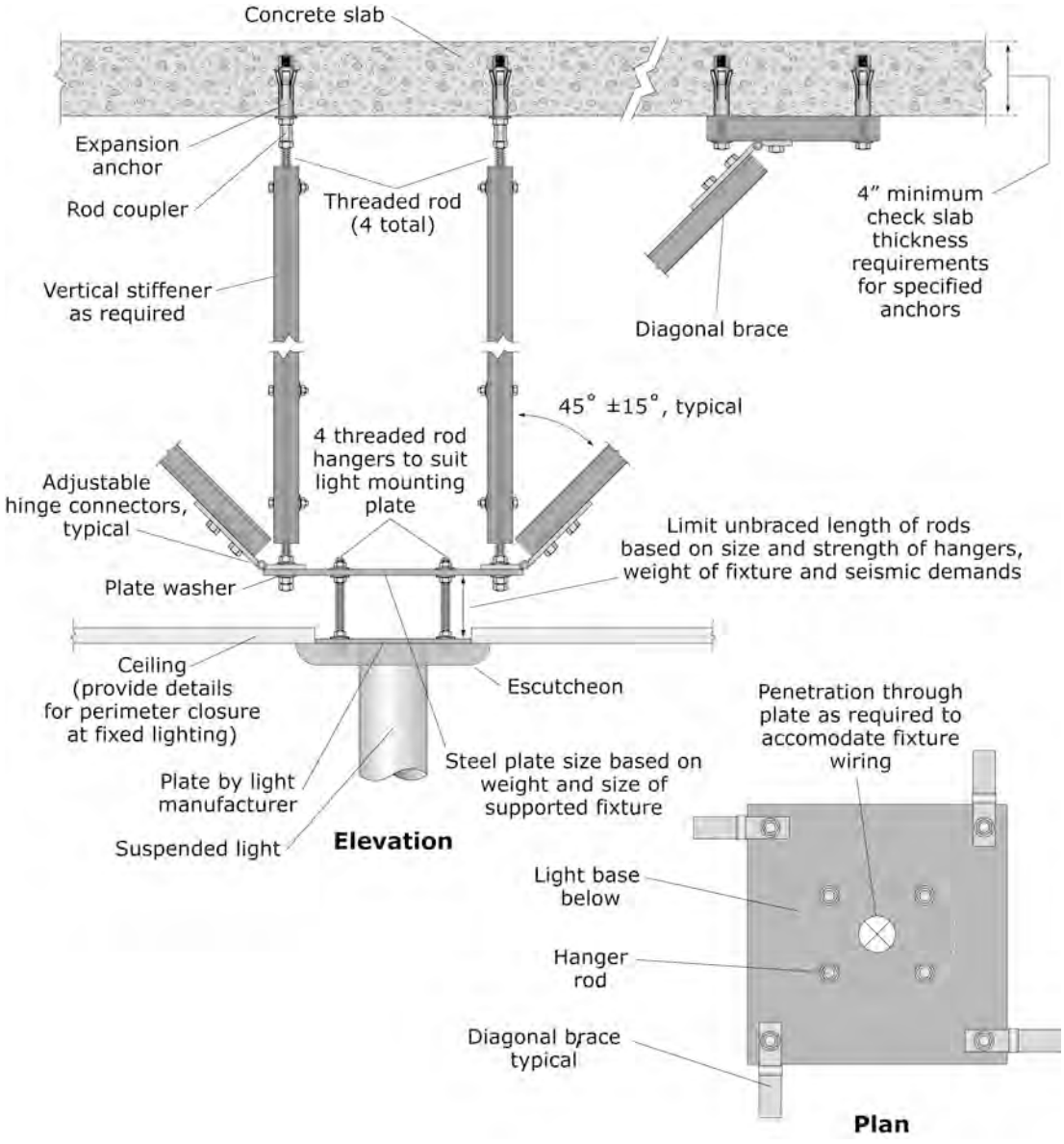


Figure 6.4.9.4-4 Details for supporting heavy light fixture directly from structure (ER).

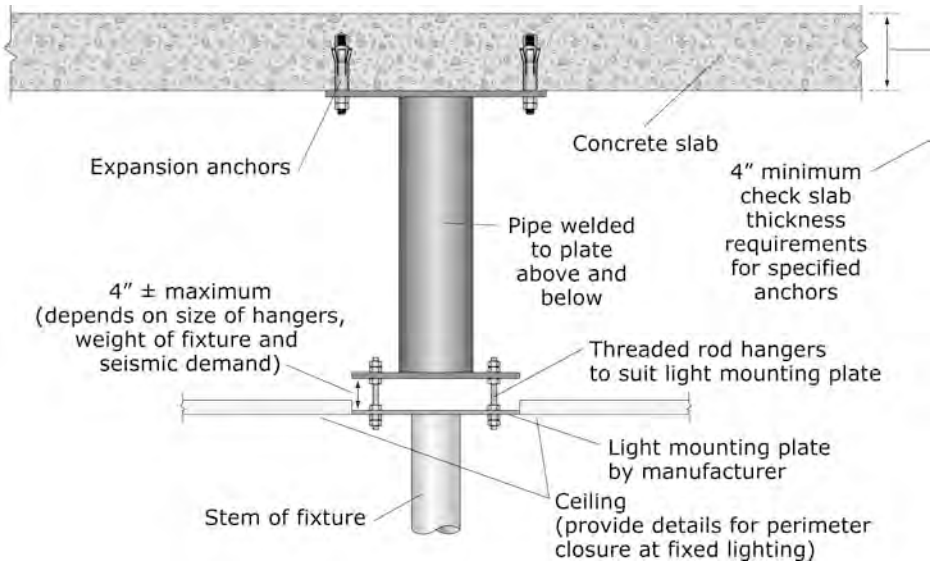


Figure 6.4.9.4-5 Details for supporting heavy light fixture directly from structure (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.10 Elevators and Escalators

Elevators are the most common type of transportation system to move people or cargo from one floor to another in buildings. Since the first passenger elevator was installed in New York in 1857 by Elisha Otis, elevators have become a ubiquitous mode of vertical transportation in buildings and they are found in practically all modern buildings around the world. An elevator is a machine that either pulls or pushes a car (or cab) located in a shaft (also referred to as hoistway). There are two main types of elevators which vary depending on the mechanical means in which the car is lifted or lowered. In hydraulic elevators a pressurized fluid in a piston is used to lift and lower the car whereas in traction (sometimes referred to as roped) elevators the car is pulled by steel ropes moved by a pulley system.

6.4.10.1 Hydraulic Elevators

The primary components of the hydraulic elevator system are the elevator cab, cab guides, doors and door mechanism, piston, cylinder, fluid reservoir, hydraulic fluid, rotary pump, valve, solenoid switch, and electrical control panel. Figure 6.4.101-1 shows a schematic view of a typical hydraulic elevator. Hydraulic elevators consist of relatively simple mechanical systems but failure of any of the component parts could disable the functionality of the entire system. The system may be tied to a seismic switch or a smoke detector which would facilitate safe shutdown in the event of an earthquake or fire.

These elevators are typically less expensive but are limited in height since they require a cylinder beneath the elevator equal to the height of the elevator cab's vertical travel. Typical heights are two to six stories.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for elevators are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. Elevators are classified as mechanical components, and are sensitive to both story drift and acceleration. Elevators designed in accordance with the seismic requirements of ASME A17.1 *Safety Code for Elevators and Escalators* (ASME, 2007a) are deemed to meet the requirements of ASCE/SEI 7-10, provided the forces and displacements used in the design meet the provisions of ASCE/SEI 7-10.

- Elevators, hoistway structural systems, elevator equipment supports and attachments, and controller supports and attachments must be designed to meet the force and displacement requirements of ASCE/SEI 7-10.
- Bracing exemptions for small diameter piping and piping supported on hangers less than 12 inches long do not apply to elevator piping.
- Elevators that operate at speeds greater than 150 feet per minute must be provided with seismic switches that are triggered by earthquake shaking. The seismic switch will prevent a potentially damaged elevator from being used.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies components of elevators as acceleration sensitive. Shafts and hoistway rails that rise through several floors are both acceleration and deformation sensitive.

- Elevators are subject to the requirements of ASCE/SEI 41-06 when the performance level is Immediate Occupancy, or in regions of high and moderate seismicity when the performance level is Life Safety.
- The evaluation must consider the anchorage of the equipment and controllers, as well as the construction of the elevator shafts.
- Acceptance criteria may be based on prescriptive procedures, or the elevator components may be analyzed for the force and displacement demands.

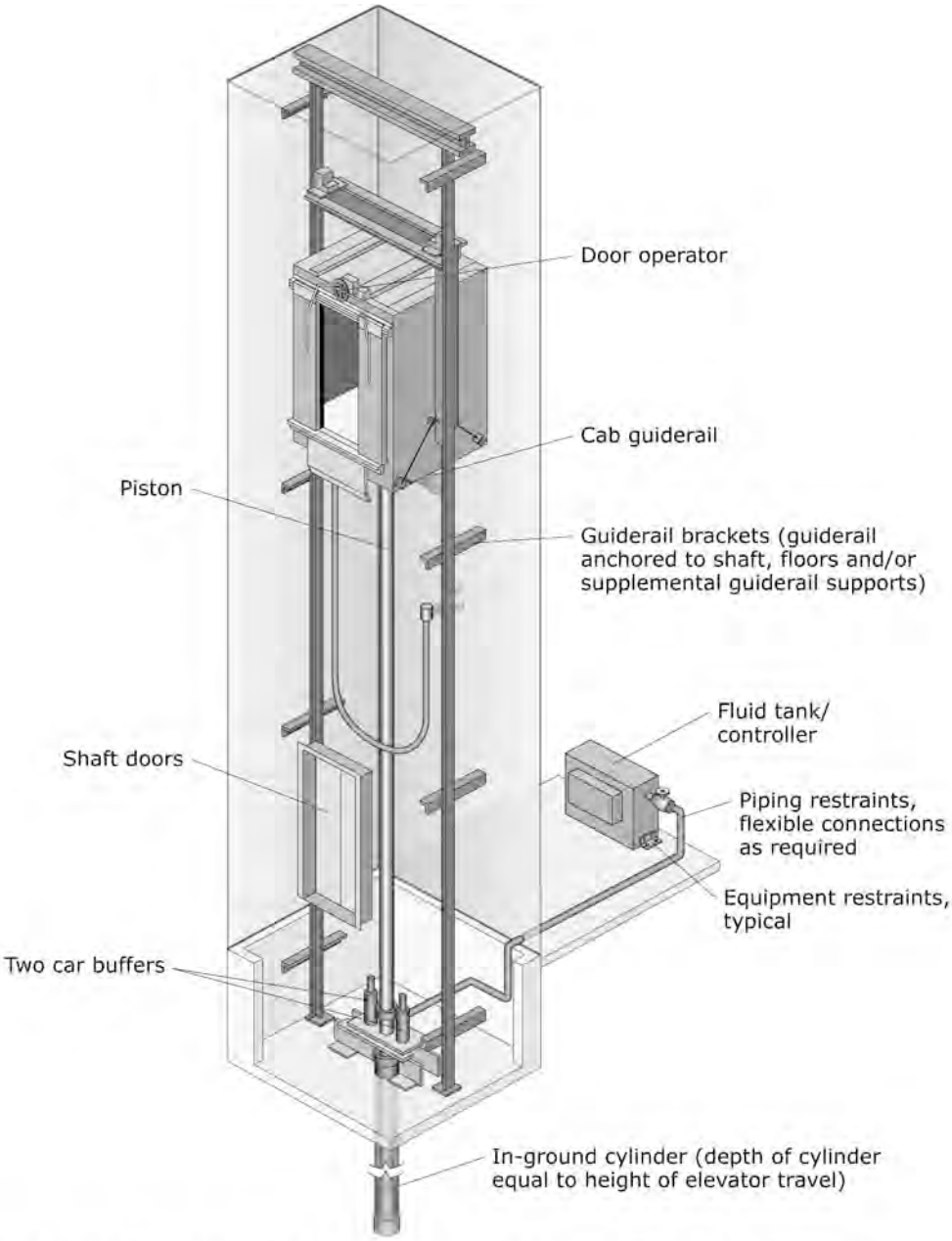
Typical Causes of Damage

- Common modes of elevator damage includedeformed door frames impeding the adequate operation of doors, failure of door rails, damaged to pump, oil leakage in hydraulic lines, and damage to hoistway switches.
- According to survey responses collected by the Division of Occupational Safety and Health Elevator, Tramway, and Ride unit, following the 1994 Northridge Earthquake 897 hydraulic elevators suffered damage such as leaks in underground feed lines, separated pipes, and failed gaskets and fittings. In addition, numerous guide rails were bent and several cars came out of rails. Tie downs on several oil tanks failed and hold-down bolts sheared and pulled out.
- In addition to property damage, passengers may become trapped in the cab following an earthquake and may need to await extraction by qualified elevator technicians.

Seismic Mitigation Considerations

- All components of the hydraulic system need to be restrained, anchored or detailed to accommodate movement to prevent damage in an earthquake. The system must be designed to accommodate the anticipated inter-story drift over the height of the elevator travel and the depth of the cylinder below. Components such as cab guides, door frames, and cylinder supports must all be detailed to accommodate lateral deformations. All mechanical and electrical equipment, sensors, piping, tanks, valves, and guides need to be properly anchored or restrained.
- All elevators should be inspected by qualified elevator technicians following an earthquake. Elevators should have a seismic switch or safety features that allow for safe shutdown in an earthquake.
- Elevator safety is governed by the prescriptive requirements in ASME A17.1/CSA B44, *Safety Code for Elevators and Escalators* (ASME, 2007a) a document that is continually evolving to reflect new elevator technologies. In addition, ASME A17.7/B44.7, *Performance Based Code for Elevator Safety* (ASME, 2007b), is the next step in the evolution of elevator safety codes in the United States and Canada. Local or state jurisdictions may have other elevator requirements.
- The internet provides information regarding hydraulic elevators. A few websites are linked below:
    - The website http:science.howstuffworks.com/elevator1.htm describes the workings of hydraulic elevators and provides links to other resources
    - Jobsite safety in the elevator industry is discussed on http://safety.elevator-world.com/disaster.htm
    - The websites of the Elevator and Escalator Safety Foundation, http://eesf.org/, and major elevator suppliers such as The Otis Elevator Company and Schindler Elevators provide additional resources.
    - The National Elevator Industry, Inc. has other resources including a discussion of the performance based code for elevator safety (http://www.pbc-elevators.com/).

MITIGATION DETAILS



Notes: Provide lateral restraints for guiderails to resist design forces and accommodate anticipated interstory drift.

Elevators should be installed, maintained, inspected and repaired by qualified elevator technicians.

Inappropriate seismic restraints may compromise the safe operation of these systems.

Figure 6.4.10.1-1 Schematic view of hydraulic elevator (ER).

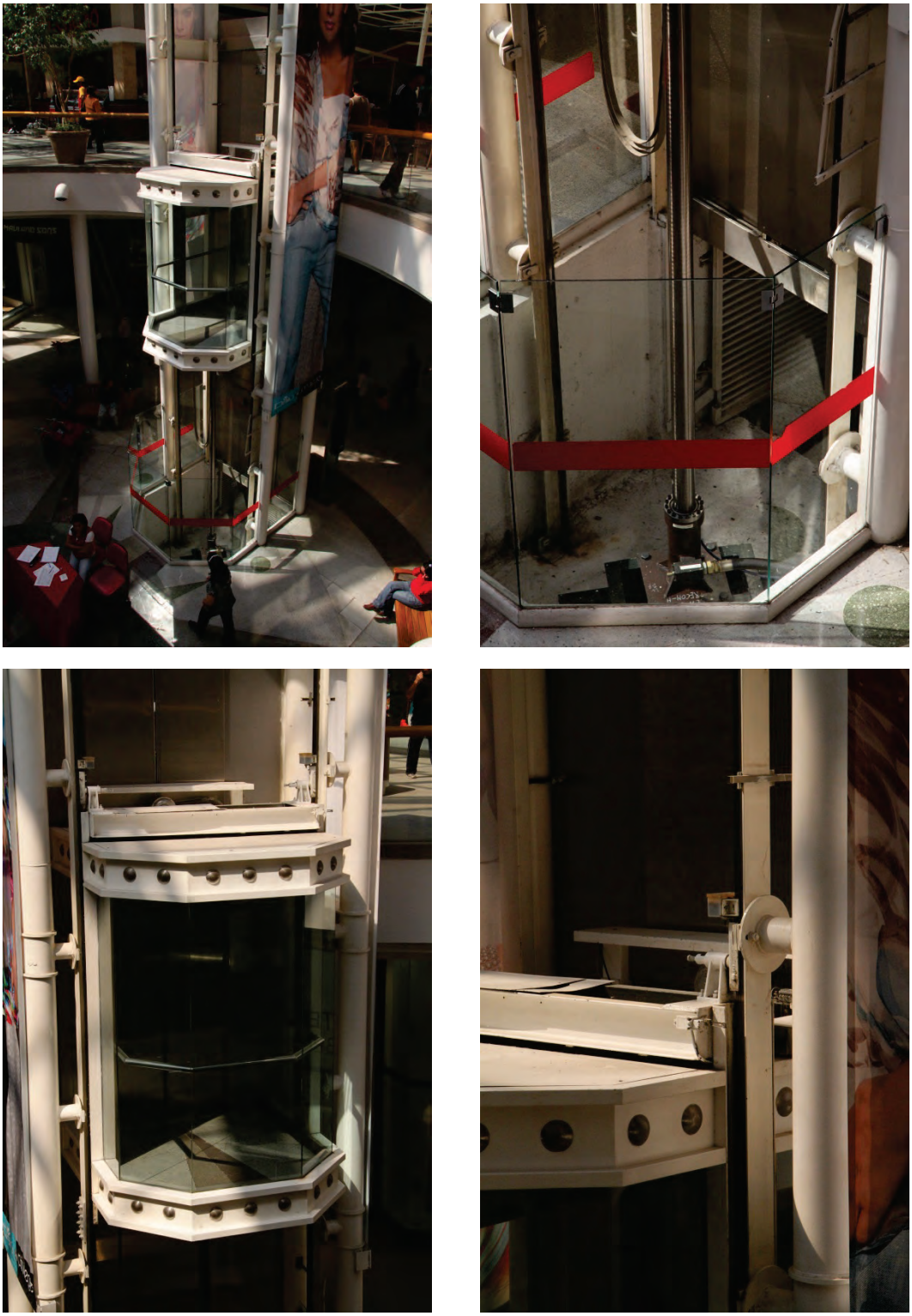


Figure 6.4.10.1-2 Hydraulic elevator that performed well during the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Miranda, Stanford University).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.10 Elevators and Escalators

6.4.10.2 Traction Elevators

Traction elevators have made high rise construction possible. These systems are continually evolving to achieve faster speeds, smoother and quieter operations. Currently there are geared traction elevators, gearless traction elevators, and "machine-roomless" elevators that use flat belts instead of steel cable. Traction elevators are complex mechanical systems that have many moving parts and electronic components and failure of any of the components could disable the functionality of the entire system. Maintaining limited functionality of some elevators following an earthquake is critical for continued operations of essential facilities or the evacuation of hospital patients.

The primary components of the traction elevator system are the elevator cab (car), counterweight, cab guide rails, counterweight guide rails, guide rail support brackets, electric motor, electrical control panel, ropes, sheaves, safety braking mechanisms, door mechanisms, and a shock absorber at the bottom of the shaft. The system may be tied to a seismic switch or a smoke detector which would facilitate safe shutdown in the event of an earthquake or fire. Any of these components could be damaged if not properly restrained.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for elevators are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. Elevators are classified as mechanical components, and are sensitive to both story drift and acceleration. Elevators designed in accordance with the seismic requirements of ASME A17.1 *Safety Code for Elevators and Escalators* (ASME, 2007a) are deemed to meet the requirements of ASCE/SEI 7-10, provided the forces and displacements used in the design meet the provisions of ASCE/SEI 7-10.

- Elevators, hoistway structural systems, elevator equipment supports and attachments, and controller supports and attachments must be designed to meet the force and displacement requirements of ASCE/SEI 7-10.
- Bracing exemptions for small diameter piping and piping supported on hangers less than 12 inches long do not apply to elevator piping.

- Elevators that operate at speeds greater than 150 feet per minute must be provided with seismic switches that are triggered by earthquake shaking. The seismic switch will prevent a potentially damaged elevator from being used.

RETROFIT STANDARD PROVISIONS

ASCE/SEi 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2006) classifies components of elevators as acceleration sensitive. Shafts and hoistway rails that rise through several floors are both acceleration and deformation sensitive.

- Elevators are subject to the requirements of ASCE/SEI 41-06 when the performance level is Immediate Occupancy, or in regions of high and moderate seismicity when the performance level is Life Safety.
- The evaluation must consider the anchorage of the equipment and controllers, as well as the construction of the elevator shafts. The possibility of derailment or displacement of the elevator counterweights must also be considered.
- Acceptance criteria may be based on prescriptive procedures, or the elevator components may be analyzed for the force and displacement demands.

Typical Causes of Damage

- The most common cause of damage in elevators is counterweight derailment. Counterweights are the heaviest component in an elevator and typically weigh the same as the cab filled at 50% capacity. Elevators are often programmed to spend more time in the ground floor and therefore when earthquakes occur the counterweight is likely to be located in the upper part of the building where the largest acceleration demands occur. This means that often counterweights are subjected to forces that are larger than those experienced by the cab (car). Counterweight derailment is a very serious type of damage because once it is out of the guide rails the heavy counterweight may violently swing in the hoistway and collide against other components causing the damage to guide rails and rail brackets. In some cases collisions with the cab occur if the elevator is operated with its counterweight derailed. In other cases, severe pounding of a derailed counterweight against the guide rails or the hoistway can cause damage to the frame of the counterweight and individual block which are typically made of cast iron or steel plates may become loose and fall into the shaft or onto the roof of the cab.
- Counterweight and car guide rails often are bent as a result of large inertia forces acting on the counterweight and car that push the guiderails during the earthquake. Damage

typically occurs when the counterweight or car are between floors where the rails are not attached to the structure and therefore are subjected to large bending deformations. Guide rails also get damaged as a result of pounding against the counterweight or the car. Bent rails often need to be replaced, which may require several days.

- Guide rails are attached to the structure by steel brackets. As shown in Figure 6.4.10.2-1 the rails are attached to the brackets by clamps that hold the flanges of the rail to the bracket. Both brackets and clamps are damaged as a result of the forces acting on the counterweight or car. The most common type of damage consists of bending of the brackets.
- Lateral motion of counterweight and of the car relative to the guide rails is constrained by a guide rolling system typically consisting of three guide wheels (or guide shoes). Guiding systems are comprised of several parts. Details vary from manufacturer to manufacturer, on the load capacity of the elevator, the travelling speed and on whether the guide is for the car or the counterweight. An example of a spring adjustable guide rolling system is shown in Figure 6.4.10.2-15. The axle bolts, pins, and supports of these rolling systems are particularly vulnerable during earthquakes where very large forces are produced in these small mechanical components as a result of inertia forces acting on the counterweight and car.
- Landing switches and limit switches are sensing elements that allow an adequate positioning of the car at each floor level. These switches consist of brackets extending into the hoistway. Damage to these elements consists of being bent by lateral motion of the car or the counterweight. They can also be damaged from steel ropes swinging in the shaft and colliding with the switches or by falling counterweight block.
- At the top of the elevator is a room that houses the elevator machines. The main components housed in the elevator machine room are the electrical motors which are usually directly attached to the shaft. The elevator machines must be properly anchored to the base otherwise a sliding may occur during earthquakes.

Damage in Prior Earthquakes

Earthquake	Date	Magnitude	Number of Derailed Counterweights
Nisqually	February 28, 2001	6.8	224
Van, Turkey	October 23, 2011	7.2	218
Darfield, New Zealand	September 3, 2011	7.1	30
Whittier Narrows	October 1, 1987	5.9	91
Loma Prieta	October 17, 1989	6.9	249
Northridge	January 17, 1994	6.7	690

- According to survey responses collected by the Division of Occupational Safety and Health Elevator, Tramway, and Ride unit, following the 1994 Northridge earthquake, the following issues were observed:
    - Water damage–sprinkler pipes pulled apart flooding machine rooms and pits causing water on top of cars, damage to door operators and door detectors, and soaking car processors and car station. Several oil buffers had to be rebuilt.
    - Falling debris in hoistways, falling plaster, loose concrete blocks, broken glass resulted in damaged door interlocks and misalignment of hatch switches and bent fascias.
    - Building settlements bent elevator guide rails; structural damage, loose and bent divider beams shifted guide rails and bending support brackets.
    - 3,528 cabled elevators were removed from service by a seismic protective device. 710 devices did not operate as intended. Some devices were located in the elevator pits which were flooded.
    - 968 electric cabled elevators sustained earthquake damage.
    - 2 minor injuries were reported, one of which was sustained by a fireman trying to open hoistway doors.
    - 39 elevators required rescue.
    - 57 instances were reported where "unauthorized persons" reset earthquake devices. Fortunately, only 5 elevators sustained additional damages.
    - 688 counterweights came out of guide rails. 8–1b rails were inadequate even with additional intermediate guide rail bracket retrofit. Several counterweight frames were twisted and bent with a few dislodged subweights. Some counterweight roller guide shoe mountings disintegrated.
- Following the 2010 Chile Earthquake, it was reported that 50%–80% of hospital elevators were damaged. In a number of locations, patients had to be carried down many flights of stairs, often cluttered with fallen debris, in order to evacuate them to safety. The most common damage was due to unrestrained movement of the counterweights, resulting in damage to the guide rails. Movement of unrestrained mechanical equipment was another problem. One security camera at a military hospital in Santiago, Chile captured a sequence through the open door of an empty elevator cab where the counterweights derailed and then the subweights came crashing down on top of the cab. (Source: Bill Holmes, March 2010).
- In addition to property damage, passengers may become trapped in the cab following an earthquake and may need to await extraction by qualified elevator technicians. Failure

of elevators are particularly critical to high-rise buildings that may become inoperable without elevators.

In recent shake table testing of a full scale 5 story building performed at UC San Diego (see Section 6.1.3), a fully operational machine-roomless traction elevator was subjected to severe earthquake motions. The elevator remained operational for all but the largest tested earthquake motion although in a normal installation, the elevator would have tripped off line by seismic sensors. For the largest motion (inter-story drifts exceeding 3%) the gypsum wall board partition distortions caused the elevator shaft doors to jam thus making the elevator in-operable. Elevators have interlocking controls that when the shaft doors are not operational, the elevator is not operational.



Figure 6.4.10.2-1 Examples of an elevator counterweight (Photo courtesy of Eduardo Miranda, Stanford University).



Figure 6.4.10.2-2 Examples of brackets and clips attaching the elevator guide rails to the structure (Photo courtesy of Eduardo Miranda, Stanford University).

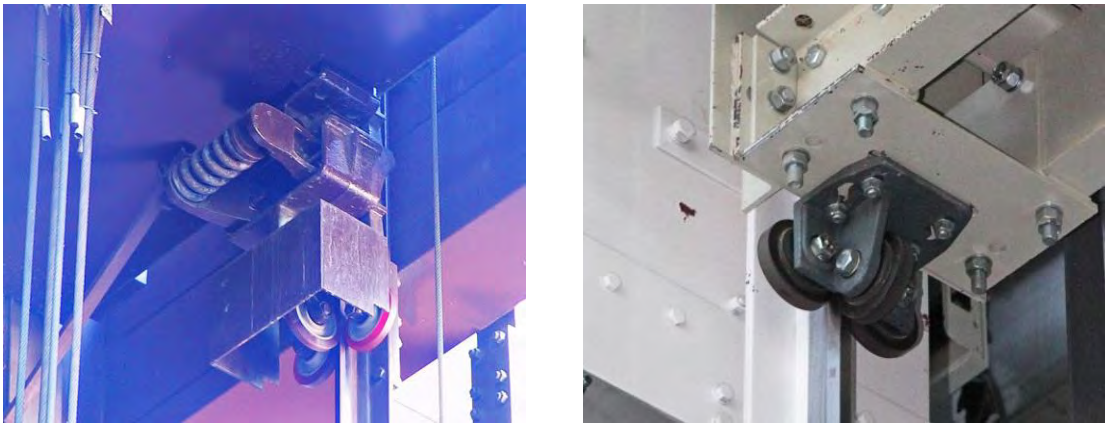


Figure 6.4.10.2-3 Examples of rolling guides at the bottom of a car (Photos courtesy of Eduardo Miranda, Stanford University).

DAMAGE EXAMPLES



Figure 6.4.10.2-4 Examples of damage to elevator machines produced by inadequate anchorage to the structure (Photos courtesy of Eduardo Miranda, Stanford University).



Figure 6.4.10.2-5 Details of bent bracket (left) and large displacement at the base of elevator machines (Photos courtesy of Eduardo Miranda, Stanford University).



Figure 6.4.10.2-6 Overturned control panels in the 2010 Chile earthquake (Photos courtesy of Eduardo Miranda, Stanford University).



Figure 6.4.10.2-7 Damage to guide rails caused by derailment of the counterweight in a hospital in Chillan during the 2010 Chile earthquake (Photos courtesy of Eduardo Miranda, Stanford University).



Figure 6.4.10.2-8 Damage to guide rail support brackets in the 2010 Chile Earthquake (Photo courtesy of Gilberto Mosqueda, SUNY Buffalo).



Figure 6.4.10.2-9 Derailed car roller assembly of the guide rail at the Santiago airport in the 2010 Chile Earthquake (Photo courtesy of Gilberto Mosqueda, SUNY Buffalo). The three rollers are supposed to travel along three sides of the stem of the T-shaped steel guide rail.



Figure 6.4.10.2-10 Glazing failures caused additional hazards at Santiago airport elevator in the 2010 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Rubén Borsochek & Associates).

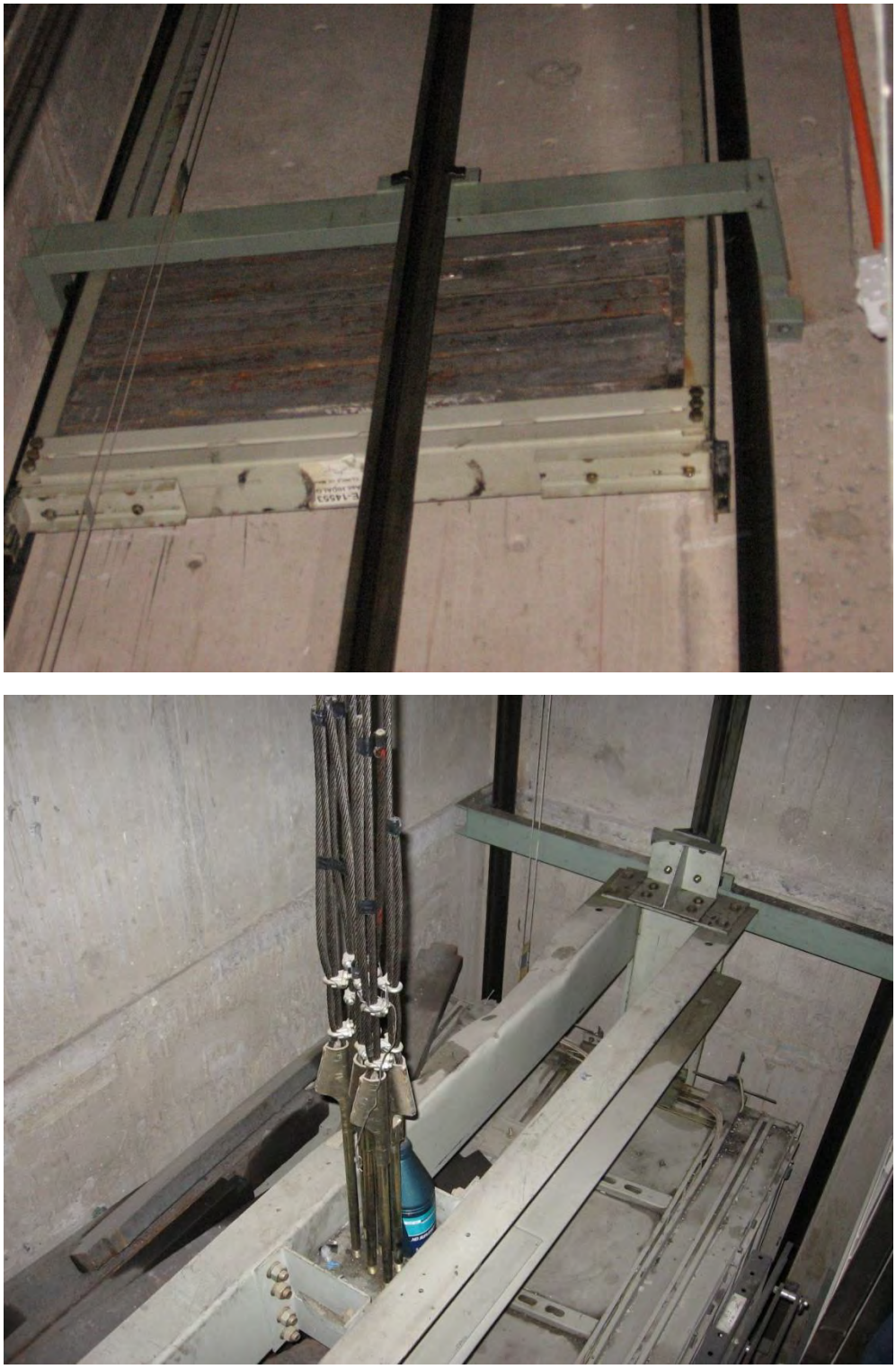


Figure 6.4.10.2-11 Unrestrained movement of the counterweights damaged the counterweight assembly and bent the counterweight guide rails; over half the subweights dropped onto the top of the cab and damaged the cab framing in the 2010

Chile Earthquake (Photo courtesy of Rodrigo Retamales, Rubén Borsochek & Associates).



Figure 6.4.10.2-12 Anchor bolt failure of the elevator generator set due to inadequate edge distance for the bolts at the Los Angeles Regional Public Hospital in the 2010 Chile Earthquake (Photo courtesy of Bill Holmes, Rutherford & Chekene).

Seismic Mitigation Considerations

- All of the components of the traction system need to be restrained, anchored, or detailed to resist lateral forces in all directions and accommodate seismic movement. The system must be designed to accommodate the anticipated inter-story drift over the height of the elevator travel. Guide rails and door frames must all be detailed to accommodate lateral deformations. All of the mechanical and electrical equipment, sensors, and guides need to be properly anchored or restrained.

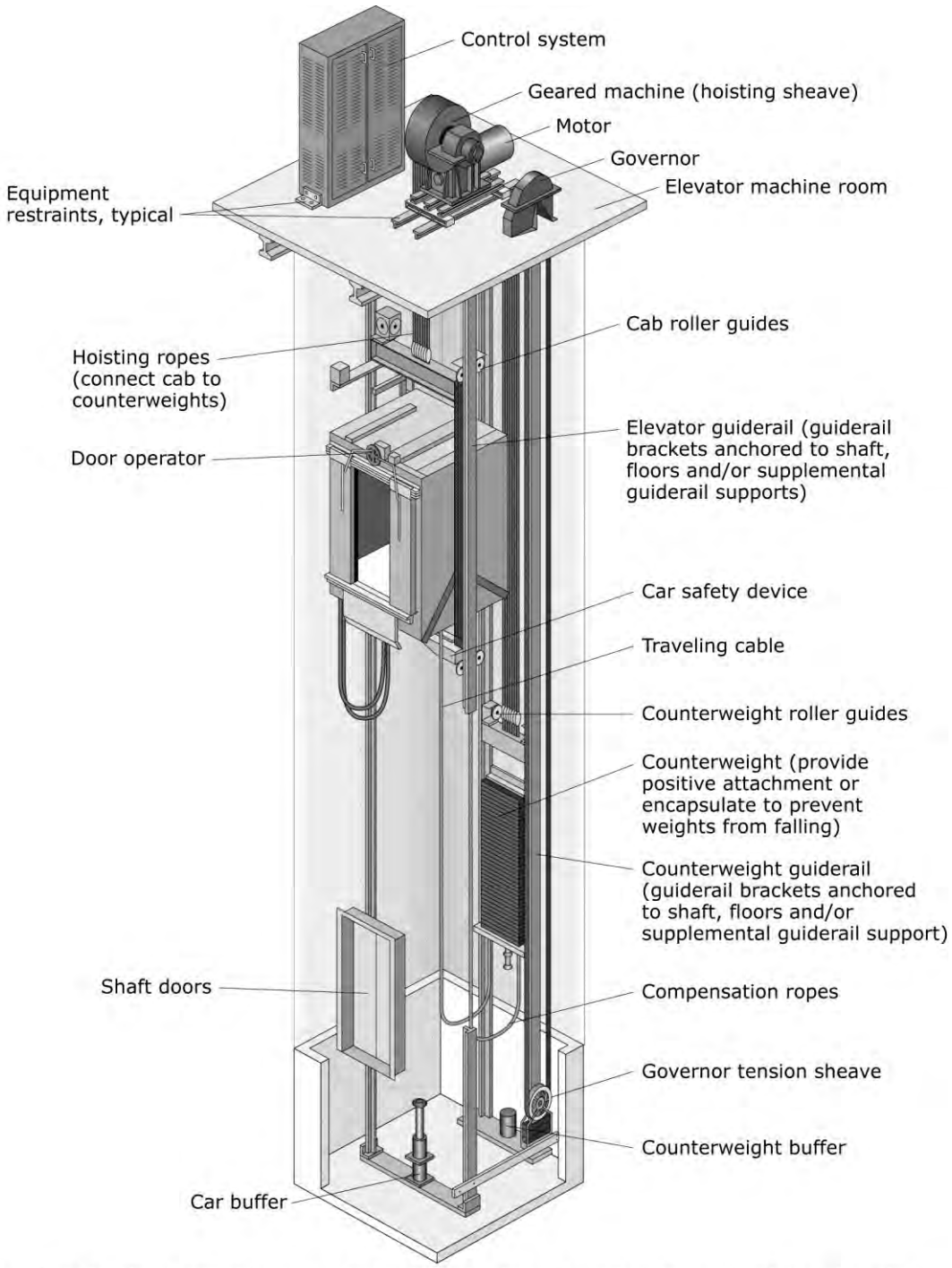
- All elevators should be inspected by qualified elevator technicians following an earthquake. Elevators should have a seismic switch or safety features that allow for safe shutdown in an earthquake.
- Elevator safety is governed by the prescriptive requirements in ASME A17.1/CSA B44 *Safety Code for Elevators and Escalators* (2007a), a document that is continually evolving reflect new elevator technologies. In addition, ASME A17.7/CSA B44.7, *Performance Based Code for Elevator Safety* (ASME, 2007b), is the next step in the evolution of elevator safety codes in the United States and Canada. Local or state jurisdictions may have other elevator requirements.
- As an example of state jurisdictions, the California Office of Statewide Health Planning and Development (OSHPD) provides special requirements for elevators in California hospitals, such as Title 24, Section 3007. These include requirements for a seismic switch connected to the essential electrical system, a visible or audible alarm, the ability to function at a "go slow" speed of not more than 150 feet per minute until the elevator can be inspected, and an additional sensor that will disable the elevator if the governor tail sheave is dislodged. For these systems, the seismic anchorage, guards and switches all need to be inspected annually.
- The internet provides a resource of information regarding elevators. A few websites are linked below:
    - The website http:science.howstuffworks.com/elevator1.htm describes the workings of a traction elevator and provides links to other resources
    - Jobsite safety in the elevator industry is discussed on http://safety.elevator-world.com/disaster.htm
    - The websites of the Elevator and Escalator Safety Foundation, http://eesf.org/, and major elevator suppliers such as The Otis Elevator Company and Schindler Elevators provide additional resources.
    - The National Elevator Industry, Inc. has other resources including a discussion of the performance based code for elevator safety (http://www.pbc-elevators.com/).

MITIGATION EXAMPLES



Figure 6.4.10.2-13 Small "machine-roomless" traction elevator with flat belts at the Academy of Sciences, San Francisco, California (Photos courtesy of Eduardo Fierro, BFP Engineers). Clockwise: Overview of elevator at roof; view of guide rails and sheaves; top of cab showing belts; view down shaft at belts, counterweight, guide rails and guide rail brackets.

Mitigation Details



Notes: Provide lateral restraints for guiderails to resist design forces and accommodate anticipated interstory drift.

Elevators should be installed, maintained, inspected and repaired by qualified elevator technicians. Inappropriate seismic restraints may compromise the safe operation of these systems.

Figure 6.4.10.2-14 Schematic view of geared traction elevator system (ER).

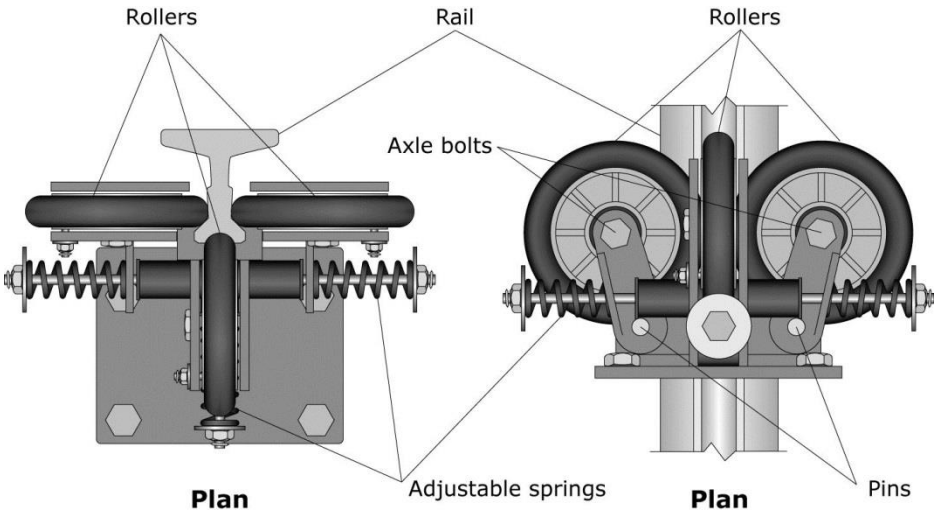


Figure 6.4.10.2-15 Spring loaded elevator guide with polyurethane rollers. Details of elevator guides vary from manufacturer to manufacturer, elevator load capacity, elevator speed, and whether used for guiding the car or counterweight.

6.4 Mechanical, Electrical, and Plumbing Components

6.4.10 Elevators and Escalators

6.4.10.3 Escalators

Escalators typically span between two floors, and although most escalators run in a straight line, spiral escalators are found in some locations. The failure of any of the component parts of the escalator or escalator equipment could disable the functionality of the system. Relative horizontal displacements between supporting floors that are greater than the displacement capacity of the connection can result in the escalator coming of its supports and falling to the floor below resulting in severe damage to the escalator and a serious life safety threat.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for Escalators are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), Chapter 13. Escalators are classified as mechanical components, and are sensitive to both story drift and acceleration. Escalators designed in accordance with the seismic requirements of ASME A17.1 *Safety Code for Elevators and Escalators* (ASME, 2007a) are deemed to meet the requirements of ASCE/SEI 7-10, provided the forces and displacements used in the design meet the provisions of ASCE/SEI 7-10.

RETROFIT STANDARD PROVISIONS

ASCE 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) does not provide seismic retrofit criteria for escalators. In lieu of specific guidance, retrofit criteria may be inferred from the requirements for stairways, as follows

- Stairs are subject to the requirements of ASCE/SEI 41-06 when the performance level is Immediate Occupancy, or in regions of high and moderate seismicity when the performance level is Life Safety. Similar criteria may be used for escalators.
- The evaluation must consider the escalator and the connection of the escalator to the supports, and adjacent supporting beams or slabs.
- Acceptance criteria should focus on verifying that the escalator has sufficient strength to resist out-of-plane forces, and the ability to accommodate the expected relative displacements.

Typical Causes of Damage

- The primary components of an escalator system are the steps, chain, inner rail, chain guide, drive gear, handrail, handrail drive, electric motor, and electrical control panel. These components are often supported by a truss that spans between the floors. Any of these components could be damaged if not properly detailed or restrained; failure of any of the component parts could disable the system.
- Escalators, like stairs, may form a strut or brace between adjacent floors unless they are detailed so the system will accommodate inter-story drift. Damage could occur to the skirt, landing plate or other components not detailed to accommodate either an extension or shortening of the distance between the two landings. An example of the results of a failure and collapse of an escalator that occurred during the 2011 Great Tokohu Japan Earthquake is provided in Figure 6.4.10.3-1. A total of 4 escalators fell in this earthquake at 3 separate locations in the Sendai and Fukushima areas.
- According to survey responses collected by the Division of Occupational Safety and Health Elevator, Tramway, and Ride unit, 65 escalators were damaged in the 1994 Northridge earthquake. It was reported that escalators came off upper supports, and several truss support angles had their bolts sheared off where one truss actually dropped. Glass came out of its supports and shattered, handrails collapsed. In addition, numerous deckboards, skirts and newels were damaged.

DAMAGE EXAMPLES



Figure 6.4.10.3-1 Photo of escalator, located in the Sendai area of Japan, which fell from the floor above onto the escalator on the floor below during the magnitude-9.0 Great Tohoku Earthquake of March 11, 2011. The probable cause of this collapse was that the relative displacements between floors exceeded the connection bearing width capacity of the escalator. This type of failure creates a serious life safety hazard (Photo source: Nekkei Architecture).

Seismic Mitigation Considerations

- Each of the components of an escalator system need to be detailed to accommodate movement, or restrained and anchored to prevent damage in an earthquake. The system must be designed to accommodate the anticipated inter-story drift between the two connected floors. Where a truss is used to span between the two floors, the bearing seats should allow movement at one or both ends. Components such as the rail supports, handrails, landing plates, and skirts must be detailed to accommodate lateral deformations. All of the mechanical and electrical equipment needs to be properly anchored or restrained.

- Escalators have traditionally been designed to run continuously, whether they are in use or not. Some more energy efficient escalators operate on an intermittent basis and are triggered by the presence of passengers but otherwise are in a standby idle mode.

- All escalators should be inspected by qualified personnel following an earthquake. Unlike elevators, escalators typically function as a usable stair when they are not operating and could be used to facilitate evacuation following an earthquake.

- Elevator and escalator safety is governed by the prescriptive requirements in ASME A17.1, *Safety Code for Elevators and Escalators* (ASME, 2007a), a document that is continually evolving to reflect new elevator and escalator technologies. Seismic requirements for escalators were first introduced into A17.1 in the 2000 edition include the design of connections for relative displacements effects between floors. Escalators installed prior to the adoption of A17.1-2000 may be particularly vulnerable. Local or state jurisdictions may have other elevator and escalator requirements. In California, Escalator Seismic Requirements are provided in Title 8 in the California Code of Regulations.

- The internet provides information regarding escalators. Websites such as http://science.howstuffworks.com/transport/engines-equipment/escalator.htm describe the workings of escalators and provide links to other resources

- Some escalator models are offered with a seismic option; check for appropriate equipment before purchasing a new escalator. The escalators should comply with the seismic requirements of Section 8.5 of ASTM A17.1 especially the drift requirements between floors.

MITIGATION DETAILS

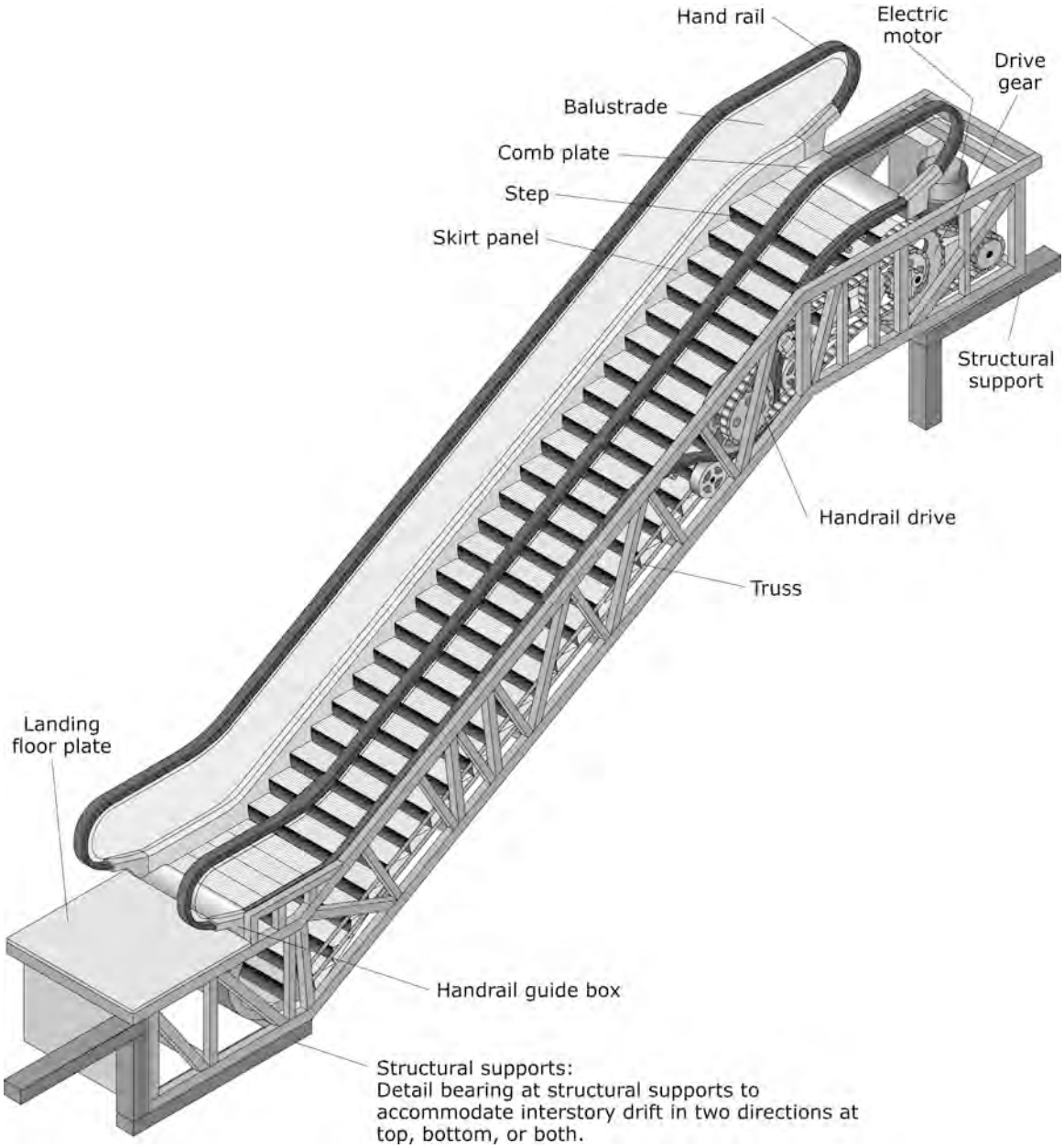


Figure 6.4.10.3-2 Schematic view of escalator (ER).

6.4 Mechanical, Electrical, and Plumbing Components

6.4.11 Conveyors

6.4.11.1 Conveyors

Material handling conveyors come in all shapes and sizes from the conveyor belt at the grocery store checkout line, the clothing conveyor at the dry cleaner's, assembly line conveyors in clean rooms, airport baggage handling conveyors, to large industrial conveyors. They are used for many purposes, such as shipping, packaging, assembling, and manufacturing. The conveyors may be horizontal, inclined, hinged, straight, curved, spiral, screw, fixed or on wheels. Tall, inclined, or overhead systems may be a falling hazard; systems critical to facility operations may be important for post-earthquake functionality.

Provisions

BUILDING CODE PROVISIONS

Conveyors are subject to the requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures,* (ASCE, 2010), Chapter 13, Nonstructural Components

- Conveyors in Seismic Design Categories D, E, and F that weigh 5 pounds or less per linear foot do not required seismic bracing if the component Importance Factor is $I_p = 1.0$.
- Conveyors that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Flexible connections must be provided between the conveyor and associated pipes or conduits or alternate means for protecting the connection must be implemented.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings* (ASCE, 2007) requires compliance with the anchorage provisions of the standard when the performance level is Immediate Occupancy. Conveyors are classified as both force and displacement controlled. The principal objectives are to prevent the component from sliding or overturning. In addition, depending on the configuration, the conveyor must accommodate building displacements if it is connected to multiple levels in the same structure, or is supported by adjacent structures.

Typical Causes of Damage

- Unanchored conveyors may slide and impact other items, tall or inclined conveyors may overturn, overhead conveyors or components may become dislodged and fall. Conveyors not designed for seismic forces may have damage to the component parts and connectors. Unrestrained conveyor motors and related equipment may be damaged and fall.
- Properly anchored conveyors may remain in place but the contents may fall. For tall or overhead conveyors, this could be a falling hazard resulting in injury and damage to materials or merchandise.
- The conveyor may shift and exceed the alignment tolerances and not be functional until repaired or realigned.

DAMAGE EXAMPLES



Figure 6.4.11.1-1 Misalignment between rice storage hopper and conveyor following the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Rodrigo Retamales, Rubén Boroschek & Associates). Where various system components interface with a conveyor, the seismic restraints for the various parts should be coordinated to maintain alignment following an earthquake.



Figure 6.4.11.1-2 Damage to industrial conveyor used to feed grain silos in the 2010 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.4.11.1-3 Damage to industrial coal conveyor on jetty in southern Peru in the 2001 magnitude-8.4 Peru Earthquake (Photos courtesy of Eduardo Fierro, BFP Engineers). Conveyor was well anchored along entire length but detailing at the seismic joint between the jetty and platform did not allow sufficient movement, resulting in misalignment at end of conveyor and damage to the supports as shown at lower left. Approximately 10% of the rollers fell; these were held in place with friction fittings and did not have positive connections.

Seismic Mitigation Considerations

- Conveyor systems and the associated motors, control systems, and control panels should be restrained or anchored to prevent earthquake damage. If life safety is the primary concern, tall or overhead components should be restrained to reduce falling hazards. If the conveyor is critical to continued operations, or the conveyed materials hazardous or particularly valuable, the system should be engineered to assure continued operations and the safety of the materials. In this case, the anchorage or restraints for interconnecting parts should be coordinated to maintain alignment tolerances following an earthquake.
- There are various conveyor mechanisms including belt driven, chain driven, gravity rollers, chain driven rollers, and flex link conveyors. Conveyors may be supplied with leveling feet which may not be sufficiently robust unless they have been designed for seismic loading. Floor to floor conveyors must be detailed the same as for stairs or escalators and be able to accommodate the anticipated inter-story drift. Where long conveyors are variously suspended, wall-mounted, or floor-mounted, the layout of the supports and restraints should consider the relative motion of the various attachment points. Special detailing is required where conveyors cross building separations or seismic joints.
- Some conveyors come supplied with predrilled base plates at each leg; these should be anchored to the floor slab. Existing conveyor platforms could be strengthened with transverse or longitudinal bracing if they have not been designed for seismic loading; clip angles could be used to anchor the legs to the floor. Check with the manufacturer prior to modifying existing equipment as equipment warranties may be affected.
- Where conveyed materials are hazardous or valuable, it may be prudent to devise guiderails or side restraints of some type to prevent the materials from falling off the conveyor in the event of an earthquake. Such restraints would have to be designed so that they do not to interfere with normal operations.

MITIGATION DETAILS

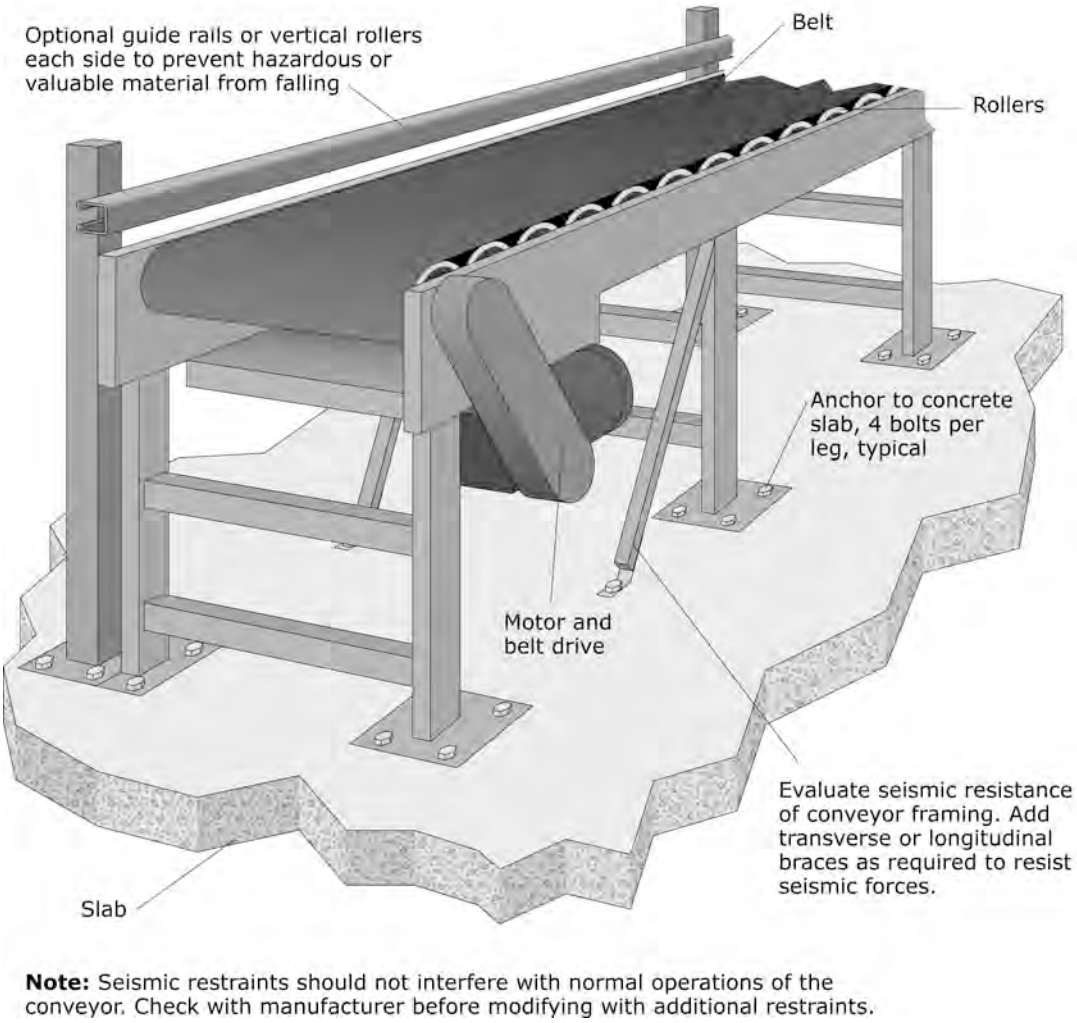


Figure 6.4.11.1-4 Anchorage details for small material handling conveyor (ER).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.1 Storage Racks

6.5.1.1 Light Duty SHelving

This category includes light duty shelving units and sheet metal storage cabinets. These items are typically tall and narrow and may be heavily loaded.

Provisions

BUILDING CODE PROVISIONS

The seismic design requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other* Structures, (ASCE, 2010) Chapter 13 are intended to apply only to permanently attached components, not to furnishings, temporary items, or mobile units. Storage cabinets and shelving units of significant mass are not considered to be exempt and should be anchored or braced,

Permanent floor-supported shelving or storage cabinets over 6 feet tall must be designed as architectural components per ASCE/SEI 7-10. Bracing and anchorage for these units should be designed considering the weight of the unit and weight of shelved contents.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies light-duty shelving as force controlled, and the principal objective of the code provisions is to prevent the component from sliding or overturning. ASCE/SEI 41-06 requires compliance with the anchorage provisions of the standard for storage racks over 4 feet in height when the performance level is Life Safety or higher. Storage racks in unoccupied spaces are exempt.

Typical Causes of Damage

- Shelving units may slide or overturn and the contents may become dislodged or fall. Where there are rows of freestanding or poorly anchored shelves, the failure of a few may result in progressive collapse of many. Broken bottles, spilled chemicals, mixed or damaged inventory are often the result of the failure of storage or display units.
- Mobile storage carts may roll, overturn, or impact other items. Stored contents may become dislodged or fall.

- Damage to contents or inventory that has fallen from shelving can be costly to repair or replace and may result in substantial business interruption.

DAMAGE EXAMPLES



Figure 6.5.1.1-1 Collapse of row of unanchored freestanding shelving units containing spare parts at an electric power plant in Port-au-Prince in the 2010 magnitude-7 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.5.1.1-2 Unanchored storage shelving slid nine inches without falling but contents scattered in the 2001 magnitude-8.4 Peru earthquake; unit lifted to original position prior to photo (Photo courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- For sheet metal cabinets or shelving, anchor units to floor, tie back-to-back units together, strap rows of units together across the top, or anchor units to an adjacent wall. Light duty steel storage racks may additionally require cross bracing.
- See Section 6.5.6.1 for recommendations regarding edge restraints and arrangement of shelf-mounted items. Do not locate cabinets or racks adjacent to doors or exits if their failure would block the exit.
- Any connections to stud walls must engage the structural studs. Stud walls and partitions may not have adequate lateral capacity to support many shelving units; engineering may be required. Where items are anchored to heavy partitions, the bracing or anchorage of these partitions to the structure above must also be checked for adequacy considering the seismic loads imposed by all anchored items.

- The details shown are intended for light duty units; heavy duty units with large loads may require engineering. See FEMA 460, *Seismic Considerations for Steel Storage Racks Located in Areas Accessible to the Public* (2005), for additional information on the performance of industrial storage racks. Some racks are available with enhanced seismic performance; check other resources, such as the internet for additional options.

MITIGATION EXAMPLES



Figure 6.5.1.1-3 Mobile carts restrained at base with clip angles anchored to the floor and removable eyebolts attached from each cart to the angles (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.5.1.1-4 Alternate restraint at base of mobile shelving unit (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.5.1.1-5 Fixed base shelving units anchored with optional seismic base plate offered by manufacturer (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.5.1.1-6 Mobile cart restrained at base with removable angles and eyebolts. Back-to-back units are interconnected (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.5.1.1-7 Fixed base shelving units anchored directly to concrete slab through base plate (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.5.1.1-8 Mobile shelving unit restrained by connection to strut fastened to full height metal studs (Photo courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

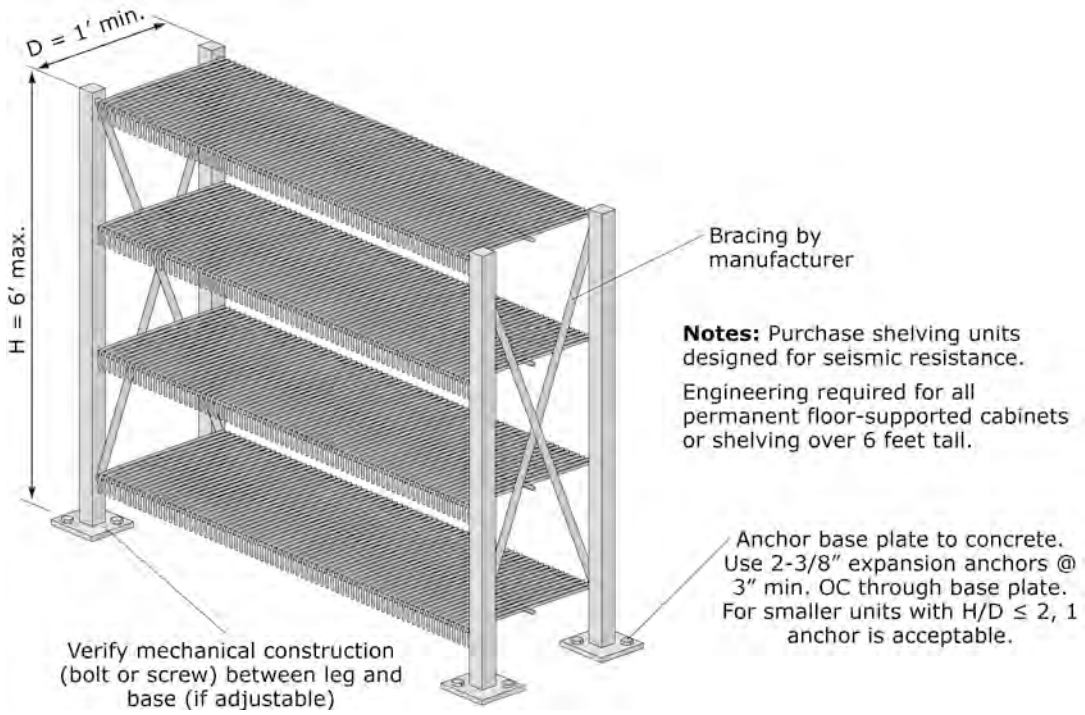


Figure 6.5.1.1-9 Light duty shelving (NE, ER).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.1 Storage Racks

6.5.1.2 Industrial Storage Racks

This subcategory includes heavy duty steel pallet storage racks such as those found in public warehouse stores. These racks are typically 42 to 44 inches deep, 8 feet wide and up to 14 to 18 feet tall, often configured with two rows back-to-back. They are composed of specially designed steel elements that permit easy installation and reconfiguration consistent with merchandising needs.

Provisions

BUILDING CODE PROVISIONS

Industrial storage racks are considered nonbuilding structures. The seismic design provisions for industrial storage racks in ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 15 include two approaches to the design of steel storage racks that are intended to produce comparable results. Racks can be designed in accordance with ANSI/RMI MH 16.1, *Specification for the Design, Testing, and Utilization of Industrial Steel Storage Racks*, (ANSI/RMI, 2008), as amended by ASCE/SEI 7-10. As an alternative, racks may be designed to comply with the requirements of ASCE/SEI 7-10 Section 15.5.3.4.

- Industrial storage racks in areas open to the public are designed with an importance factor of $I_p = 1.5$.
- While beyond the scope ASCE/SEI 7-10, contents on the storage racks may pose a potentially serious threat to life should they fall during an earthquake. It is recommended that restraints be provided.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) may require compliance with the anchorage provisions of the standard when the performance level is Hazards Reduced, Life Safety, or Immediate Occupancy. Storage racks over 4 feet in height should be evaluated. Storage racks in unoccupied spaces where the performance level is Life Safety are exempt. When the performance level is Hazards Reduced, storage racks in areas of public assembly must comply with the provisions of the standard.

Typical Causes of Damage

- Industrial storage racks may slide or overturn, or failure of individual components can cause collapse or partial collapse.
- Stored contents may become dislodged and fall. Items falling from the upper shelves can cause serious bodily harm. Damage to merchandise or inventory may be costly to replace and reshelf and may result in significant business interruption.
- In cases with heavy stored products and light structural framing, collapsed racks and falling goods have caused damage to structural framing members and/or architectural cladding.
- Industrial storage racks can be weakened if damaged from collisions with forklifts. Bent or damaged legs or anchor bolts reduce the lateral capacity of the rack system.

DAMAGE EXAMPLES



Figure 6.5.1.2-1 Damage to overloaded racks during the 1994 magnitude-6.7 Northridge Earthquake (FEMA 460, 2005).



Figure 6.5.1.2-2 Spilled contents during the 1994 Northridge Earthquake (FEMA 460, 2005).



Figure 6.5.1.2-3 Rack collapse during the 1994 Northridge Earthquake. Note the minimal damage to shrink wrapped merchandise (FEMA 460, 2005).



Figure 6.5.1.2-4 Failure of anchored racks in the 2010 magnitude-8.8 Chile Earthquake. The racks are leaning precariously due to inadequate bracing in the longitudinal direction and weak connections between the components. The welded fitting at the end of the beam failed at the weld in many places. Note that most items were shrink wrapped so merchandise did not scatter (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

Seismic Mitigation Considerations

- Storage racks in warehouse-type retail stores may pose a greater seismic risk to the general public than exists in low-occupancy warehouses or more conventional retail environments, due to their higher occupant load. The use of an Importance Factor of 1.5 provides an appropriate level of additional safety in areas open to the public.
- Project specific design of industrial storage racks is required. Each design must account for proprietary members and connectors that are used. Anchorage of the rack to the floor must be engineered and verification of the adequacy of the slab to accommodate forces generated by the rack is required. Storage racks are classified as nonbuilding structures.
- Industrial storage rack systems may experience high lateral displacements during strong shaking. For the purposes of providing adequate clearances between the rack and adjacent structural and nonstructural elements, ASCE/SEI 7-10 specifies relative displacements of not less than 5 percent of the height of the rack.
- Pallet racks should be installed by trained and experienced personnel working from installation drawings provided by the rack designer. Reconfiguration from the as-designed condition should be evaluated by the designer.
- To prevent or minimize the falling hazard posed by stored overhead merchandise, a dual approach is recommended: prevent merchandise from falling down from one shelf to the next; and prevent pallets and individual merchandise from falling from the shelves into the aisles. The use of wire decking or spaced framing on each shelf will reduce the potential for fall-through of merchandise. Stretch-wrapping, shrink-wrapping, banding or use of integral pallet box units can reduce the potential falling hazard posed by pallets. Restraining bars, chains or cables, netting and/or slip-resistant containers can reduce the potential for loss of individual merchandise.
- FEMA 460 *Seismic Considerations for Steel Storage Racks Located in Areas Accessible to the Public* (2005) provides a comprehensive treatment of seismic resistant design considerations for steel storage racks.
- The Rack Manufacturers Institute (RMI) publishes industry-wide standards for engineering design of steel storage racks.
- Purchase storage racks designed for seismic resistance. Some industrial storage racks are now available with proprietary schemes for improved seismic performance such as base isolation, added damping, or shelves sloped toward the back of the rack.

MITIGATION EXAMPLES

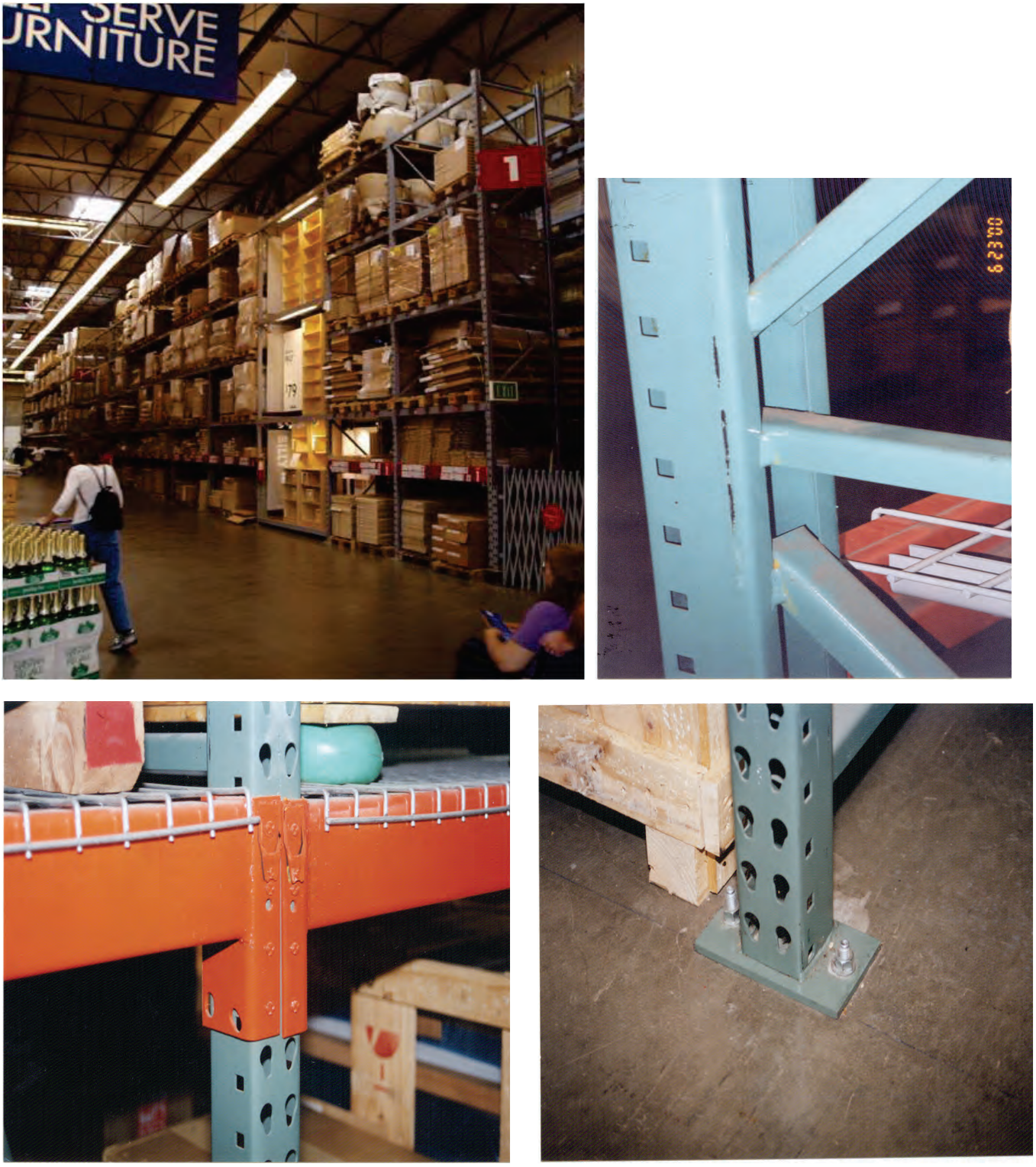
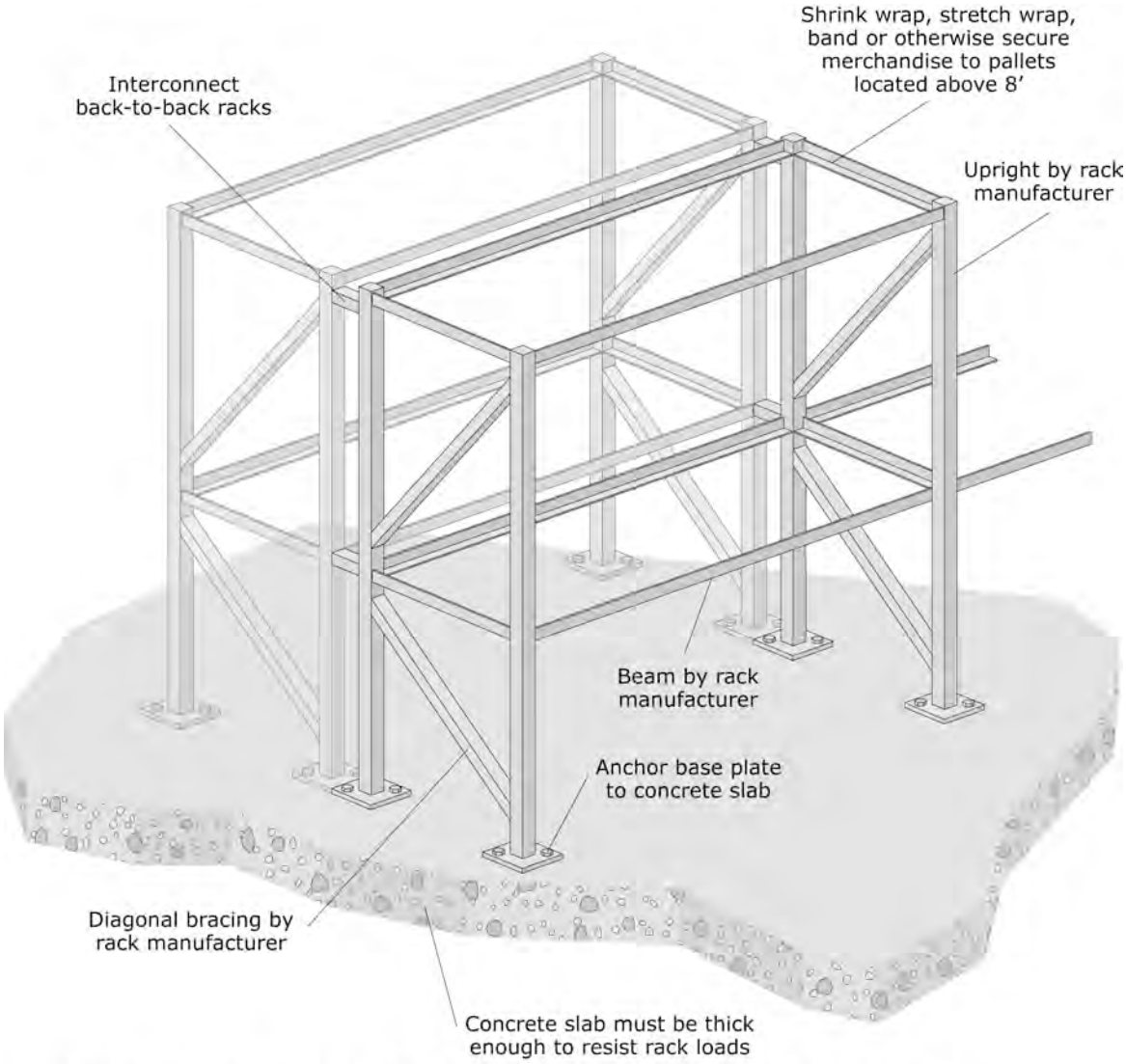


Figure 6.5.1.2-5 Typical pallet storage rack configuration and details (Photos courtesy of Maryann Phipps, Estructure).



Figure 6.5.1.2-6 Photo showing netting used to keep storage on upper portions of steel storage racks in a big box hardware store (Photo courtesy of Mike Mahoney, FEMA).

MITIGATION DETAILS



Note: Purchase storage racks designed for seismic resistance. Storage racks may be classified as either nonstructural elements or nonbuilding structures depending upon their size and support conditions. Check the applicable code to see which provisions apply.

Figure 6.5.1.2-7 Industrial storage rack (ER).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.2 Bookcases, Shelving

6.5.2.1 Bookshelves

Tall wood or metal shelving units frequently tip or overturn in earthquakes unless they are properly anchored.

Provisions

BUILDING CODE PROVISIONS

The seismic design requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13 apply to permanent floor-supported library shelving, book stacks, and bookshelves over 6 feet tall in Seismic Design Categories C, D, E, and F. The weight of the contents must be included when determining the seismic loads.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies bookshelves as force controlled, and the principal objective of the code provisions is to prevent the component from sliding or overturning. ASCE/SEI 41-06 requires bookshelves 4 feet in height comply with the anchorage provisions of the standard when the performance level is Life Safety or higher.

Typical Causes of Damage

- Tall, narrow shelving may tip, slide, overturn or collapse and the contents may spill. Overturned shelving may injure occupants and block doors or exits.
- Books, files, medical records may fall and get scrambled or damaged. Clean-up and reorganization of spilled items may take many hours or days and result in costly business interruption.

DAMAGE EXAMPLES



Figure 6.5.2.1-1 Failure of poorly anchored wood and metal book shelves at the Lawrence Livermore Laboratory, Livermore, California (NGDC, 2009).



Figure 6.5.2.1-2 Failure of poorly anchored shelving; toggle bolt pulled out of gypsum board wall in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).



Figure 6.5.2.1-3 Bookcase overturned onto desk in the 1971 magnitude-6.6 San Fernando Earthquake (Photo courtesy of Degenkolb Engineers).

Seismic Mitigation Considerations

- Permanent floor-supported shelving or storage cabinets over 6 ft tall must be designed as architectural components per ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010). Bracing and anchorage for these units should be designed considering the weight of the unit and weight of shelved contents. The details shown in Figure 6.5.2.1-4 and 6.5.2.1-5 are for shelving units up to 6 feet tall.
- Bookcases and shelving should be anchored to an adjacent stud wall or concrete or masonry wall. For freestanding units, see Section 6.5.1.1 for recommended details for bracing units and tying back-to-back units together.
- See Section 6.5.6.1 for recommendations regarding edge restraints and arrangement for shelf-mounted items. Do not locate shelving adjacent to doors or exits if their failure would block the exit.
- Any connections to stud walls must engage the structural studs; do not rely on gypsum or plaster to support shelving. Stud walls and partitions and unreinforced or lightly reinforced heavy partitions may not have adequate lateral capacity to support multiple

shelving units; engineering may be required. The bracing or anchorage of walls and partitions to the structure above must also be checked for adequacy considering the seismic loads imposed by all anchored items.

- Bookcase or cabinet anchorage can be located either outside or inside the unit as long as the attachment properly engages the "structural" studs. Where aesthetics are a concern, it may be preferable to locate the screws or clip angles on the inside of the unit. In a commercial setting where maintenance personnel or movers may need to verify the anchorage or relocate the unit periodically, it may be preferable to provide exterior anchorage that is readily visible.

MITIGATION DETAILS

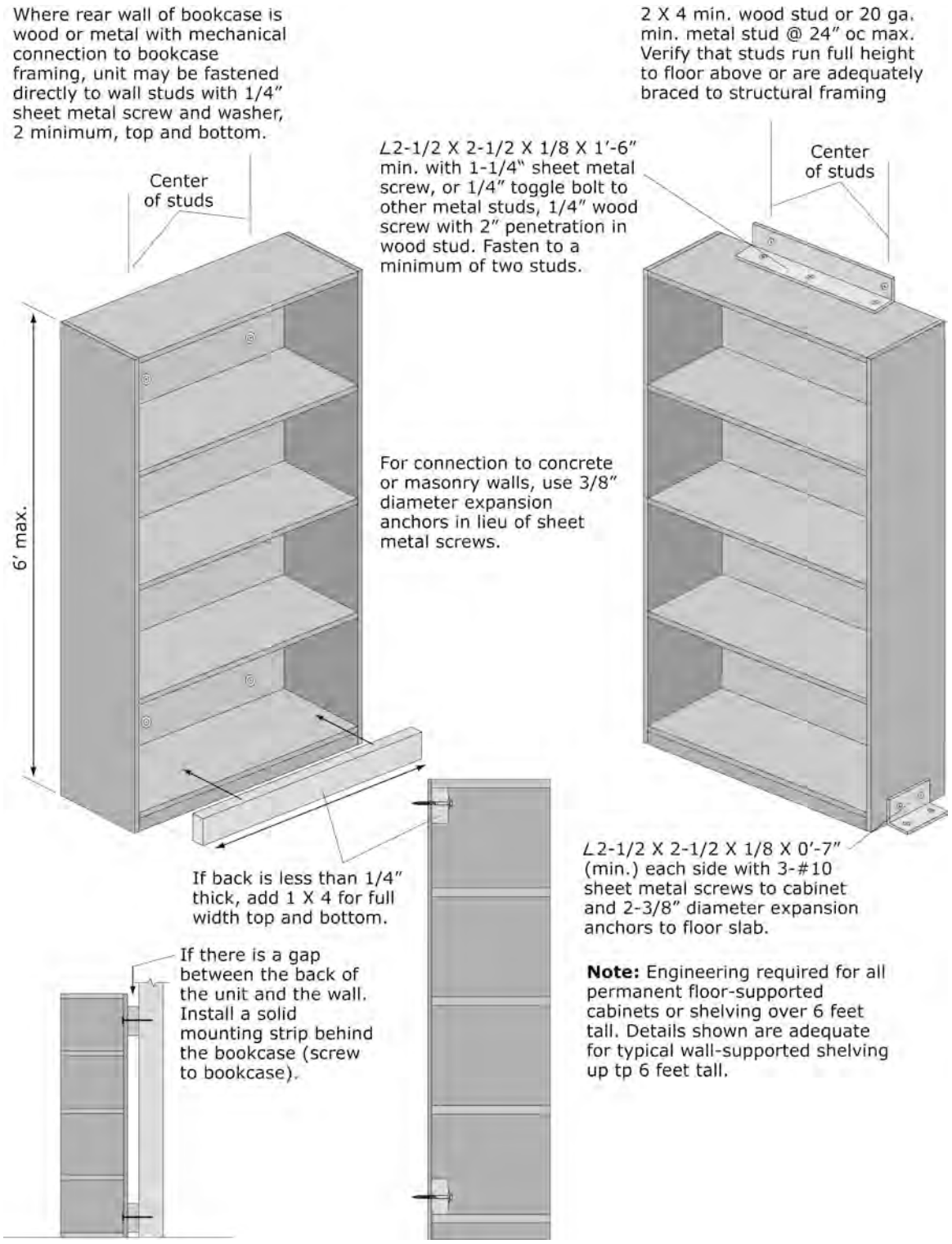
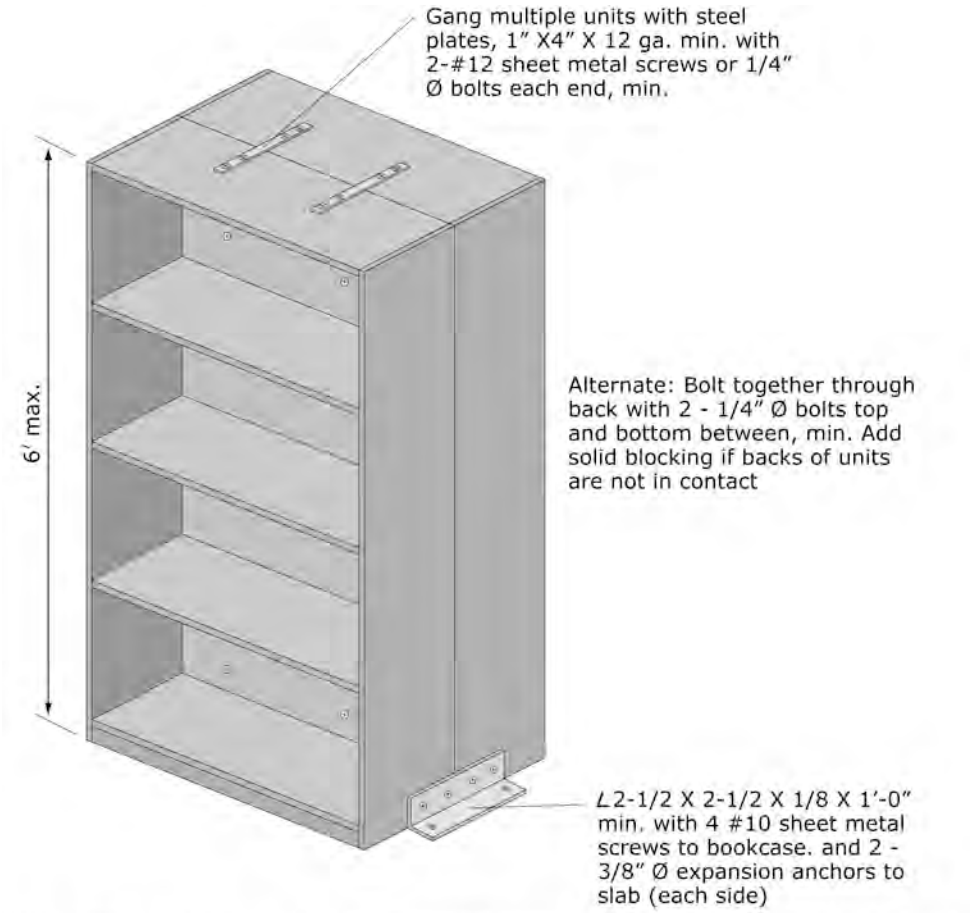


Figure 6.5.2.1-4 Bookshelves against wall (NE, ER).



Note: Engineering required for all permanent floor-supported cabinets or shelving over 6 feet tall. Details shown are adequate for typical shelving 6 feet or less in height.

Figure 6.5.2.1-5 Anchorage of freestanding book cases arranged back to back (NE, ER).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.2 Bookcases, shelving

6.5.2.2 Library and Other Shelving

Library shelving typically consists of many rows of tall back-to-back shelving units that are heavily loaded. There have been many costly failures of library shelving in earthquakes; this includes failures of both unrestrained and poorly restrained shelving units.

Provisions

BUILDING CODE PROVISIONS

Bookshelves are considered force controlled, and the principal objective of the code provisions is to prevent them from sliding or overturning.

- The seismic design requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13 apply to permanent floor-supported library shelving, book stacks, and bookshelves over 6 feet tall in Seismic Design Categories C, D, E, and F. The weight of the contents must be included.

RETROFIT STANDARD PROVISIONS

- ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) requires bookshelves 4 feet in height comply with the anchorage provisions of the standard when the performance level is Life Safety or higher.

Typical Causes of Damage

- Unrestrained or poorly restrained library shelving can slide or overturn resulting in damage to the contents, damage to the shelving units, and damage to partition walls or other contents. Shelving failures may result in personal injuries. It may be costly and time consuming to repair the shelving units and reshelf all of the books.
- Unrestrained or poorly restrained library shelving has failed in a variety of ways. If the base anchorage is inadequate, the bolts can fail and the units may slide or tip. If overhead transverse ties are provided between many shelving units, but no longitudinal bracing or ties are provided, the units may collapse in their longitudinal direction. If undersized transverse ties are provided, or they are attached at the extremes to walls or partitions with insufficient capacity or with inadequate connectors, the units may all

topple in their transverse direction like dominos. If individual or back-to-back shelving units are braced to the structure above, these restraints may fail or buckle if they are undersized.

- Damage to rare books or irreplaceable museum collections can be devastating. These materials may need to be rebound or restored at great expense to the institution. Where water leakage from failed sprinkler piping is also an issue, these items may be beyond restoration.

DAMAGE EXAMPLES



Figure 6.5.2.2-1 Photo showing collapsed library shelving in the 2010 magnitude-7.1 Canterbury New Zealand Earthquake (Photo courtesy of University of Canterbury).



Figure 6.5.2.2-4 Shelving units with longitudinal ties did not fall over but all of the contents spilled to the floor in the 2010 Canterbury Earthquake. The use of lips or wires would have prevented the damage.(Photo courtesy of University of Canterbury).



Figure 6.5.2.2-3 Longitudinal failure of library shelving units (Photo courtesy of NISEE-PEER, U.C. Berkeley). Transverse ties used to tie units together but this was not enough to prevent longitudinal failure.



Figure 6.5.2.2-2 Failure of overhead transverse bracing for bookshelves were anchored to gypsum board partition in the 1984 magnitude-6.2 Morgan Hill Earthquake (Photo courtesy of Santa Clara County Office of Emergency Services). The anchors were not attached to wall studs, only to gypsum board.



Figure 6.5.2.2-5 These shelving units remained in place but all of the contents spilled in the 2010 magnitude-6.5 Eureka, California Earthquake (Photo courtesy of Steve Mahin, PEER).

Seismic Mitigation Considerations

- Following damage to library collections in the 1994 Loma Prieta Earthquake, the California Library Association developed a library shelving standard, ANSI/NISO Z39.73, *Single-Tier Steel Bracket Library Shelving* (ANSI/NISO, 1994) for single-tier steel bracket library shelving.
- Large library collections may contain rare or valuable items that need to be preserved; such library shelving should be engineered to prevent costly downtime and damage to the collection.
- For new library installations, it is important to procure heavy duty shelving that has cross bracing or solid sides and backing that will prevent longitudinal collapse. In addition, for units that will receive additional overhead bracing, the unit should be strong enough to receive the attached ties and bracing. Light duty steel shelving or weak wood shelving units may require strengthening. Steel shelving may require additional cross bracing. Wood shelving units could be strengthened with the addition of corner brackets or hardware to tie the top, back and sides more securely together.
- Anchor the shelving units to the floor. Where shelving units are located against a structural wall, anchor the top of the units to the structure. Tie freestanding back-to-back units together to create a larger base. A one-way transverse grid or two-way grid may be installed, either at the top of the units or above the ceiling surface, to tie many units together. This grid in turn should be anchored to structural walls at the perimeter of the grid or to the structural slab or framing above. However, if the shelving units are anchored to the floor and braced to the framing above, the shelving and brace assembly must accommodate story drift through distortion of the shelving. While bracing to the structure above will prevent the units from toppling, it may result in damage to the shelving itself, if the story drifts are significant.
- Any connections to stud walls must engage the structural studs. Stud walls and partitions typically do not have adequate lateral capacity to support many shelving units unless they have been engineered with heavy gauge studs and braced to resist the imposed lateral loading from the shelving. Anchorage to structural concrete or masonry walls is preferred.
- The location of the library shelving will influence the design loading. Floor accelerations typically increase as you go higher in a building and may also be higher at locations such as poorly braced mezzanine floors.
- See Section 6.5.6.1 for recommendations regarding edge restraints and the arrangement of shelf-mounted items. Especially rare or valuable items may need to be stored in

well-anchored temperature controlled and water tight cabinets to protect them from deterioration, dust, sprinkler damage, or from falling.

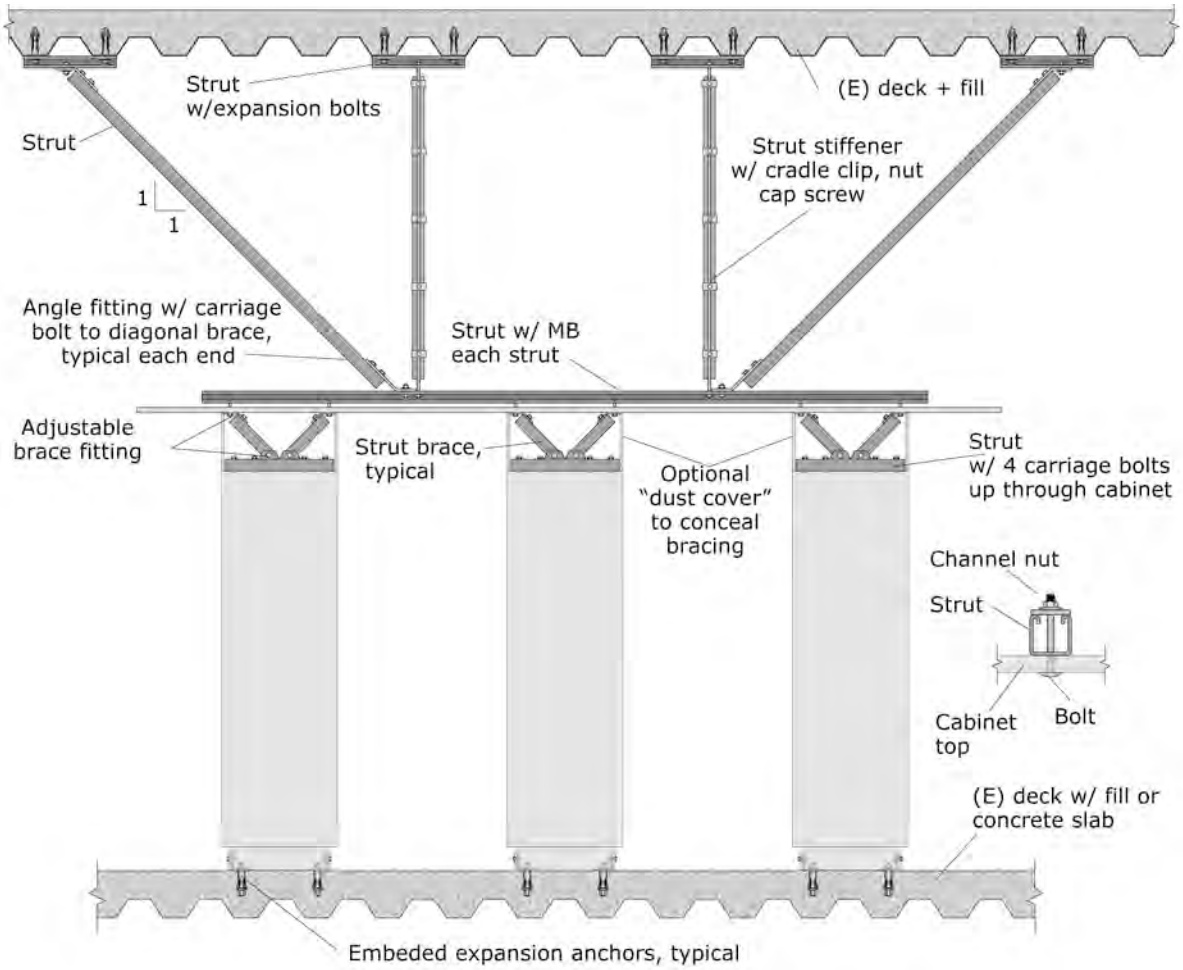
- Do not locate shelving adjacent to doors or exits if their failure would block the exit.

MITIGATION EXAMPLES



Figure 6.5.2.2-6 Examples of struts and hardware used to retrofit library shelving at the University of California, Berkeley (Photos courtesy of Mary Comerio, Dept. of Environmental Design, University of California Berkeley).

MITIGATION DETAILS



Note: since the shelving system is anchored to the floor below and the floor above, use of this detail should be limited to structures with limited interstory drift such as those braced with concrete or masonry shear walls.

Figure 6.5.2.2-7 Concealed overhead restraints for library and other shelving (ER).

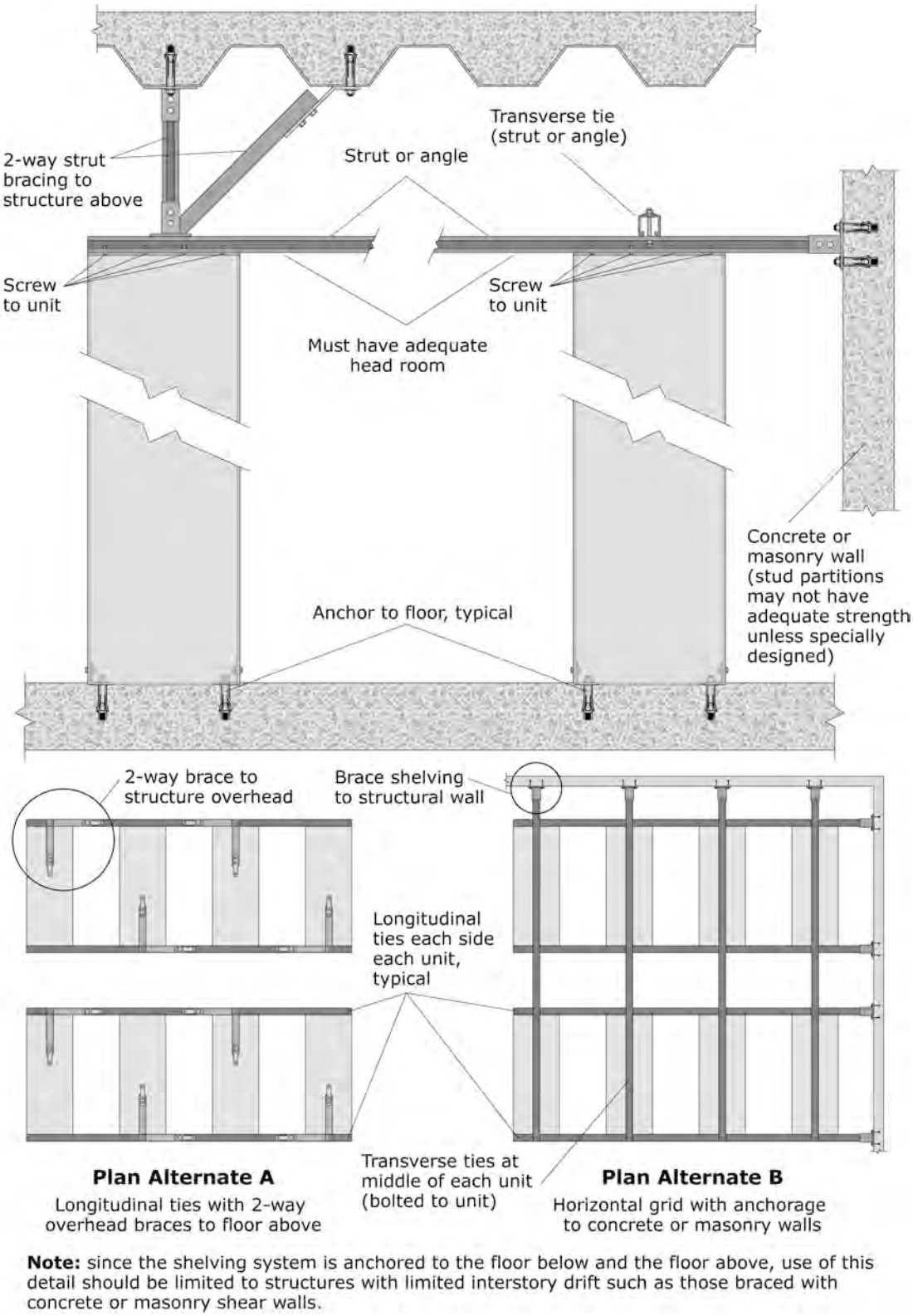


Figure 6.5.2.2-8 Overhead restraints for library and other shelving (ER).

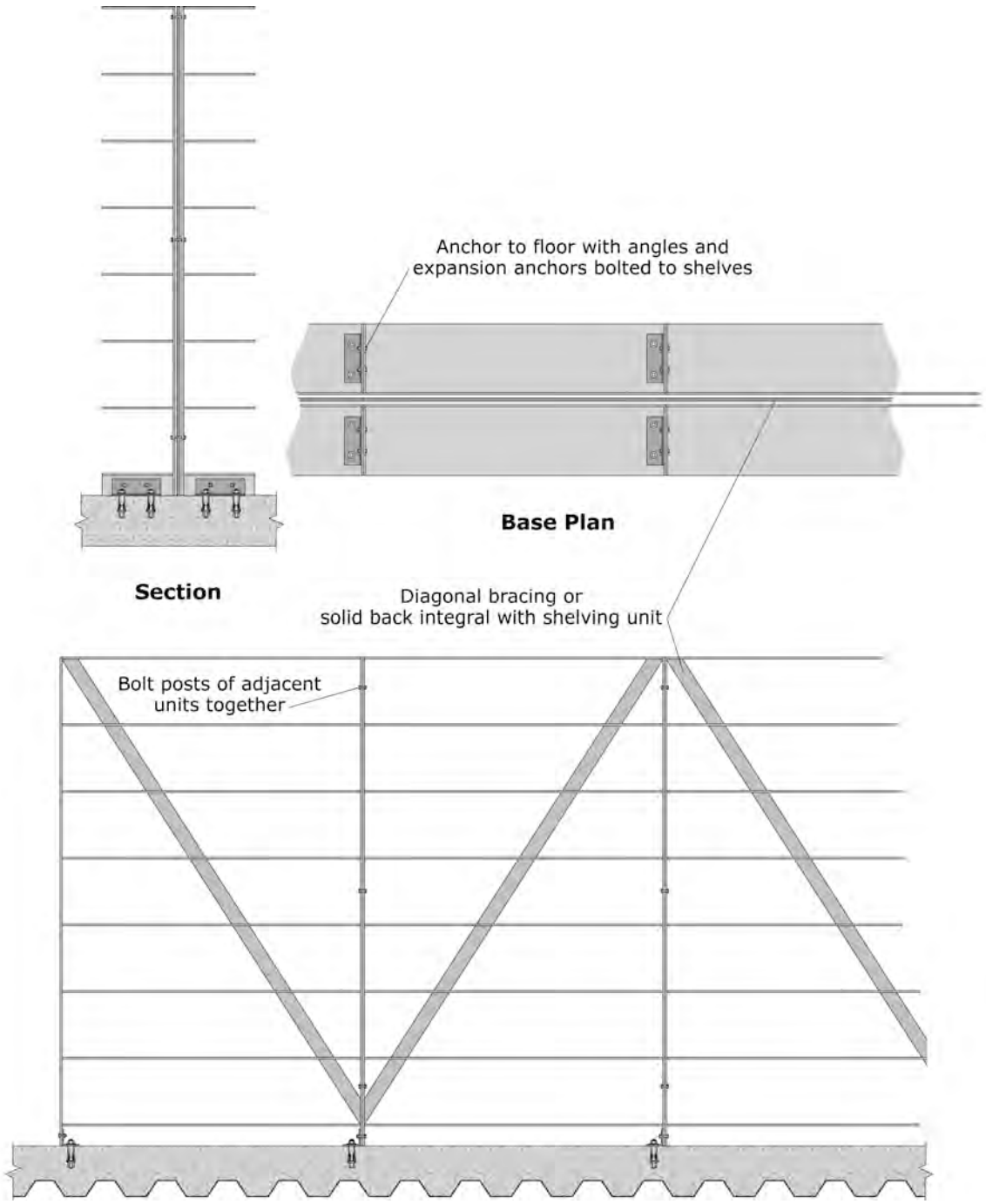


Figure 6.5.2.2-9 Freestanding library and other shelving units (ER).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.3 Computer and Communication Equipment

6.5.3.1 Computer Access Floors and Equipment

Computer access floors are raised floor systems used in many facilities with heavy use of computer equipment; these provide space to run the equipment cables under the flooring.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for computer access floors are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13. The principal objective is to prevent the floor from displacing or buckling under seismic loads. ASCE/SEI 7-10 requires that 100 percent of the weight of all equipment fastened to the floor, and 25 percent of the weight of all equipment supported by, but not fastened to the floor, be used when calculating the design seismic force. The effects of overturning of equipment attached to the floor must be considered, and a complete load path for vertical and lateral forces is required,

Improved performance may be obtained by specifying Special Access Floors. To be considered "special," access floors must meet specific design and detailing requirements.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies access floors as both acceleration and deformation sensitive. ASCE/SEI 41-06 requires compliance with the anchorage provisions of the standard when the performance level is Immediate Occupancy. Retrofit of access floors may utilize prescriptive procedures or project specific analysis. The analysis should consider buckling and racking of the floor supports, connections, and the effects of mounted equipment.

Typical Causes of Damage

- Access floors may collapse if not adequately braced and anchored.
- Equipment located on access floors that are not anchored or tethered may slide and hit a wall or other equipment and may suffer internal damage. Equipment castors can get lodged in floor openings.

DAMAGE EXAMPLES



Figure 6.5.3.1-1 Temporary bracing for access floor collapsed in the1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).



Figure 6.5.3.1-2 Damage to access floor with short anchored pedestals in the 2010 magnitude-6.7 Chile Earthquake; floor did not have lateral bracing. Note many tiles misaligned (Photos courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).



Figure 6.5.3.1-3 Undamaged access floor with braced pedestals in the 2010 Chile Earthquake (Photo courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

Seismic Mitigation Considerations

- Access floor base pedestals should be anchored to the floor slab; taller pedestals may also need diagonal bracing. In zones of low or moderate seismicity, or where the floor height is less than 12 inches high, it may be feasible to adhere the pedestals to the floor slab rather than anchoring them. Check the internet for vendors who supply access floors with a seismic capacity rating.
- Equipment placed on access floors should be tethered; heavy equipment should be anchored to structural slab below. Anchorage may be accomplished through installation of an independent frame beneath the equipment. Alternatively, the equipment may be anchored to properly designed access floor framing, or supplemental bracing components.
- If unrestrained equipment on castors is present, cable openings through access floor should have lips to prevent the wheels from getting stuck.
- Proprietary base isolation systems are also available. The equipment is anchored to the isolation base and the isolation base is anchored to the structural slab.

MITIGATION EXAMPLES



Figure 6.5.3.1-4 Raised floor braced with strut (Photo courtesy of Maryann Phipps, Estructure).



Figure 6.5.3.1-5 Data rack bolted through access floor to supplemental strut bracing below (Photo courtesy of Maryann Phipps, Estructure).

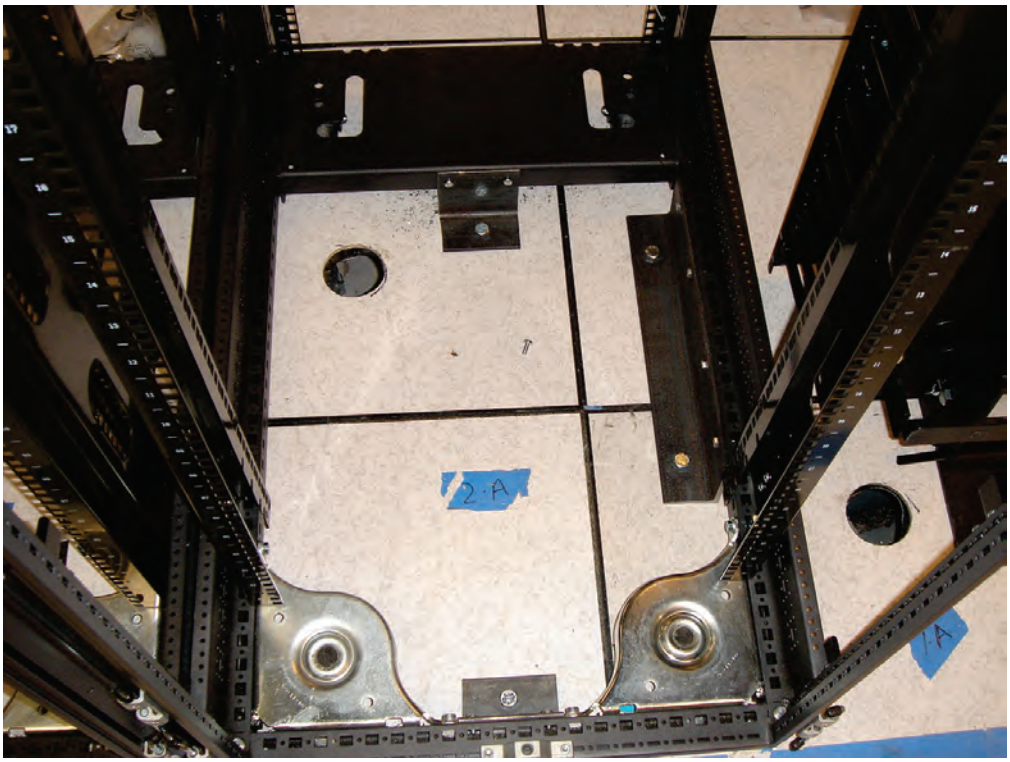


Figure 6.5.3.1-6 Base of data cabinet with supplemental angles bolted to strut bracing below floor (Photo courtesy of Maryann Phipps, Estructure).

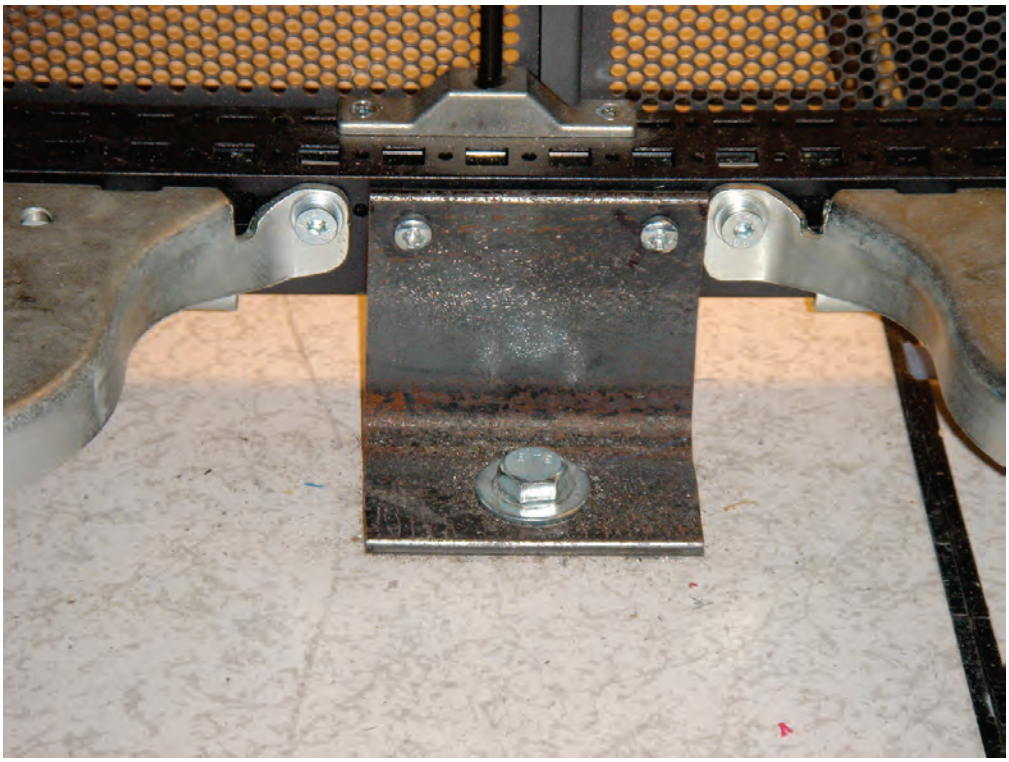
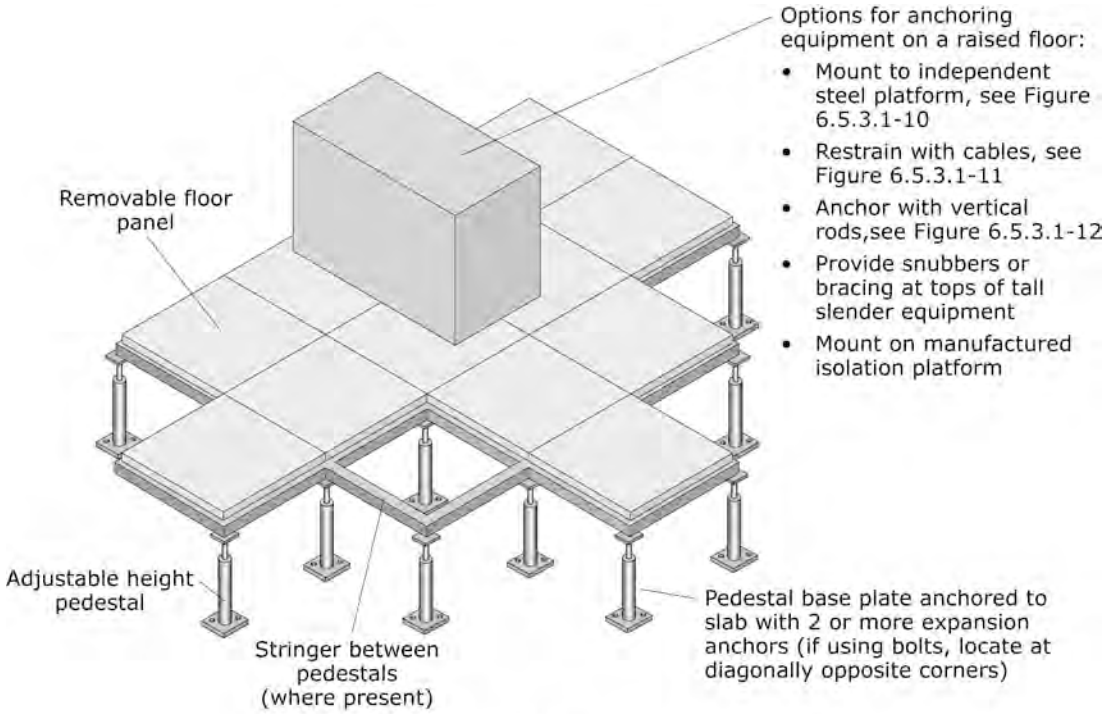


Figure 6.5.3.1-7 Close-up of supplemental angles connecting data cabinet to strut bracing below floor (Photo courtesy of Maryann Phipps, Estructure).

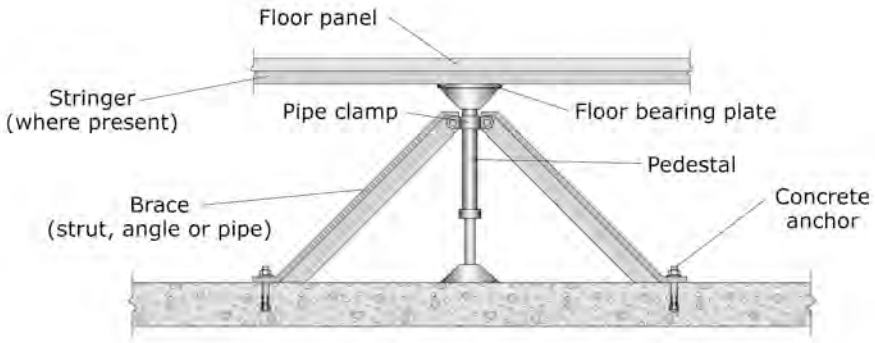


Figure 6.5.3.1-8 Strut framing added to brace data cabinet located on access floor. Bolts from angles above are connected to strut framing below (Photo courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS



Cantilevered Access Floor Pedestal



Braced Access Floor Pedestal
(use for tall floors or where pedestals are not strong enough to resist seismic forces)

Note: For new floors in areas of high seismicity, purchase and install systems that meet the applicable code provisions for "special access floors."

Figure 6.5.3.1-9 Equipment mounted on access floor (ER).

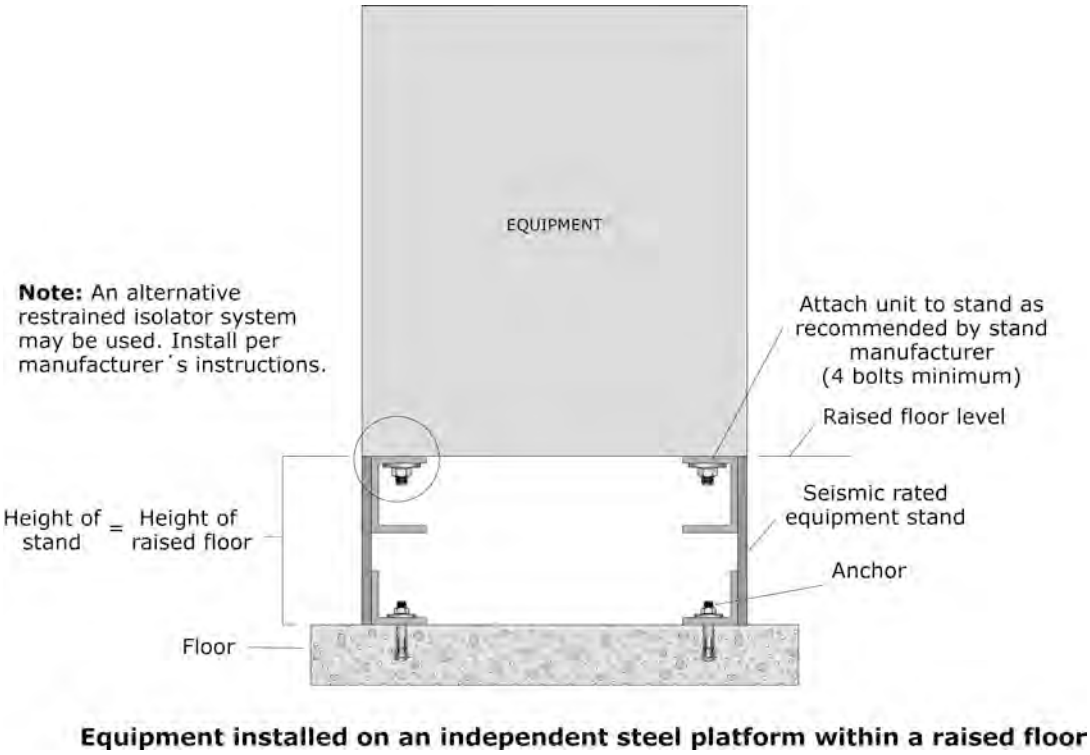


Figure 6.5.3.1-10 Equipment mounted on access floor - independent base (ER).

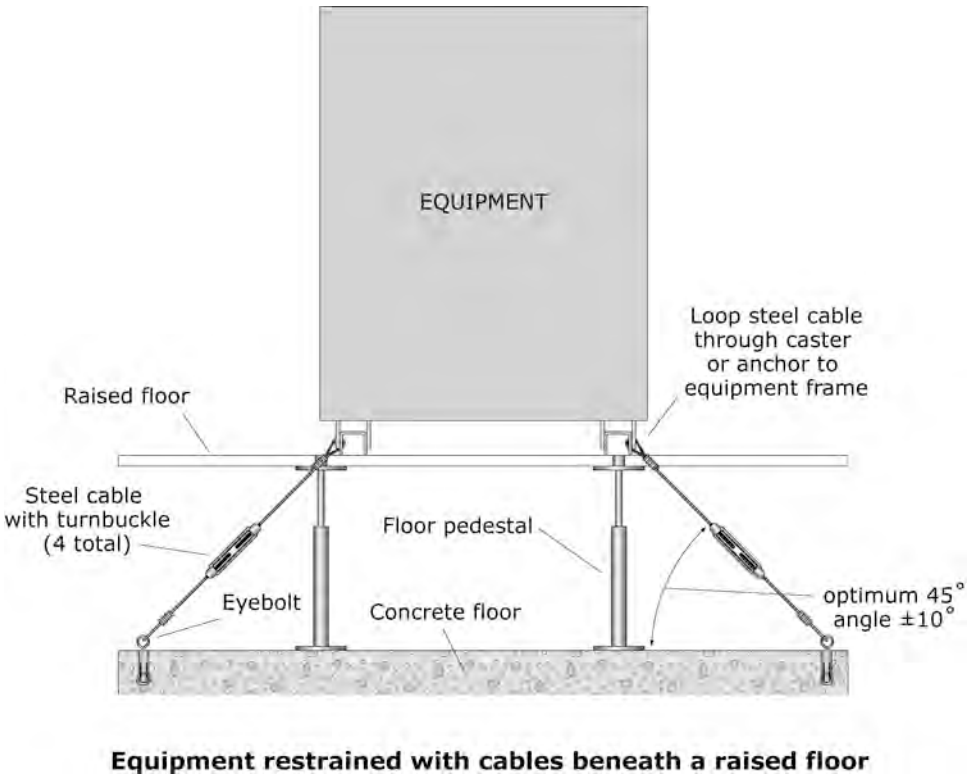


Figure 6.5.3.1-11 Equipment mounted on access floor – cable braced (ER).

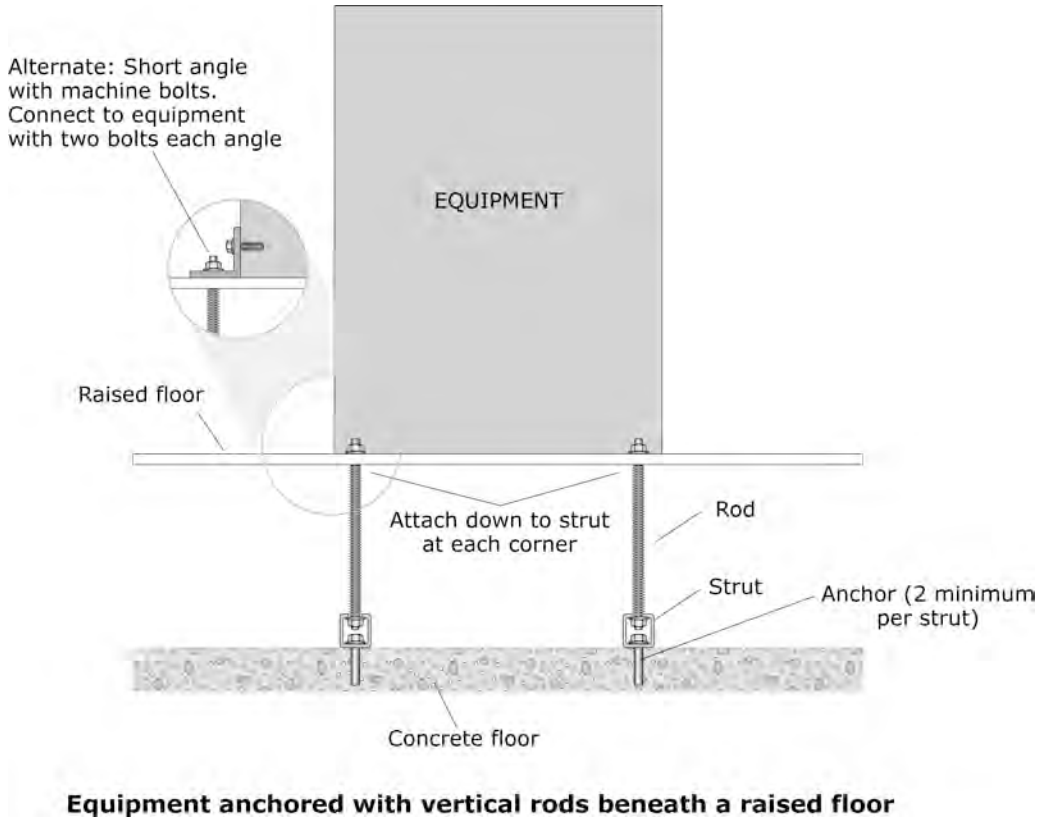


Figure 6.5.3.1-12 Equipment mounted on access floor – tiedown rods (ER).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.3 Computer and Communication Equipment

6.5.3.2 Computer and Communication Racks

Steel racks for servers or communications equipment may be open or closed, wall or floor mounted or portable. To prevent damage and loss of communication links, racks should be braced, anchored, or tethered with equipment firmly secured to the rack and cables arranged with adequate slack.

In recent shake table testing of a full scale 5-story building performed at UC San Diego (see Section 6.1.3), 3 servers that were operating and connected on line at the time of the shaking were subjected to severe earthquake motions. The servers were anchored per code requirements. With the exception of the largest test motion, the servers continued functioning during and following the earthquake motion without a problem. For the largest test motion, the servers momentarily went off line, reset themselves, automatically reconnected themselves and then continued functioning.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for computer and communication racks are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13. The principal objective is to prevent the racks from toppling or buckling under seismic loads,

- ASCE/SEI 7-10 requires anchorage for all equipment in Seismic Design Categories D, E, and F weighing over 400 pounds, and items weighing over 20 pounds that are mounted over 4 feet above the floor. Lighter items may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents. Flexible connections must be provided between the equipment and associated conduit or raceways.
- The racks themselves should be checked for adequate strength and stiffness.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies computer and communication racks as force controlled. These components are subject to the provisions of the standard when the performance level is Immediate Occupancy. Acceptance criteria for electrical equipment focus on providing adequate anchorage for seismic forces. Buckling or racking failure of rack framing components must also be considered.

Typical Causes of Damage

- Unbraced, unanchored, or poorly anchored racks can slide, tip, overturn or collapse. Equipment may slide, bang, or fall and suffer internal damage; cable connections may pull loose and get scrambled.

DAMAGE EXAMPLES



Figure 6.5.3.2-1 Damage to communication and computer racks (Photo courtesy of Degenkolb Engineers).

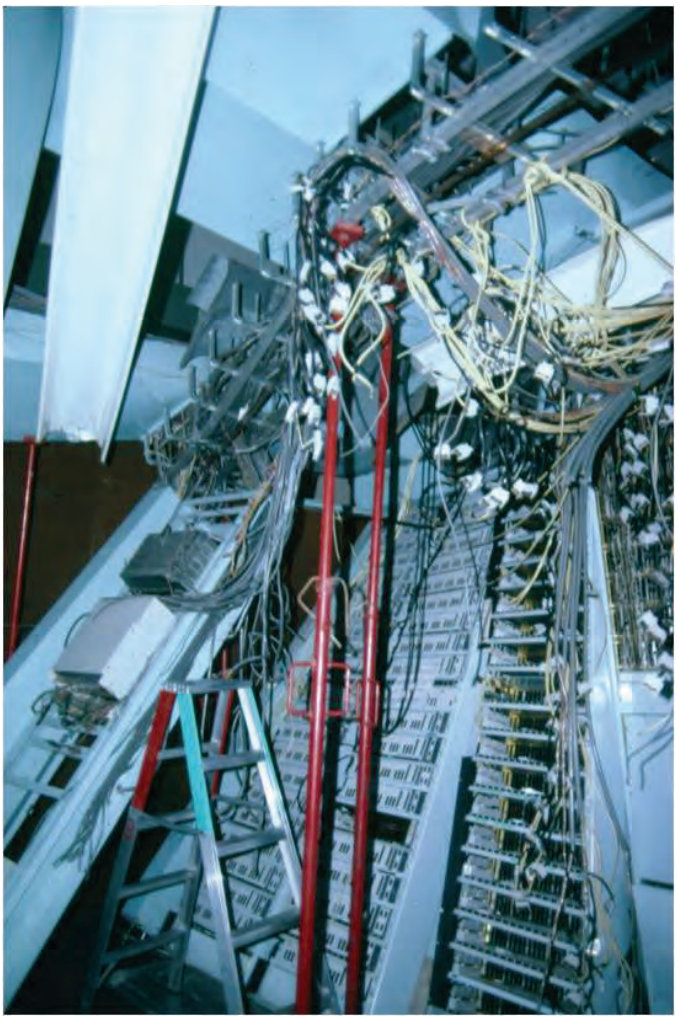


Figure 6.5.3.2-2 Damage to communication and computer racks (Photo courtesy of Degenkolb Engineers).

Seismic Mitigation Considerations

- Check suppliers for seismic rated cabinet racks or server racks that come with predrilled holes and hardware for floor or wall anchorage. Where items are anchored to a partition wall, make sure that the wall and wall anchorage or bracing to the structure above are adequate to resist the imposed loads. Cables and wiring should be installed with sufficient slack to allow for some seismic deformations.
- See also Section 6.5.3.1 for equipment on access floors; see Section 6.4.7.1 for details for anchorage of electrical cabinets. Also refer to FEMA 413, *Installing Seismic Restraints for Electrical Equipment* (2005), for general guidelines for anchorage of electrical items.
- Develop a backup and recovery plan for all electronic data including offsite backup to a location not likely to be affected by the same earthquake.

MITIGATION EXAMPLES



Figure 6.5.3.2-3 Base anchorage details for data cabinets; top photos shows internal anchorage, bottom photo shows external anchorage (Photos courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

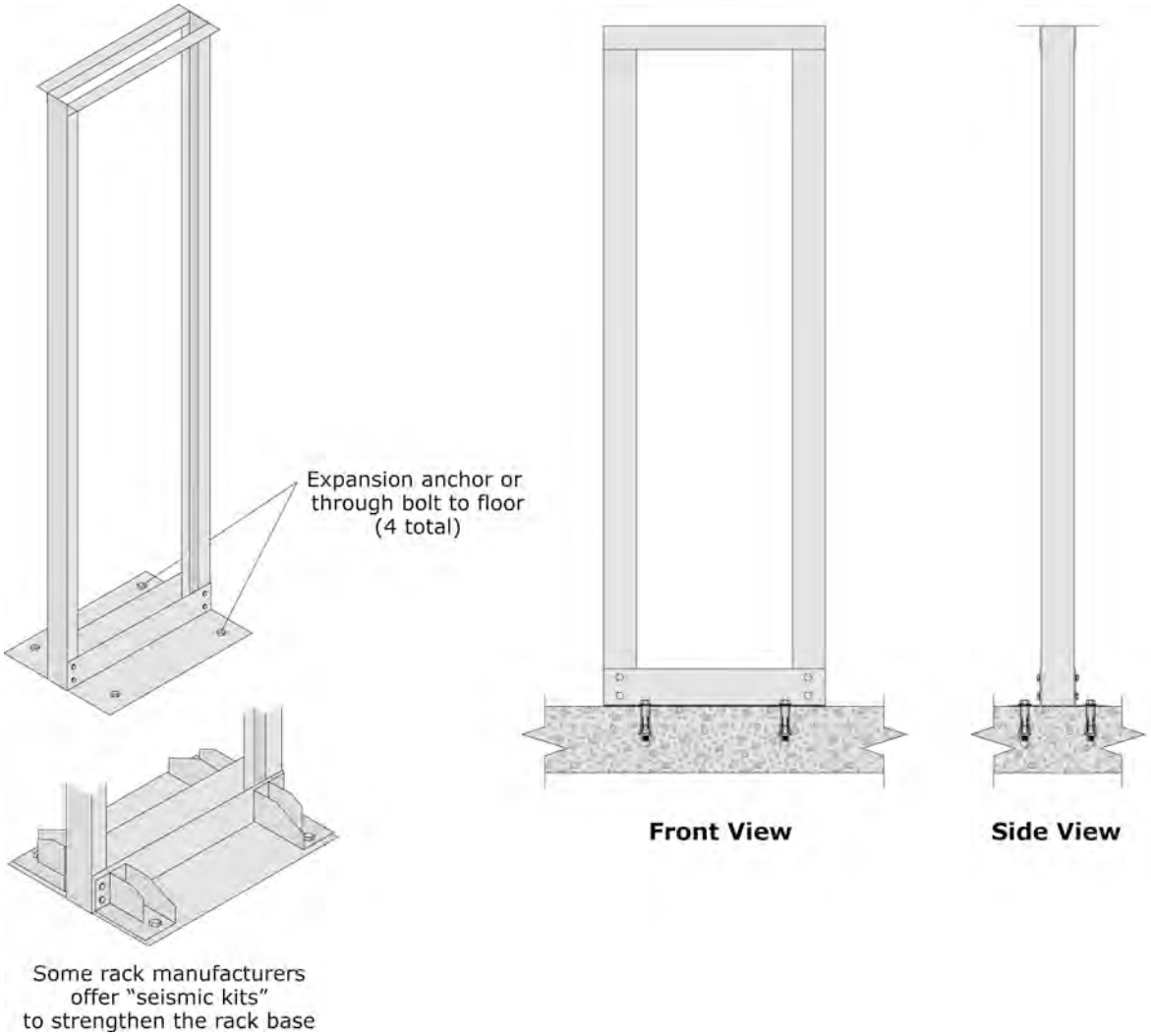


Figure 6.5.3.2-4 Data rack (ER).

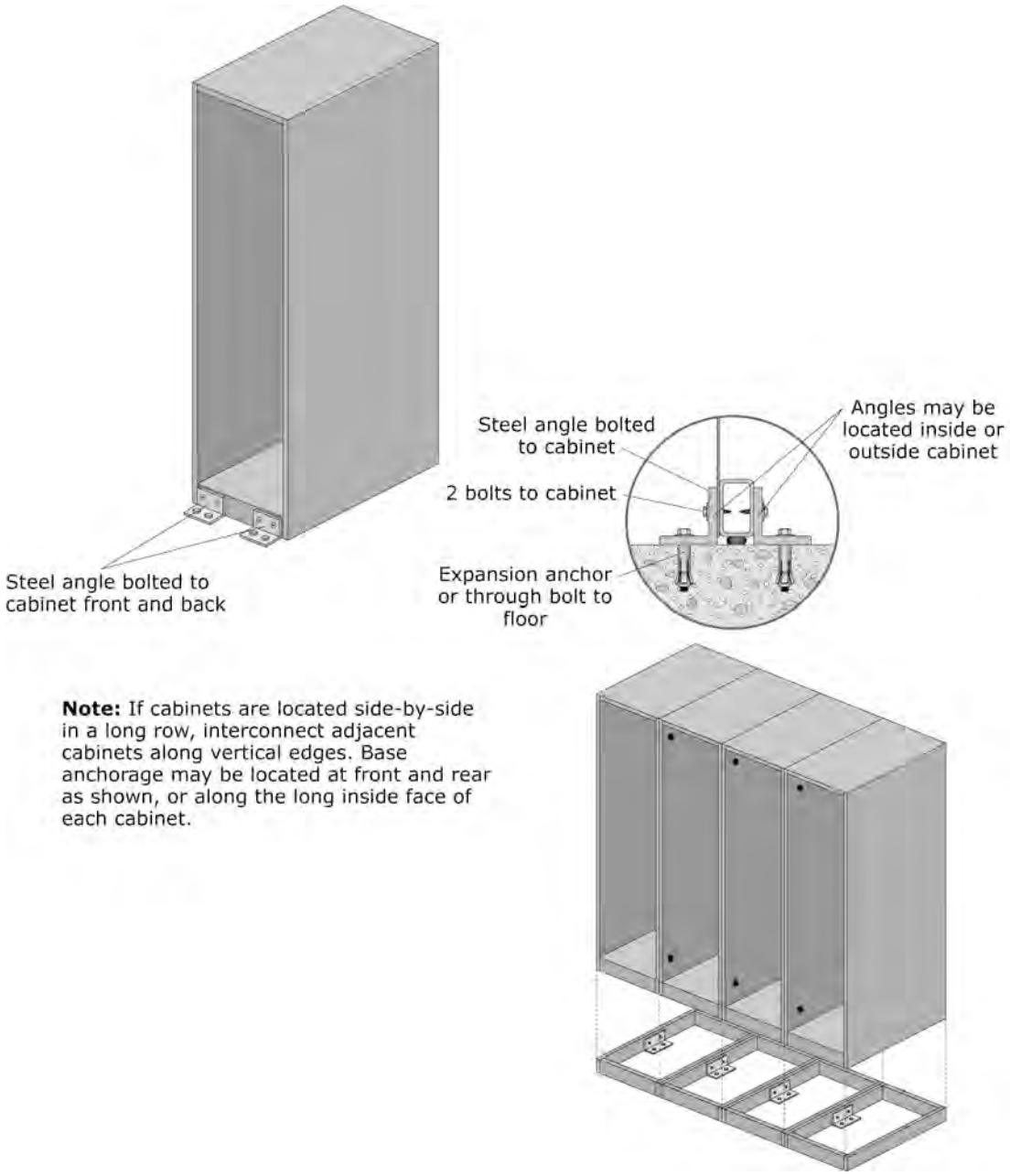


Figure 6.5.3.2-5 Data cabinet (ER).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.3 Computer and Communication Equipment

6.5.3.3 Desktop Computers and Accessories

Computers, printers, monitors, projectors, scanners and other electronic equipment are found nearly everywhere, most of them resting on desks and tables without restraint.

Typical Causes of Damage

- Desktop items may slide, tip, collide with other items or fall. If one item falls, the cords and cables may pull other items down resulting in additional damage.
- Equipment may suffer internal damage and be rendered inoperable. Business interruption losses may result.

DAMAGE EXAMPLES



Figure 6.5.3.3-1 Computer monitor slid off desktop onto floor in the 2010 magnitude-6.5 Eureka, California Earthquake (Photo courtesy of Steve Mahin, PEER).

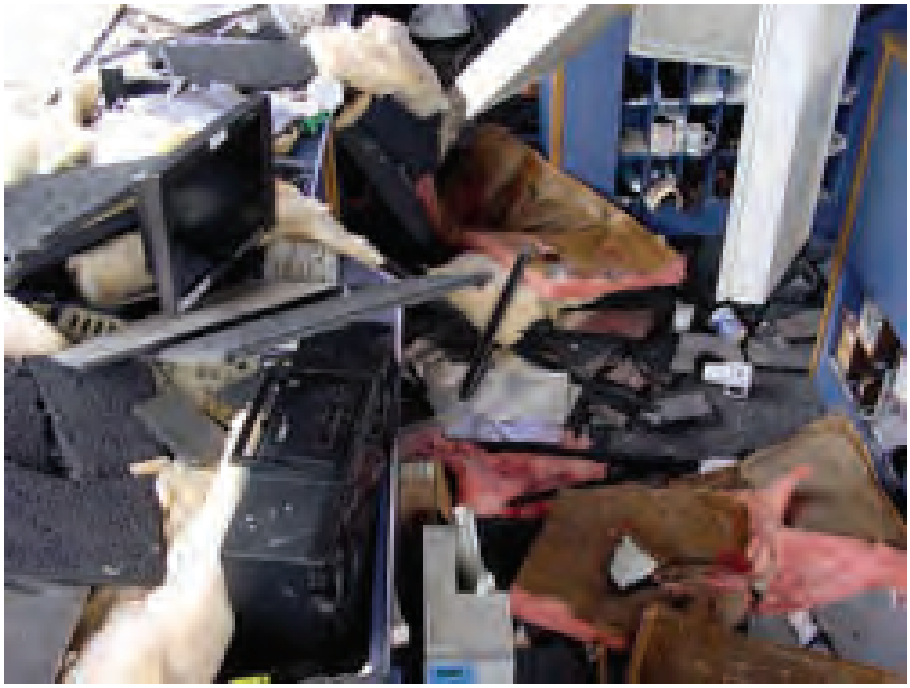


Figure 6.5.3.3-2 Damage to control tower at the SeaTac Airport in the 2001 Nisqually Earthquake (Photo courtesy of JCP Geologists).

Seismic Mitigation Considerations

- Desktop equipment should be anchored or tethered to prevent earthquake damage, loss of equipment and loss of electronic files. The supporting desk, table or cart should also be anchored or tethered if movement could cause additional damage. Alternatively, cables and cords should be installed with sufficient slack to allow for some movement.
- Many proprietary safety fasteners are currently available to use to restrain desktop items. See also Section 6.5.6.2 for tether details.

MITIGATION DETAILS

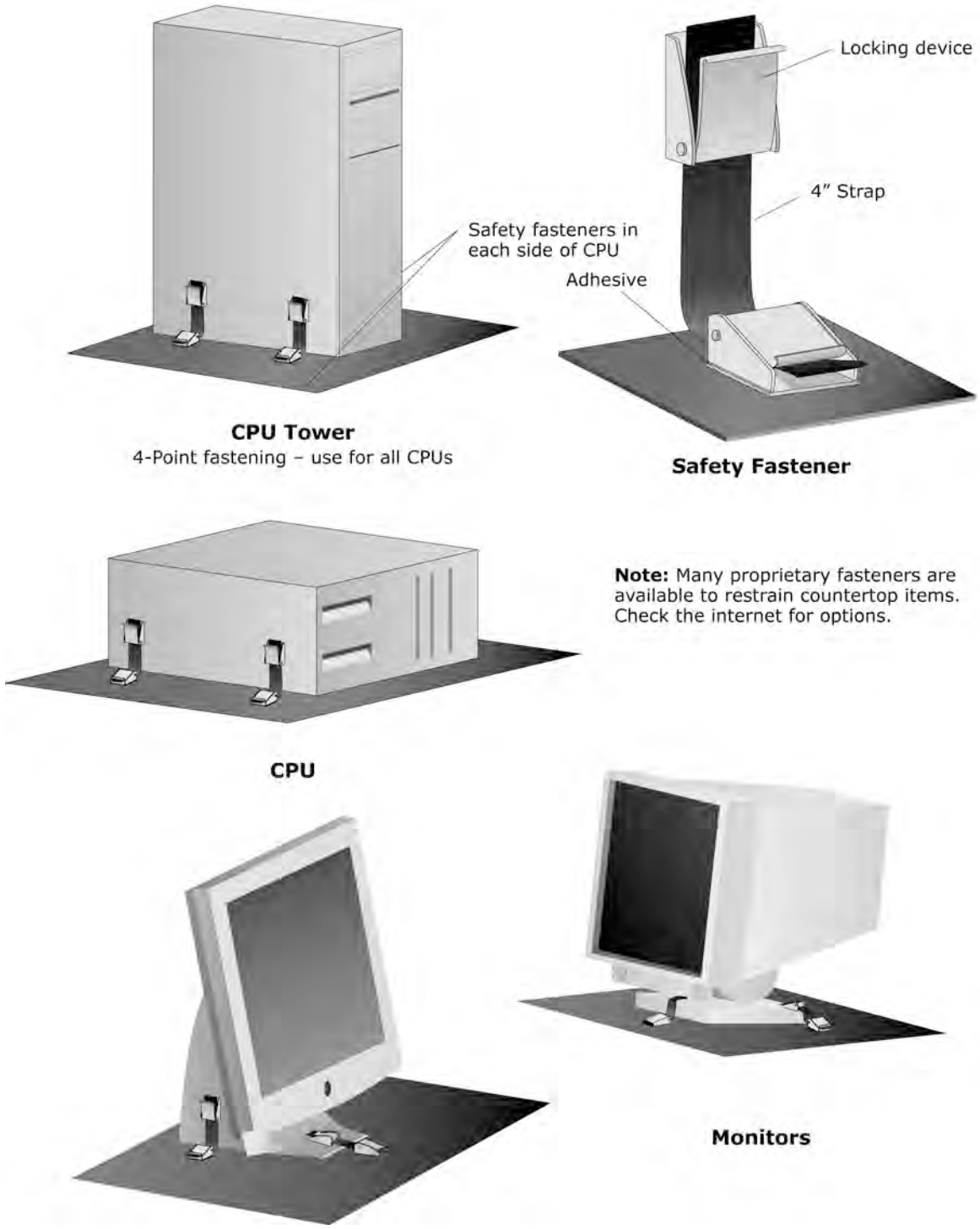


Figure 6.5.3.3-3 Desktop computers and accessories (NE).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.3 Computer and Communication Equipment

6.5.3.4 Televisions and Video Monitors, Wall-Mounted

Wall and ceiling mounted televisions, monitors and projectors are found in many places including homes, classrooms, airports, and hospital rooms.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for wall mounted television and video monitors are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13. The principal objective is to prevent the components from falling.

- ASCE/SEI 7-10 requires anchorage for all equipment in Seismic Design Categories D, E, and F weighing over 20 pounds that are mounted over 4 feet above the floor. Lighter items may be exempt if the component Importance Factor $I_p = 1.0$.
- Items that are exempt from the anchorage requirements noted above are still required to be positively anchored to the structure. The anchorage need not be designed or detailed on the construction documents.
- Many proprietary wall mounts will provide adequate protection, if they are rated for seismic loads.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) does not directly address wall mounted television and video monitors. Given the level of risk posed by these components, evaluation for the presence of adequate attachment and support should be performed for all performance levels in high and moderate seismicity areas.

Typical Causes of Damage

- These items may shake, bounce, impact adjacent items, or fall. Wall or ceiling-mounted items can become dislodged and fall from the supporting bracket, the bracket could pull out from the wall or ceiling, or the bracket can break and the television or monitor may be damaged or broken.
- These items are heavy and could cause serious bodily injury if they fall on someone.

EXISTING CONDITION



Figure 6.5.3.4-1 Wall-mounted monitor fell from the bracket in a hospital in the 2010 magnitude-8.8 Chile Earthquake; bracket still anchored to the wall (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates)

Seismic Mitigation Considerations

- Proprietary video mounting brackets are available to support overhead or wall-mounted televisions, monitors, and screen of all sizes. These come as rigid mount, tilt mount, or motorized mount. Check the internet; some of these products indicate they are seismic rated for safer installations.
- Brackets will not provide seismic protection unless properly installed; follow the manufacturer's installation instructions. It is critical that the lag bolts, screws, or expansion bolts used be installed directly into structural elements such as studs, concrete or masonry wall, or ceiling joists that have adequate capacity to support the additional loading. Do not anchor to gypsum board, plaster or a suspended ceiling grid. See the installation notes in Section 6.6 of this document for more information on anchorage details.
- If the bracket can be adjusted into different positions, make sure it cannot swing and hit a window or light; providing a safety cable or tether to restrict the range of motion may reduce the risk of impact with other objects and the risk of falling.
- Do not locate overhead items directly over a bed, couch, bench, or desk in a classroom where people are likely to be.
- For televisions or monitors resting on furniture or a home entertainment center, heavy-duty safety fasteners or tethers should be used to prevent the television from falling and the furniture should be anchored to the floor or wall.

MITIGATION EXAMPLES



Figure 6.5.3.4-2 Wall-mounted television bracket anchored with sheet metal screws to wall studs at four locations. Bracket must be rated for the weight of television or monitor and that the unit must be securely attached to the bracket (Photo courtesy of Maryann Phipps, Estructure).

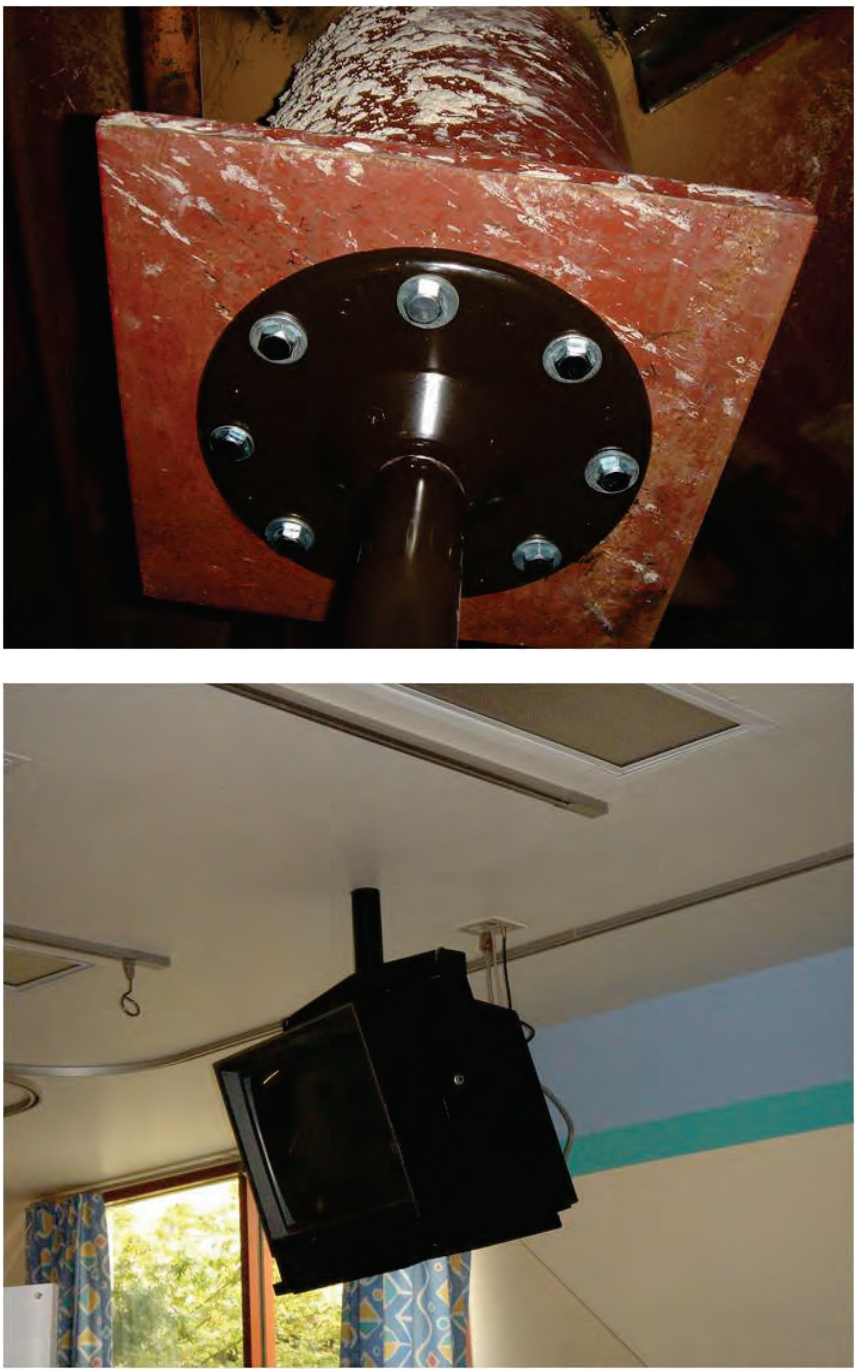


Figure 6.5.3.4-3 Mounting plate above ceiling for overhead television bracket in a hospital room. Television or monitor must be securely attached to the bracket (Photos courtesy of Maryann Phipps, Estructure).

MITIGATION DETAILS

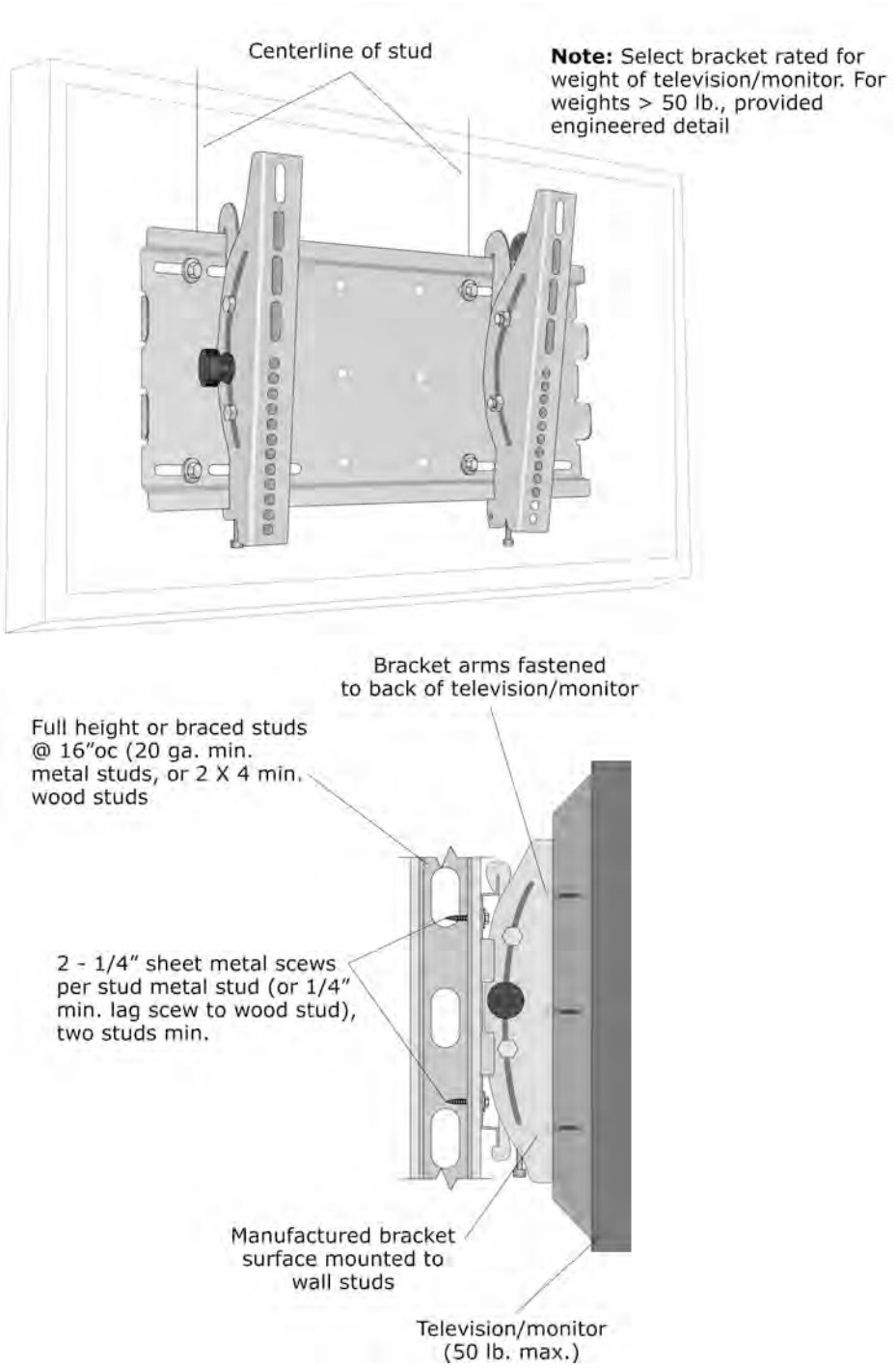


Figure 6.5.3.4-4 Wall-mounted bracket for television or monitor weighing less than 50 lb (NE).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.4 Hazardous Materials Storage

6.5.4.1 Hazardous Materials Storage

Unsecured or improperly stored hazardous materials resulting in a release may close businesses located in an otherwise undamaged building. Hazardous materials may include cleaning supplies, laboratory or production chemicals, medical sharps, and biohazard containers. These may be stored in fragile containers or may be in open vats in an industrial setting.

Provisions

BUILDING CODE PROVISIONS

The seismic design requirements of ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010) Chapter 13 are intended to apply only to permanently attached components, not to furnishings, temporary items, or mobile units. Storage cabinets and shelving units that contain hazardous materials are not considered to be exempt and should be anchored or braced. In addition, storage cabinets and shelving units that contain toxic, highly toxic, or explosive materials above a threshold quantity are considered designated seismic systems with a component importance factor, I_p, of 1.5 and may require engineering calculations, special certification, and additional inspections.

Permanent floor-supported shelving or storage cabinets over 6 ft tall must be designed as architectural components per ASCE/SEI 7-10. Bracing and anchorage for these units should be designed considering the weight of the unit and weight of shelved contents.

RETROFIT STANDARD PROVISIONS

ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2007) classifies hazardous materials storage as force controlled, and the principal objective of the code provisions is to prevent the component from sliding or overturning. The emphasis of the hazardous materials storage provisions is on materials in containers. For materials stored in cabinets or shelves, the provisions for storage racks may be used. ASCE/SEI 41-06 requires compliance with the provisions of the standard for hazardous materials storage when:

- The performance level is Immediate Occupancy or Life Safety in high and moderate seismicity areas.

- The performance level is Life Safety in low seismicity areas or Hazards Reduced in high, moderate, and low seismicity areas and the system is in close proximity to occupancy such that leakage could cause an immediate life safety threat.

Typical Causes of Damage

- Loose containers may slide, tip, overturn, or fall. Glassware may break; hazardous contents may slosh or spill and create noxious fumes and toxic mixtures.
- Spilled flammable liquids may cause a fire and destroy a home or business that otherwise may have survived an earthquake without damage.
- Unknown spills may cause building closure until a HAZMAT team can investigate.

DAMAGE EXAMPLES



Figure 6.5.4.1-1 Spilled chemicals in high school chemistry lab in the 1971 magnitude-6.6 San Fernando Earthquake (Photo courtesy of EERI).



Figure 6.5.4.1-2 Spilled pharmaceutical and medical supplies in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Robert Reitherman).



Figure 6.5.4.1-3 Spilled fluids in a hospital in the Costa Rica Earthquake (Photo courtesy of Degenkolb Engineers).



Figure 6.5.4.1-4 Fire destroyed the chemistry building containing the entire chemistry department at the University of Concepción in the 2010 magnitude-8.8 Chile Earthquake; fire exacerbated by the presence of hazardous chemicals (Photo courtesy of Bill Holmes, Rutherford & Chekene).

Seismic Mitigation Considerations

- The National Fire Protection Association (NFPA), the International Building Code, and the International Fire Code (IFC) contain many requirements pertaining to the classification, labeling, handling, monitoring, shipping, containment, and storage of hazardous materials. Check the applicable jurisdiction for requirements. See also the discussion of hazardous materials piping in Section 6.4.5.1.
- Hazardous materials storage cabinets and lockers are available with secure door closures and internal containment in case materials spill inside the cabinet. Brace and anchor all shelving units or cabinets used for storage of hazardous materials. See Section 6.5.1.1 and 6.5.2.1 for restraint details. Where shelving or cabinets are anchored to a partition wall, check that the partition, bracing and attachments to the structure above are adequate for the imposed loads.
- See Section 6.5.6.1 for recommendations for edge restraints and arrangement of shelved items. Provide edge restraints for containers of flammable or hazardous substances even if they are in closed cabinets.
- Secure large containers of production chemicals or cleaning supplies; these may be secured using tether cables or chains. See Section 6.4.2.3 or Section 6.5.5.3 for similar restraint details.
- Store small or breakable items in original packaging or in “egg crate” type boxes; not loose on shelves or in drawers.
- Ensure that all toxic items are in the correct containers and properly labeled.

- Ensure that employees know what to do in case of a spill. Make sure they know where to find the Material Data Safety Sheets (MSDS). The MSDS contains physical data for chemicals, chemical compounds and chemical mixtures and provides information for workers and emergency personnel regarding the safe use and potential hazards of each product. The MSDS includes information such as melting point, boiling point, flash point, reactivity, toxicity, health effects, protective equipment required, first aid procedures, storage and disposal procedures, spill-handling procedures, and labeling requirements. Facilities that use or store chemicals should have an MSDS for each product on site; employees should know where to locate the MSDS binder and know what steps to take in case of a spill.

- Store incompatible materials at a safe distance from each other to avoid mixing if the containers fall and break.
- Order hazardous lab chemicals in unbreakable plastic bottles or in glass bottles with an exterior plastic safety coating.

- Keep all large containers or vats of toxic, hot, or hazardous items covered to prevent surging in an earthquake.

6.5 Furniture, Fixtures, Equipment and Contents

6.5.5 Miscellaneous Furniture, Fixtures and Equipment

6.5.5.1 File Cabinets

Sheet metal file cabinets are often tall, narrow and heavily loaded. These cabinets frequently overturn in earthquakes; the time required to pick up and reorganize files may be significant business expense and result in lost productivity.

Typical Causes of Damage

- Unanchored file cabinets can slide, tip, or overturn. Drawers may slide open increasing the chance that the cabinet will overturn; contents may fall and get scrambled.
- Overturned cabinets may block doors and exit corridors.

DAMAGE EXAMPLES



Figure 6.5.5.1-1 Failure of file cabinets in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).



Figure 6.5.5.1-2 Tipped filing cabinets and other office equipment at the Lawrence Livermore Lab, California (NGDC, 2009).



Figure 6.5.5.1-3 Unanchored cabinets toppled in the 1994 Northridge Earhtquake (Photo courtesy of Wiss, Janney, Elstner)

Seismic Mitigation Considerations

- ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), requires that permanent floor supported cabinets or shelving over 6 ft tall be treated as architectural components. This requirement does not apply to wall mounted items with both base and wall anchorage.
- Do not locate cabinets where their failure would block a door or exit corridor; note some school districts do not allow file cabinets within 6 feet of a doorway. Do not locate where they could fall and break a window or glass partition.
- File cabinets should be anchored to the floor or wall. Where cabinets or shelving are anchored to a partition, check that the partition, bracing and attachment to the structure above are adequate for the imposed loading.
- Adjacent freestanding file cabinets should be anchored together and to the floor. Gang multiple units together to create a more stable arrangement.
- Provide strong drawer latches to prevent the drawers from sliding open. Fluids and files don't mix; do not place flower vases or other breakable fluid containers on top of file cabinets.
- There are many acceptable ways to reliably protect file cabinets from earthquake damage. The following details illustrate measures that can protect loaded cabinets up to 6 ft tall in severe ground shaking at the highest locations within a building; engineering may be required for floor-supported items taller than 6 feet. Alternate less robust details may be developed for less severe loading conditions.

MITIGATION DETAILS

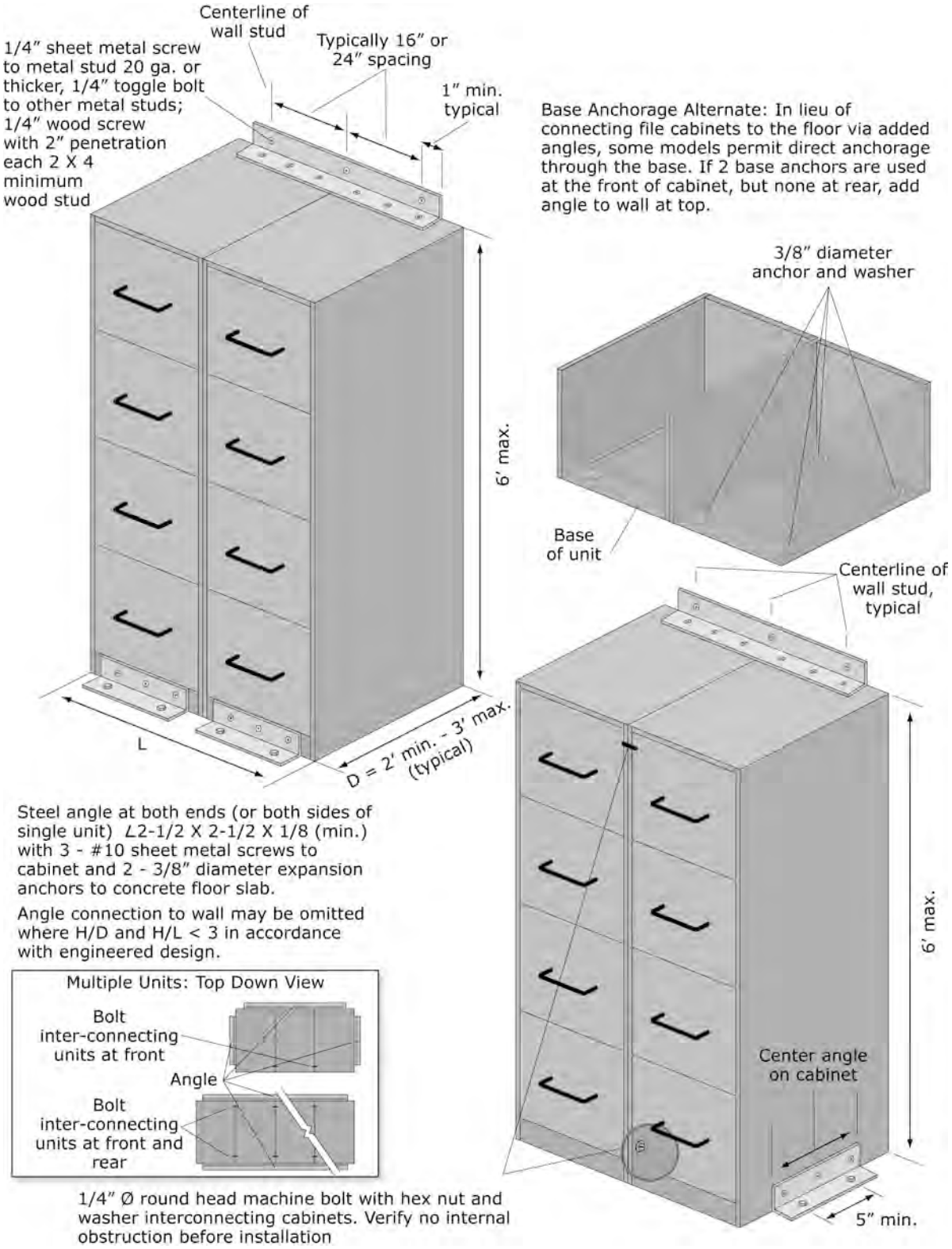


Figure 6.5.5.1-4 Wall-mounted file cabinets (NE).

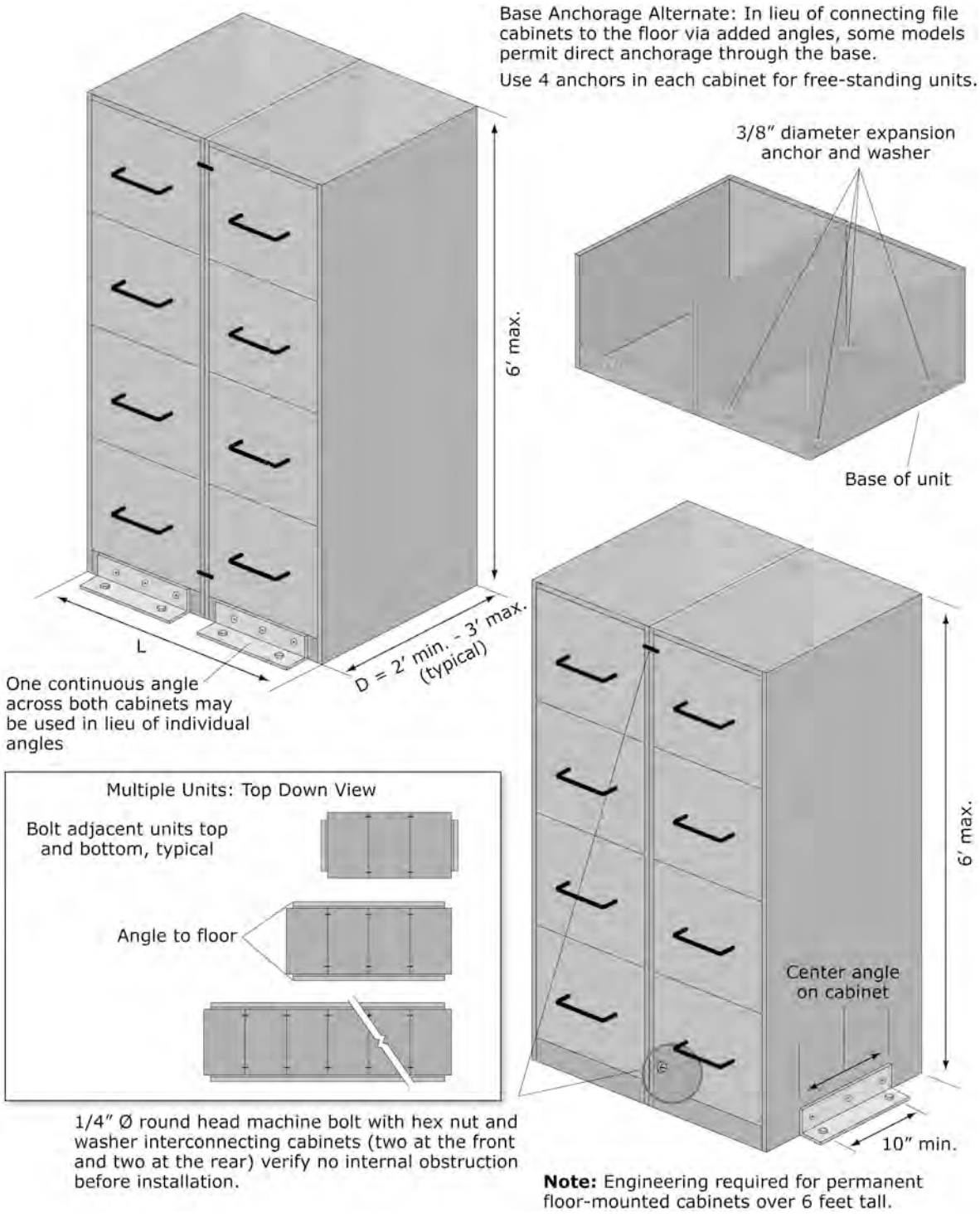


Figure 6.5.5.1-5 Base-anchored file cabinets (NE).

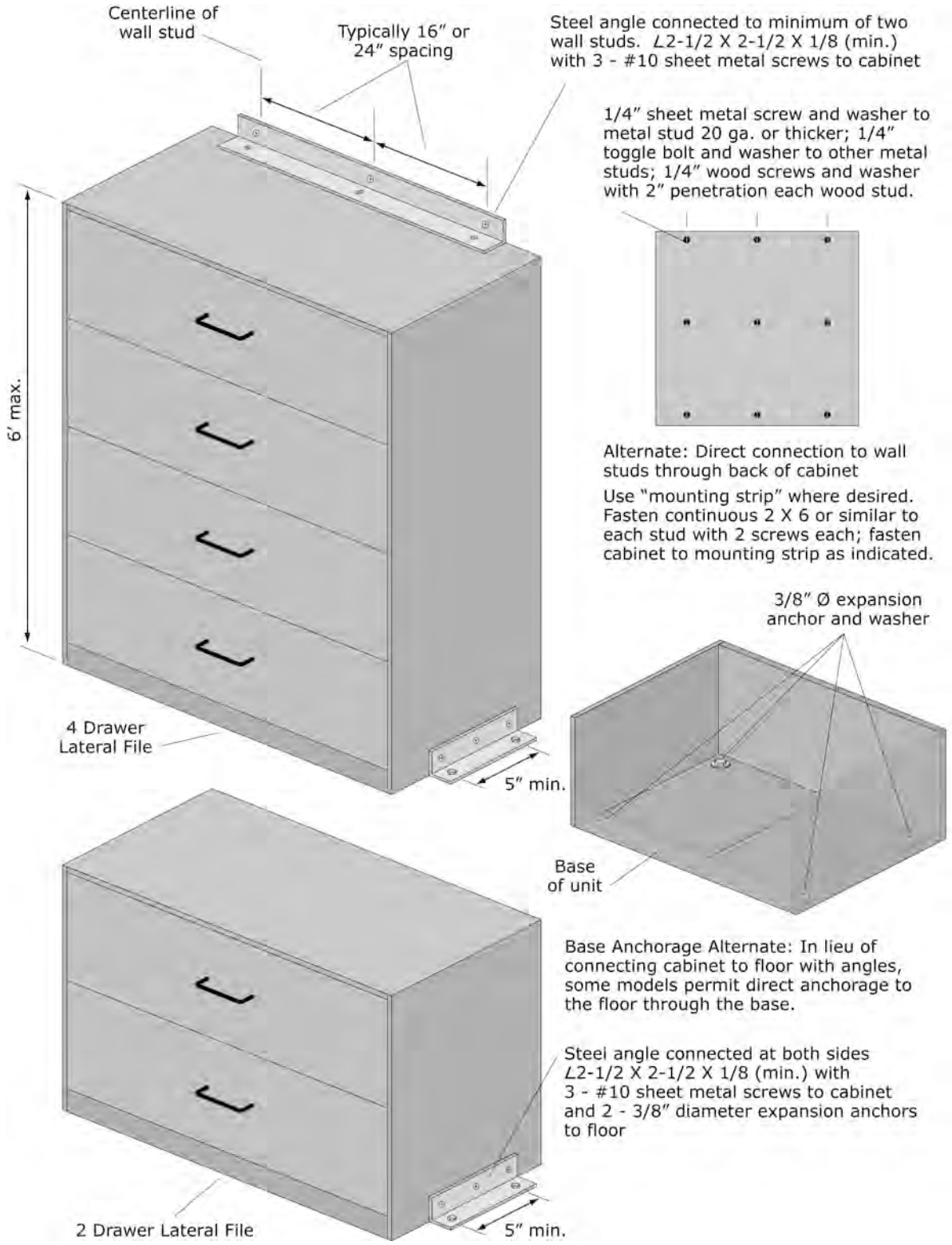


Figure 6.5.5.1-6 Wall-mounted and base-anchored lateral file cabinets (NE).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.5 Miscellaneous Furniture, Fixtures and Equipment

6.5.5.2 Demountable Partitions

These are freestanding half-height partition walls that are often used to delimit office work spaces. These partitions are typically installed by tenants or occupants and may be readily relocated.

Typical Causes of Damage

- Long runs of unbraced panels are vulnerable to falling over if not specially detailed.
- Partitions that support overloaded shelving units are particularly vulnerable.

DAMAGE EXAMPLES



Figure 6.5.5.2-1 Damage to demountable partitions at the Veterans Administration Medical Center in Sepulveda as a result of the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of James O. Malley).



Figure 6.5.5.2-2 Damage to unbraced demountable partition in Silicon Valley office building in the 1989 magnitude-6.9 Loma Prieta Earthquake (Photo courtesy of Maryann Phipps, Estructure).

Seismic Mitigation Considerations

- Check the internet for demountable partitions with seismic rated capacity; some of these have been shake table tested and have improved seismic detailing.
- Panel manufacturers typically have guidelines for acceptable panel configurations for use in earthquake prone areas. Shorter runs of panels with panels at 90 degrees to one another provide favorable conditions for earthquake resistance. Panel anchorage at the base and interconnectivity between panels is also needed for reliable performance.Where panels are not stabilized by return panels, or where panels are tall, bracing at the tops of the panels, up to the structural framing, may be required. Anchorage to the floor slab is another alternative as shown in Figure 6.5.5.2-4.

MITIGATION DETAILS

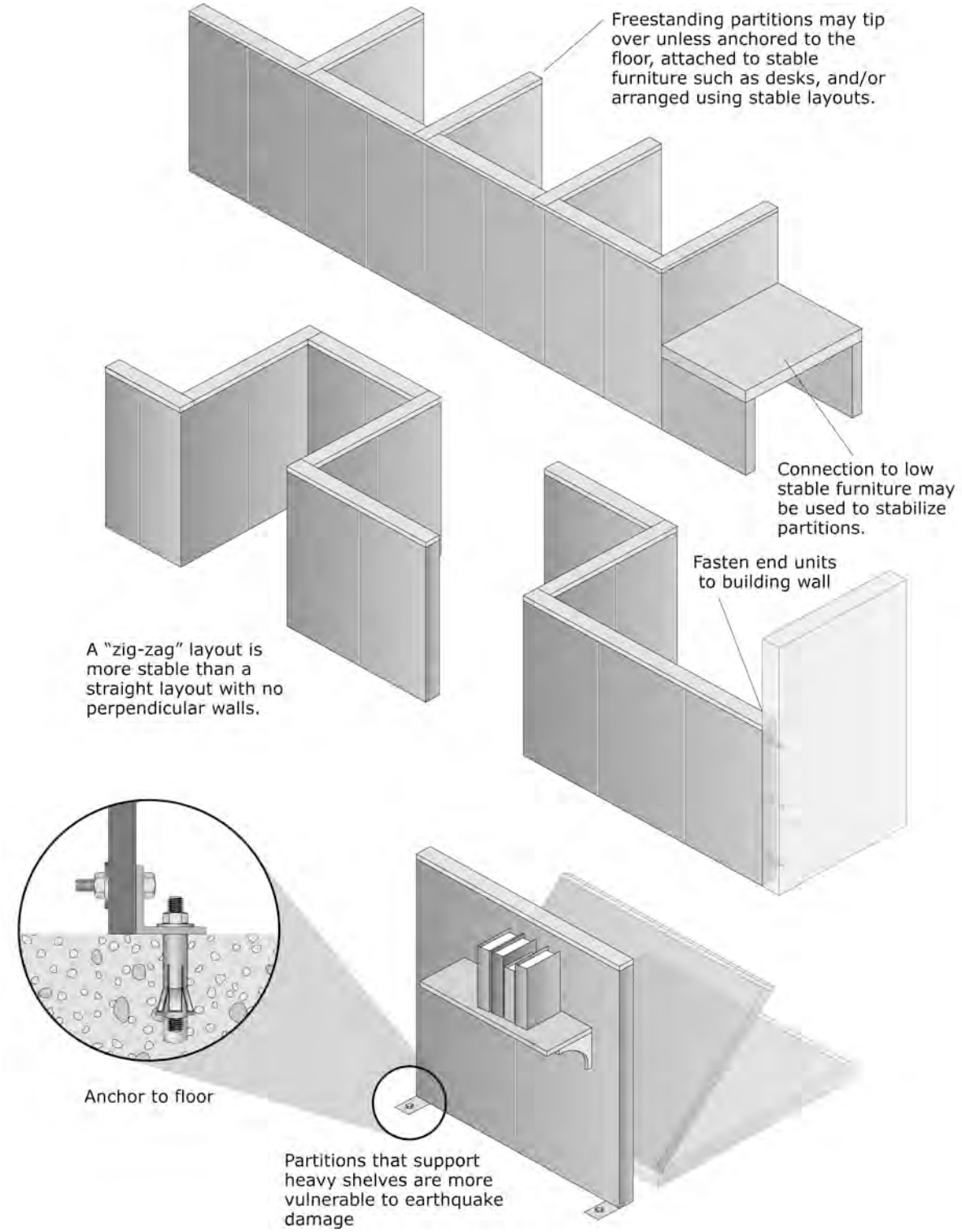


Figure 6.5.5.2-3 Demountable partitions (NE).

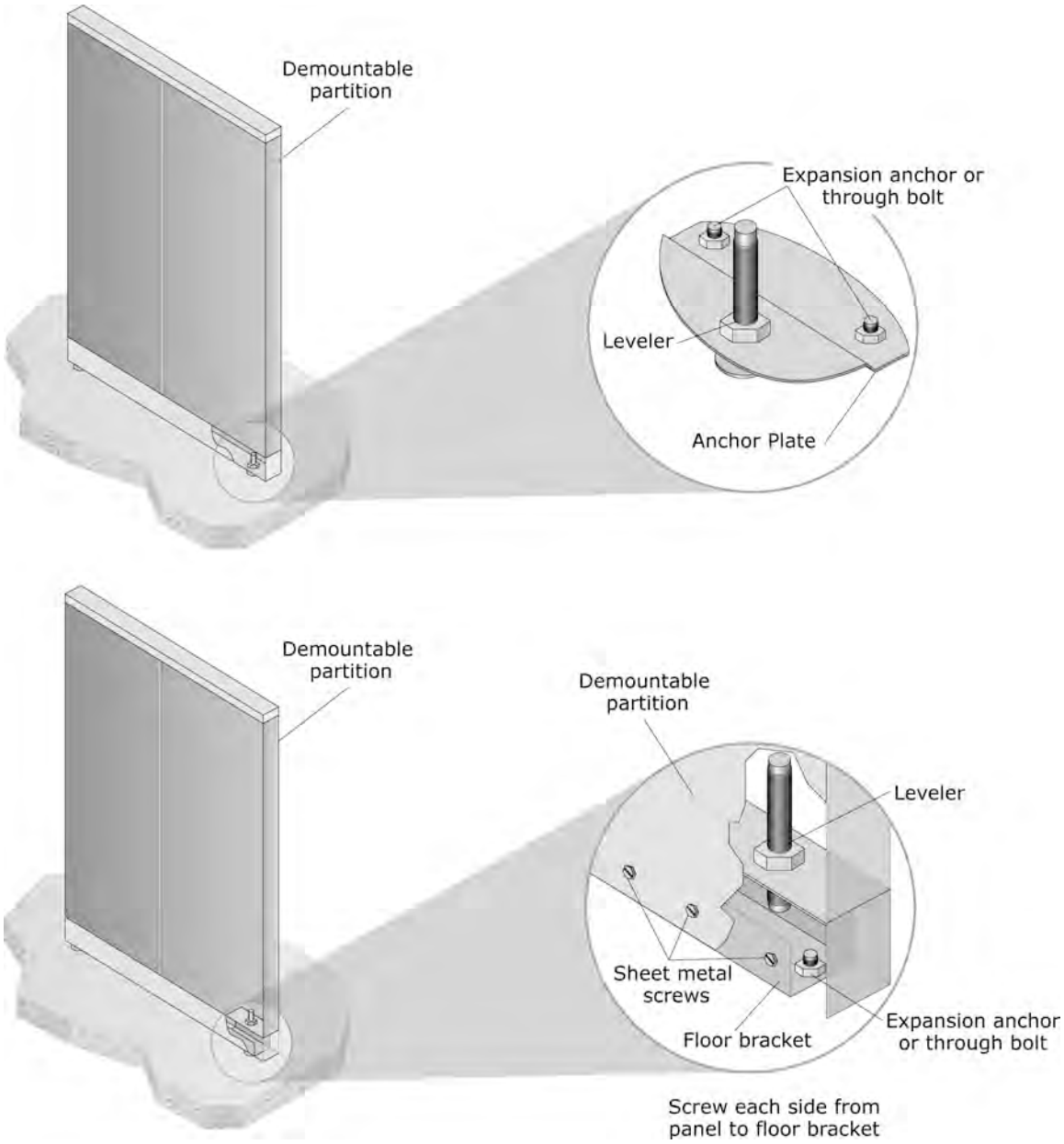


Figure 6.5.5.2-4 Demountable partition details (NE).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.5 Miscellaneous Furniture, Fixtures and Equipment

6.5.5.3 Miscellaneous Furniture and Fixtures

Furniture and fixtures come in all shapes and sizes. Items on castors will roll; squat items are likely to slide; medium height items may slide, rock back and forth, or overturn; tall narrow furniture is likely to overturn. This category provides general recommendations for a wide range of items such as shop and kitchen equipment, vending machines, large office copiers, pianos, china hutches, and entertainment centers.

Typical Causes of Damage

- Unrestrained items may slide, impact other items, tip, and/or overturn. Failure of one item may damage others or cause the collapse of other items.
- Contents supported on furniture or fixtures may fall, break, or spill.

DAMAGE EXAMPLES



Figure 6.5.5.3-1 Residential damage in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Wiss, Janney, Elstner Associates).



Figure 6.5.5.3-2 Existing condition: Unrestrained kitchen equipment (Photo courtesy of EQE for the Salt Lake City School District).



Figure 6.5.5.3-3 Equipment on wheels did well during the 2010 magnitude-8.8 Chile Earthquake; there were no reported injuries or examples of overturning related to equipment mounted on wheels. Centrifuges on wheels shown in photo (Photo and information courtesy of Bill Holmes, Rutherford & Chekene).

Seismic Mitigation Considerations

- Many proprietary items are available to restrain a wide variety of furniture and fixtures. Check the internet for seismic safety fasteners and security restraints.
- Provide floor or wall anchorage for vulnerable items, especially items near doors, exits, beds or other locations where people spend many hours. Anchor freestanding items together and to the floor. Provide tethers for items like kitchen equipment, vending machines, or grand pianos. Provide edge restraints and drawer and cabinet latches.
- Canvas or metal straps can be used to attach some items where it is not acceptable to penetrate the furniture or housing. Multiple tethers may be needed for strength and stability; for instance a tether to only one leg of a grand piano may pull the leg off.
- Where several items need to be tethered and the edges do not line up with studs in the adjacent wall, a continuous steel angle or wood 2x4 may be attached to the wall and

then the tether restraints in turn attached to the steel angle wood stud. Where items are attached to partitions, verify that the partition and attachment or bracing to the structure above are adequate for the imposed loading.

MITIGATION EXAMPLES



Figure 6.5.5.3-4 Anchored wood key cabinets in industrial plant control room; note top and bottom units anchored together and both anchored to wall (Photo courtesy of Eduardo Fierro, BFP Engineers).



Figure 6.5.5.3-5 Typical tethering details for kitchen equipment and vending machines. Tether provided on both sides of equipment and does not penetrate the equipment housing (Photos courtesy of Maryann Phipps, Estructure).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.6 Miscellaneous Contents

6.5.6.1 Shelf-Mounted Items

Loose items stored on bookshelves, shelves of storage racks or cabinets, and store display racks are all vulnerable during earthquakes. This includes retail merchandise, pharmaceutical and medical supplies, laboratory supplies, stored inventory as well as shelved items found in every home, school or office.

Typical Causes of Damage

- Items may slide, break, or fall. Inventory may be damaged, library books and medical records may be scrambled or damaged; broken glass and spilled chemicals may be hazardous for occupants.
- Items falling from shelves can pose a safety hazard for occupants.

DAMAGE EXAMPLES



Figure 6.5.6.1-1 Merchandise fallen from drug store shelving in the 1979 magnitude-6.4 Imperial Valley Earthquake (NGDC, 2009).



Figure 6.5.6.1-2 Items fallen from kitchen cabinets in townhouse near Northridge Fashion Center in the 1994 magnitude-6.7 Northridge Earthquake. An occupant cut her foot on glass when she ran into the kitchen area in the dark when the power was out (NGDC, 2009).

Seismic Mitigation Considerations

- Unless each item is packed tightly or individually restrained, loose material will slide around during an earthquake. Thoughtful organization of shelved items can reduce the potential for damage. For instance,
  - Keep items in their original packaging
  - Place larger and heavier items on lower shelves and lighter and smaller items on upper shelves
  - Provide edge restraints with wood, clear plastic or wire as shown
  - Provide individual restraints for especially toxic or costly items
  - Purchase storage racks or shelving units with shelving that slopes 3–4 degrees towards the back; or attach a thin wedge to each shelf sloping towards the back as this prevents many items from falling to the floor
  - Provide positive latches to prevent cabinet doors or drawers from opening; baby proof latches are one example. Don't keep loose shelved items above a bed, desk or other location that is occupied for long periods of time.
  - In industrial settings, shrink wrapping of goods on pallets may reduce the risk of falling hazards

MITIGATION EXAMPLES



Figure 6.5.6.1-3 High school lab supplies protected on shelving with edge restraints (Photo courtesy of EQE for the Salt Lake City School District).



Figure 6.5.6.1-4 Shelf restraint example; shock cord made of wire and springs used to restrain liquor bottles (Photo courtesy of Robert Reitherman).



Figure 6.5.6.1-5 Plexiglass lip provides restraint for pharmaceuticals (Photo courtesy of Degenkolb Engineers).

MITIGATION DETAILS

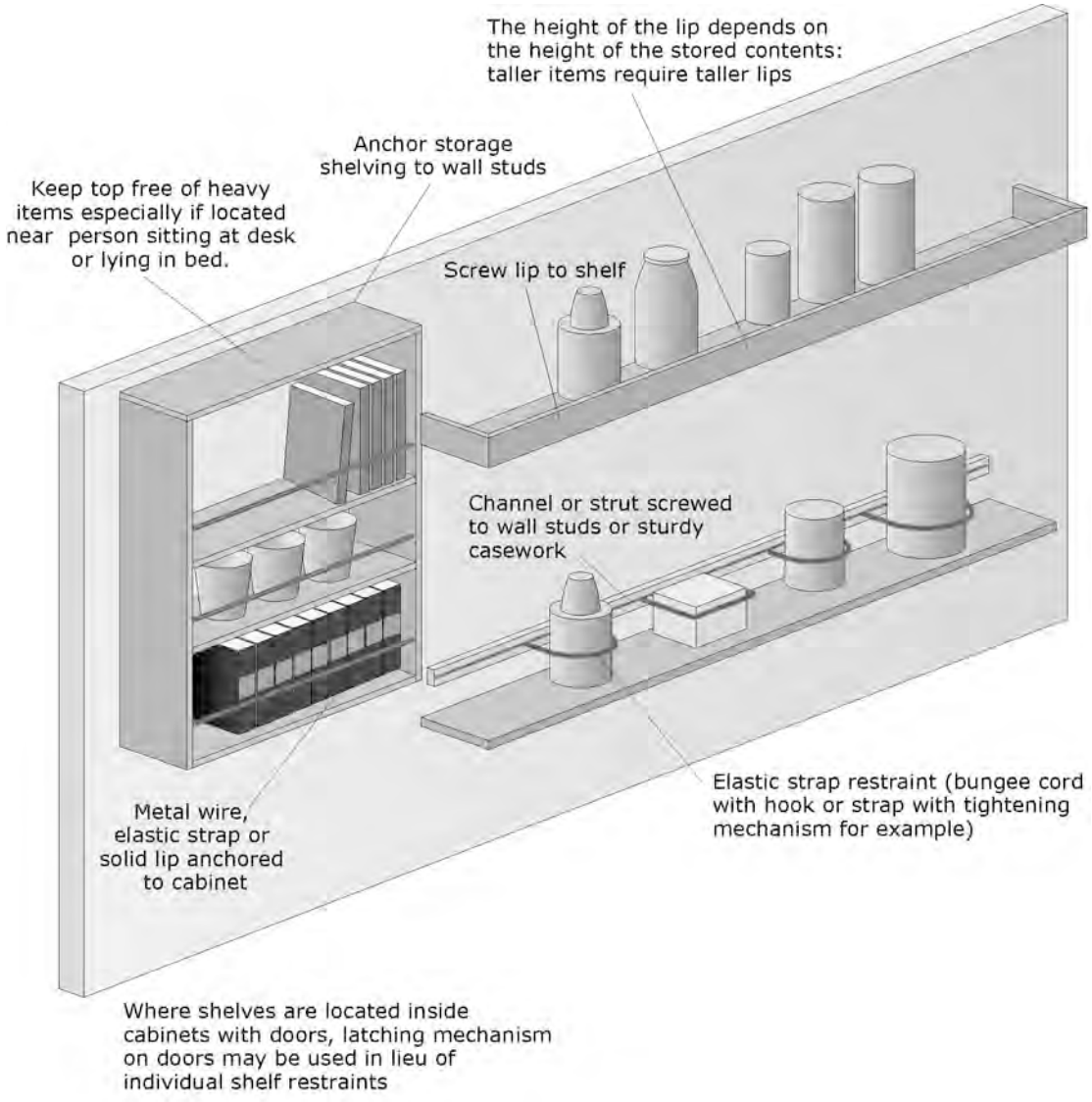


Figure 6.5.6.1-6 Shelf-mounted items (NE).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.6 Miscellaneous Contents

6.5.6.2 DeskTop, CounterTop Items

Many types of office and laboratory equipment items rest on desktops, workbenches or countertops. This may range from microwaves, microscopes, lab and medical equipment to displayed items.

Typical Causes of Damage

- Desktop and countertop items may be affected by movement of the surface on which they are supported; they may slide, bang, overturn, or fall. Equipment and glassware may be damaged or be broken.

DAMAGE EXAMPLES



Figure 6.5.6.2-1 Incubator in the microbiology lab at the University of Concepción was ruined in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Bill Holmes, Rutherford & Chekene).

Seismic Mitigation Considerations

- Provide bracing and anchorage for desks, work benches, and laboratory tables, if located near doors and exits, or if the supported items are required for post-earthquake operations.
- Provide bracing and anchorage for overhead items such as lights, air diffusers, ceilings, and piping that can fall and damage the desktop items.
- Provide tethers, anchors, bumpers, or other safety fasteners to keep desktop items from colliding with other items or falling. Many proprietary devices are available for this purpose; check the internet for seismic safety straps and devices. Many of these are the same as those used for computer equipment. Devices are also available that provide base isolation for individual pieces of delicate or valuable equipment.
- Ensure that any electrical cords or cables have sufficient slack to allow the item to travel to the end of any tether. Tangled cords and cables attached to one item that falls may pull other items down if the cords are tangled; use nylon ties to keep the cords and cables organized.
- Items must be anchored to structural wall or studs; do not use plaster or gypsum board for anchorage. Provide a continuous steel shape or wood 2x4 along the wall at a convenient height anchored to each stud or at 2 foot spacing to facilitate anchorage for multiple items.

MITIGATION EXAMPLES



Figure 6.5.6.2-2 Set-up for shake table testing at UC Irvine of typical laboratory bench and shelving with countertop equipment and shelved books and supplies. Testing was done in order to develop fragility curves for use in developing performance based design parameters (PEER Testbed Study on a Laboratory Building: Exercising Seismic Performance Assessment; Comerio, Editor. PEER 2005/12).

MITIGATION DETAILS

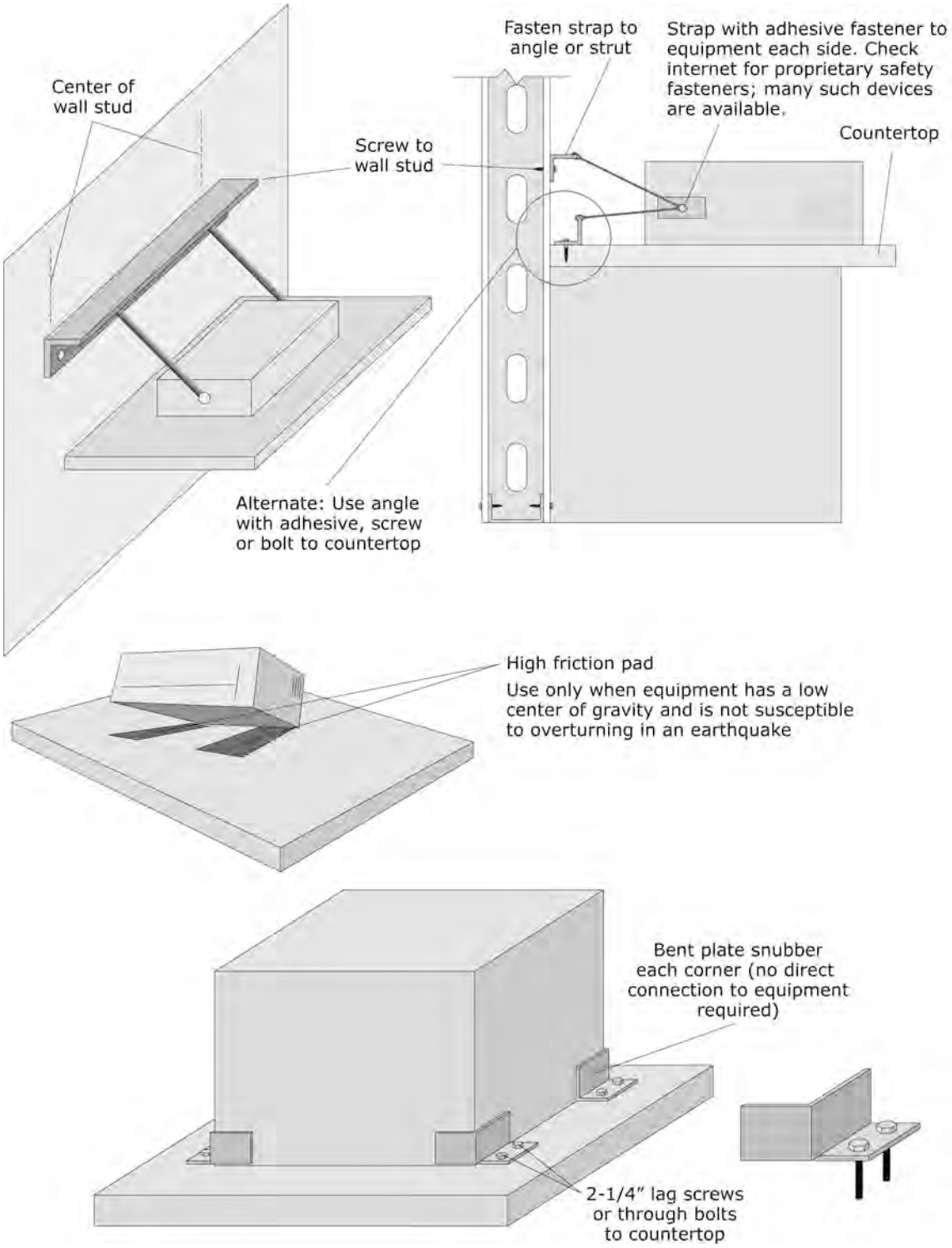


Figure 6.5.6.2-3 Desktop/countertop equipment restraints (NE).

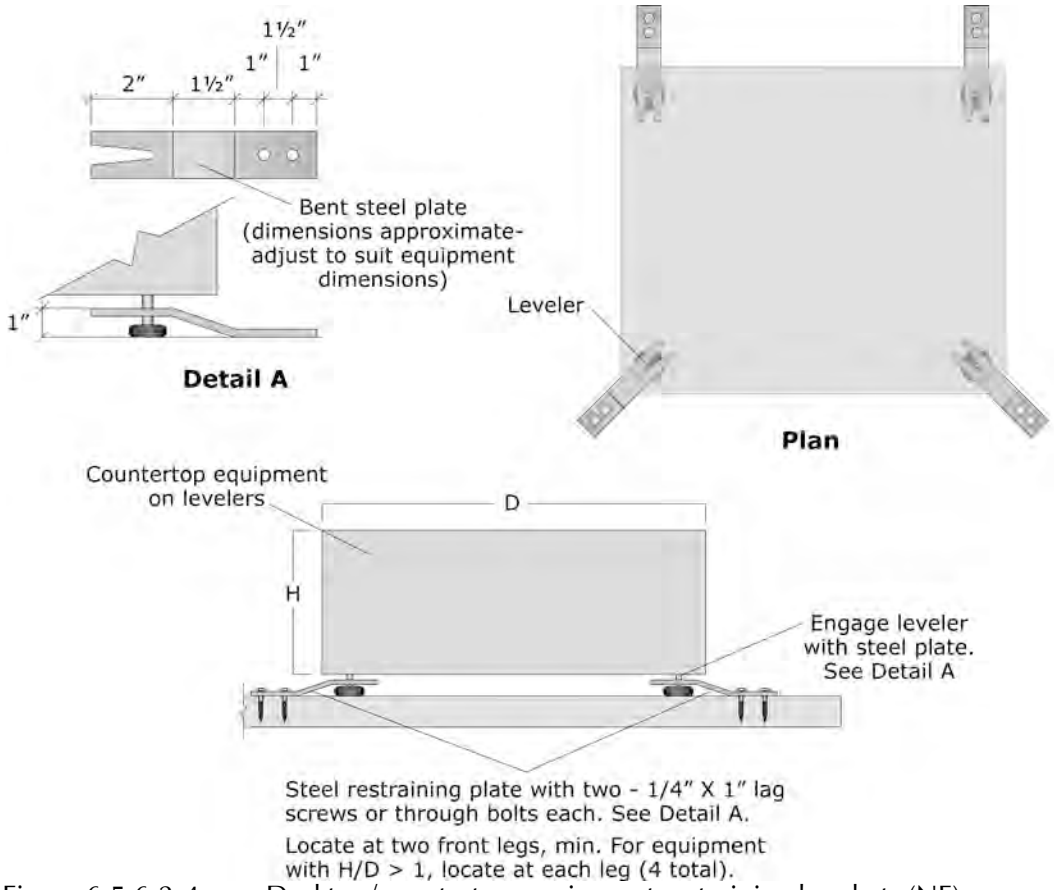


Figure 6.5.6.2-4 Desktop/countertop equipment restraining brackets (NE).

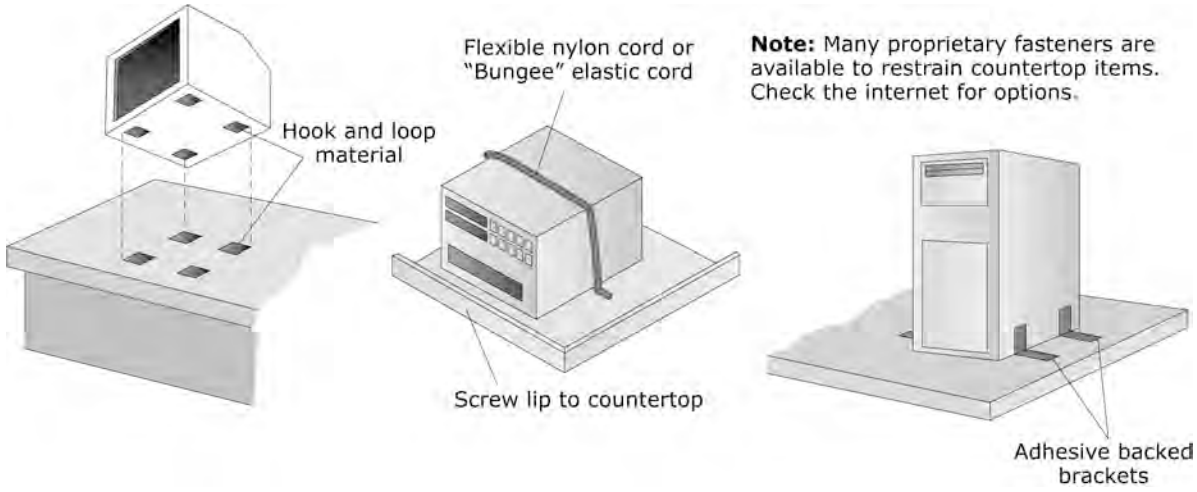


Figure 6.5.6.2-5 Desktop/countertop equipment restraining straps (NE).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.6 Miscellaneous Contents

6.5.6.3 Fragile Artwork

Paintings, vases, glassware, ceramics, sculptures, or museum collections are often stored or displayed without any seismic restraints.

Typical Causes of Damage

- Loose items on shelves or hanging items may slide, bang, overturn or fall. Paintings or other wall hangings may fall Sculptures may slide or fall due to shaking.

DAMAGE EXAMPLES



Figure 6.5.6.3-1 Fallen sculpture that collapsed in the 2010 Chile Earthquake (Photo by Natach Pisarenko, AP Photo).







Figure 6.5.6.3-2 Leaning fountain after the 2010 Chile Earthquake; corrosion was a factor (Photos courtesy of Eduardo Fierro, BFP Engineers).

Seismic Mitigation Considerations

- Many proprietary safety straps, mats, small enclosures, base isolation platforms and other devices are available to protect fragile or expensive art, collectibles and other artifacts. Check the internet for available devices.
- Items hanging on walls should be secured with a positive attachment such as an eyebolt with closed wire loops. Ceramics, glassware, and decorative items on shelves should be individually restrained or provide edge restraint for the shelves. Items hanging from the ceiling should be anchored to structural framing; heavy items should not be located where they can swing and impact a window, wall, or other object. Provide positive restraint for statuary and large vases.Items displayed outdoors must be protected from corrosion and weathering; mounting and connection hardware should be corrosion resistant.
- For protection of valuable items and museum artifacts, seek professional guidance. The J. Paul Getty Museum and Getty Conservation Institute in Los Angeles, California have published a number of references, such as *Advances in the Protection of Museum Collections from Earthquake Damage*, (Podany, 2006) and *Building an Emergency Plan, a Guide for Museums and other Cultural Institutions* (Dorge and Jones, 1999).

MITIGATION EXAMPLES



Figure 6.5.6.3-3a Seven foot tall marble statue located in the Archaeological Museum of Olympia, Greece (Photo courtesy of University at Buffalo).



Figure 6.5.6.3-3b Installation of base isolation devices to support reinforced concrete slab for statue *(Photo courtesy of University at Buffalo)*.



Figure 6.5.6.3-3c Completed installation of statue on platform with base isolation (Photo courtesy of University at Buffalo, SUNY).



Figure 6.5.6.3-4 Seismic restraint of an object with artistic and historical value with nylon filament (fishing line) in the Tokyo Museum in Ueno Park (Photo courtesy of Robert Reitherman, CUREE).

MITIGATION DETAILS

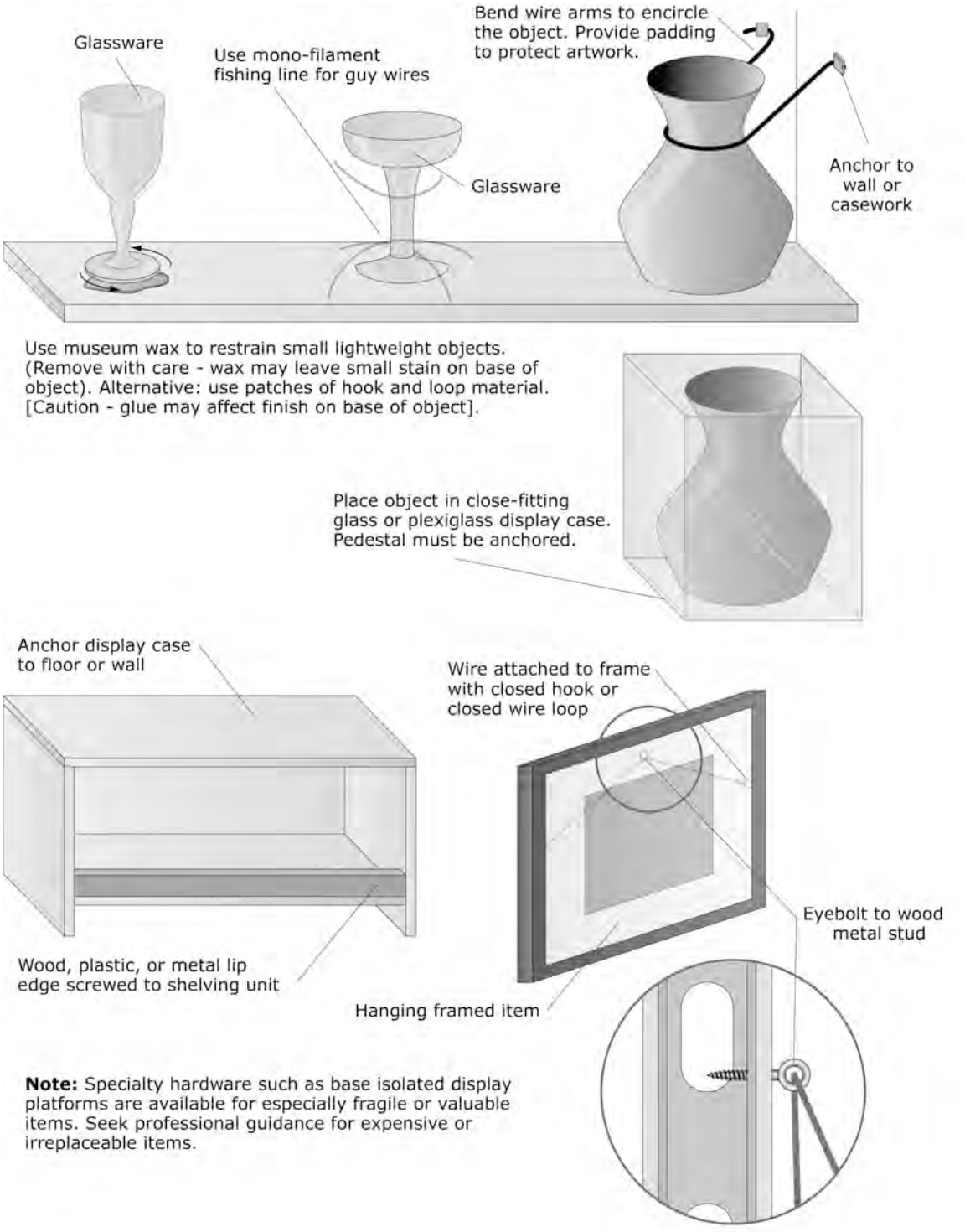


Figure 6.5.6.3-5 Fragile artwork restraints (NE).

6.5 Furniture, Fixtures, Equipment and Contents

6.5.6 Miscellaneous Contents

6.5.6.4 Fire Extinguisher and Cabinet

Fire extinguishers are often hung from a wall-mounted hook or placed in cabinets which may be wall-mounted.

Typical Causes of Damage

- Extinguishers can fall and roll; they may be damaged and not function properly. If located in a glazed enclosure, the enclosure may be damaged and the glass may break.

DAMAGE EXAMPLE



Figure 6.5.6.4-1 Fire extinguishers damaged during the 2010 magnitude-8.8 Chile Earthquake at an industrial facility (Photos courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).

Seismic Mitigation Considerations

- Provide safety fasteners with quick release straps for fire extinguishers.
- Anchor cabinets for extinguishers and hoses to structural wall or studs.

MITIGATION DETAILS

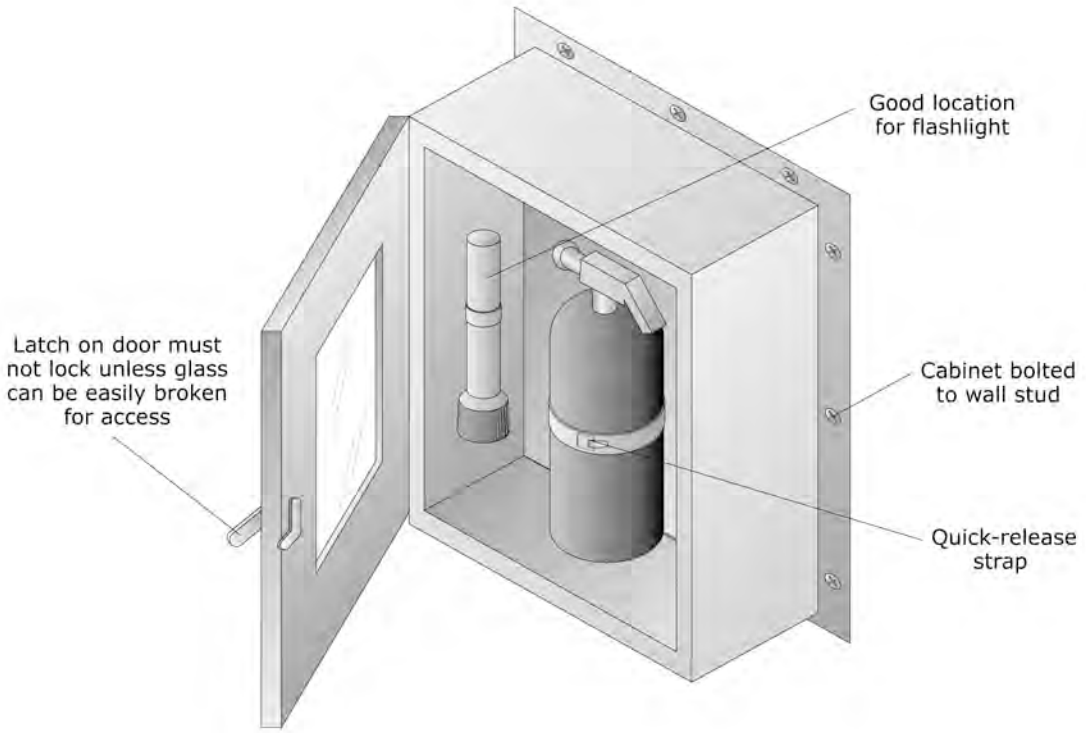


Figure 6.5.6.4-2 Fire extinguisher and cabinet (NE).

6.6 Installation Notes, Safety Warnings, and additional guidelines

For those details for which the non-engineered approach is acceptable, a few words of caution are in order. Many items shown in the upgrade details can be purchased at any hardware store, but it is important to select hardware that is appropriate for the task at hand. A toggle bolt mounted in gypsum board may hold a light picture frame on the wall, but it is not appropriate for any of the details shown in this guide. At the other extreme, a 1-inch diameter bolt is too large for a 2x4 wood stud, since the hole required to accommodate the bolt will unacceptably weaken the 1 1/2- inch wide stud and does not meet the required edge distance in NDS 2005 *National Design Standard Specifications for Wood Construction* (AFPA/ANSI, 2005). The following discussion provides general guidelines on hardware selection and installation procedures for the details shown in this chapter.

FEMA 412 *Installing Seismic Restraints for Mechanical Equipment* , FEMA 413 *Installing Seismic Restraints for Electrical Equipment*, and FEMA 414 *Installing Seismic Restraints for Duct and Pipe* contain additional details for mechanical, electrical, and plumbing components. These guides include lists and tables covering many specific types of MEP equipment with recommendations on the type of detail, housekeeping pads, and anchorage hardware to use. In addition, safety warnings that are important for anyone working on or around electrical equipment are included in these guides; these warnings are repeated here in Section 6.6.8.

6.6.1 Positive Connections

The objective of nonstructural anchorage or restraint details is to provide what engineers refer to as a positive connection between the item and a hard attachment point, such as a structural wall, braced partition, concrete floor, or built-in countertop. Positive connections generally consist of some combination of screws, bolts, cables, chains, straps, steel angles, and other steel hardware that transfer seismic loads to structural framing. Positive connections do not rely solely on the frictional resistance produced by the effects of gravity. Frictional resistance between the base of an object and the floor or mechanical friction connections such as C-clamps or thumbscrew clamps are not considered

Earthquake Forces

Keep in mind that although heavy objects are hard to move by hand, their weight (mass) interacts with the shaking (accelerations) of an earthquake to produce large inertial forces. Those forces mostly act sideways to make the object slide or tip, and there are also vertical motions in earthquakes that temporarily "lighten" an object and reduce frictional resistance.

positive connections. The most common nonstructural connection details for wall attachments, floor or ceiling attachments, countertop attachments, and attachments between adjacent items are discussed below.

6.6.2 Typical Wall Attachment Details

Many types of nonstructural items can be anchored, braced, or tethered to an adjacent wall to provide stability in an earthquake. Before installing any anchorage details, however, one should determine whether the wall has adequate structural capacity to support the nonstructural items. The wall element should consist of concrete, masonry, or structural framing members that are securely attached to the structural framing at both the top and bottom of the wall.

Anchorage to Wood or Metal Stud Partition Walls

Any type of attachment hardware or brace should be attached directly to a structural stud, not to a gypsum board or to plaster wall covering. Gypsum board and most other interior wall coverings have little capacity to resist out-of-plane loading, that is, loads perpendicular to the wall. A nail or screw can simply pull out of this type of wall covering during an earthquake, leaving a hole in the wall. Even a toggle bolt can pull through the wall sheathing if the demands are sufficient.

Typical wood and metal stud walls are constructed with vertical studs located at either 16- or 24-inch spacing. Many interior partition walls in non-residential construction extend only to the ceiling line and should not be used to anchor heavy nonstructural items, unless the top of the partition wall is braced to the structure above. Heavy items anchored to unbraced partitions may bring the partitions down with them, if they fall during an earthquake. Partition bracing should consist of diagonal elements of similar size and material as the vertical studs, spaced every few feet, connecting the top of the partition to the structure above. Engineering advice may be needed if the partitions appear questionable.

The structural studs should be located at the start of a project, to confirm that they are within reach of the items to be anchored. In situations where many items must be anchored to a stud wall, it is sometimes advantageous to install a mounting strip first, in order to avoid having to relocate items to line them up with studs. Sometimes referred to as seismic molding, a mounting strip is a horizontal member mounted to the wall and anchored to each stud. The strip should be located at or near the top of the items to be anchored. Furniture or cabinets may then be anchored directly to the mounting strip without regard to stud locations. A mounting strip may be constructed of a structural-grade wood 2x4 or 2x6 or a continuous steel channel or angle. The strip can be finished to have an appropriate architectural

appearance. In fact, horizontal strips a few feet off the floor were often included in older architectural styles and were called chair rails; even today in many settings, such as hotel conference rooms, there are similar architectural features.

In new construction this is typically accommodated by installing “backing plates” directly on the studs, before sheathing is installed. Backing plates are commonly 16 gauge steel plates, runner tracks or studs.

HARDWARE – RECOMMENDED

- Attach steel angle directly to wood studs using a minimum 1/4-inch diameter by 3-inch lag bolt (maximum 3/8-inch lag bolt). Embed the bolt at least 2 inches into the wood stud.
- Attach steel angle to metal studs using #12 sheet-metal screws long enough to penetrate the flange material. Use two screws per connection, located 3 inches apart vertically.
- Attachments for anchoring sheet-metal shelving or cabinets may be made by using a minimum 1/4-inch diameter machine bolt. Where possible, attach the bolt through two layers of material, for example where the top and side or back and side pieces overlap. Otherwise, use an oversized 2-inch diameter by 3/32-inch thick fender washer with the nut on the inside of the cabinet to provide additional strength.
- For seismic molding, use #14 flat-head wood screws, with countersunk heads, with at least 2 inches embedded into the wood stud behind the wall covering. Locate screws along the centerline of the 2x4 or 2x6, and anchor the strip to each stud with maximum spacing of 24 inches. For attachments to the wood molding strip, do not screw or bolt anything within 1-inch of each edge of the wood member.
- Small quick-release safety hooks (carabiners) and nylon cord or straps, are often available at sporting goods stores that carry mountain climbing equipment. Self-drilling screws may be useful, especially for a connection to metal studs. These items may be used for tethering small office equipment.

HARDWARE - NOT RECOMMENDED

- Toggle bolts mounted in gypsum board or plaster are not recommended for any of the details presented here. They may be useful for items weighing only a few pounds.
- Nails have little capacity in tension or withdrawal, i.e., when pulled directly on the head of the nail. Thus, nails are not recommended for any of these details.

Anchorage to Concrete or Masonry Walls

Connections to existing concrete or grouted masonry walls should be made with steel anchor bolts made to insert into walls after they are built. Many types of anchors are available from various vendors, including expansion anchors, sleeve anchors, and epoxy anchors. Since the installation procedures and capacities for these anchors vary widely, it is important to check the local building code or vendor literature for the allowable load capacity and to install the anchors in accordance with the manufacturer's recommendations. Holes into concrete or masonry walls should be drilled with care, in order to avoid cutting any reinforcing steel (rebar). A magnetic device can be used to locate the steel prior to drilling. If rebar is encountered while drilling, stop, and relocate the hole; **do not cut through the reinforcing steel** unless directed by a structural engineer who has examined the specific condition. In buildings with post-tensioned construction, post-tensioning cables must be positively located prior to anchor installation.

The capacity of an anchor bolt in concrete is governed by the strength of the concrete, the bolt diameter, the depth of embedment of the bolt into the concrete, the spacing between adjacent bolts, and the distance to the edge of the concrete. Improper installation can result in a bolt with virtually no capacity. The bolt will have a greatly reduced capacity if it is too near to an edge or too close to an adjacent bolt, or if it has insufficient embedment into the concrete. In order to develop the full capacity of a concrete anchor, as a rule of thumb, the spacing of the bolts should be at least 12 bolt diameters, with a minimum edge distance of 6 diameters. The minimum embedment length is typically 8 bolt diameters. Specific requirements for edge distance, spacing and embedment depth are determined by anchor manufacturers and code requirementsCaution should be used in selecting anchors to ensure that they have been prequalified for seismic applications and are capable of maintaining their strength under repeated cyclic loading including installations in cracked concrete. The most common post-installed anchors are expansion anchors, where part of the shank expands to press against the sides of the hole as the nut is tightened. Recently, large screw anchors have been gaining popularity. Other types of anchors include sleeve anchors and adhesive anchors. Sleeve anchors consist of a threaded sleeve installed directly into the concrete, flush with the concrete surface, and a bolt that is screwed into the sleeve. Sleeve anchors may be advantageous in situations, in which items may be moved frequently. The bolt may be removed, leaving the sleeve flush with the wall (or floor) and without leaving a protruding bolt. Adhesive anchors are inserted into slightly oversized holes with epoxy or polyester resin so that the adhesive will hold the bolt in place. Extreme care is required to ensure that the epoxy components are mixed in the proper proportions within the hole and that dust is removed from it; otherwise the bolt will never reach the manufacturer's rated capacity. Quality control is critical for all post-

installed anchors. Installation by experienced personnel and inspection by professional inspectors is recommended.

HARDWARE AND PROCEDURES – RECOMMENDED

- Do not cut reinforcing steel, tendons, or electrical conduit embedded in concrete or masonry walls. Locate the steel or conduit prior to drilling. There are many types of devices available for locating steel in concrete or masonry. These devices require the user to be familiar with their limitations.
- Follow manufacturer's recommendations for installation. Remove dust from the hole prior to inserting the anchor bolt by using a hand-held vacuum cleaner; or blow the dust out with a bellows or a bulb.
- For anchorage to reinforced concrete walls, expansion anchors are commonly used.
- To check if an anchor is properly installed, test a sample of installed bolts with a proof load or by torque as required by the manufacturers, test reports, or direction by the design professional of record.
- Use galvanized or preferably stainless steel bolts and other hardware in locations where they will be exposed to moisture or weathering.
- Corrosion resistant chains, eyebolts, and quick-release safety hooks can often be found at marine supply stores, hardware stores, or ordered from industrial catalogues. These fasteners may be needed to provide wall anchorage for gas cylinders or other items stored outside or in a damp location.
- For anchors in walls constructed of concrete masonry units, the expansion anchors should be installed only in grouted cells, where the cavity in the masonry unit is filled with grout and reinforcing steel. In order to achieve adequate embedment into the grout, longer bolts may have to be used in concrete masonry unit walls. Through-bolts, where feasible, generally provide the highest capacity and reliability. These are machine bolts that go through the concrete slab and are fastened with nuts and steel plate washers on the underside of the slab. Unreinforced masonry walls, particularly cantilever partition walls, may not have adequate strength to anchor heavy nonstructural items. For light loads, up to 100 pounds, masonry toggle bolts can be used in ungrouted cells.
- For unreinforced masonry walls, engineering assistance is recommended. Published capacities for expansion anchors typically apply to concrete, not to brick. Anchorage to the floor may be a preferable solution in a brick building.
- Anchorage hardware, installation procedures, and code requirements are continually evolving. Some types of bolts may not be appropriate for overhead applications,

vibratory loading, seismic loading, or cracked concrete applications; check with the manufacturer for recommended usage.

HARDWARE AND PROCEDURES - NOT RECOMMENDED

- Adhesive or epoxy anchors are not recommended, unless they are installed by experienced personnel with proper quality control. Unless specifically tested for high temperature applications, adhesive or epoxy anchors should not be used in unconditioned environments, since their strength can be reduced at elevated temperatures.
- Inserts made of lead or plastic placed in holes drilled in concrete or masonry and used with lag screws have very limited capacity and are not recommended.

6.6.3 Typical Floor and Ceiling Attachment Details

For heavy items, anchorage to a concrete floor slab is often preferable to wall anchorage because it avoids the additional seismic load to the wall. Ceiling attachment details are required for many types of piping, ducts, light fixtures, and overhead fans or heaters. The type of detail used in each situation will depend on the structural materials of the floor and ceiling framing.

Anchorage to Wood Framing

Because wood flooring such as1/2-inch plywood or 1/4 to 3/8-inch strip oak flooring typically does not have adequate strength to resist large concentrated forces, floor or ceiling anchorage hardware should be attached directly to the floor or ceiling beams or joists.

HARDWARE AND PROCEDURES - RECOMMENDED

- Locate the floor or ceiling joists prior to beginning work. If wood beams or joists are not situated within a convenient distance, then wood blocking may be used to provide additional anchor locations. Install blocking perpendicular to the joists, using, as a minimum, a member of the same size as the joists. Anchor the blocking with framing clips to the joists at each end. Do not toenail the blocking.
- Wood screws or lag bolts should be used for simple anchorage connections for lighter items. A 1/4-inch diameter by 3-inch lag bolt will be adequate for many types of connections.
- For anchorage of heavier items to the roof or floor, add blocking beneath the anchor location, run A307 bolts through the blocking, and tighten them on the underside with nuts and washers.

HARDWARE AND PROCEDURES - NOT RECOMMENDED

- Do not anchor heavy items directly to wood or plywood floor or roof sheathing, as these materials typically do not have adequate capacity to resist significant out-of-plane loads.
- Nails are not recommended for nonstructural anchorage details.

Anchorage to Steel Framing

Caution should be used in anchoring nonstructural items to structural steel framing. Engineering expertise may be needed to determine whether holes can be drilled through structural steel framing without compromising the integrity of the structural members. There are several types of connection details that do not require holes through the steel framing. In addition, where steel framing is fireproofed, special measures may be needed to restore the fire rating after connections are made.

HARDWARE - RECOMMENDED

- Vendor catalogues of hardware that can be used to provide both vertical and lateral support for piping often include fittings specifically designed for steel framing. While C-clamps are not recommended, there are a variety of other devices that clamp mechanically around the flange of a steel beam or are designed to fit between column flanges. These devices are typically load-rated by the vendors and come in a variety of sizes. Besides bracing piping and ducts, this type of hardware might also be used for bracing or anchoring items like lights or ceiling fans.

Anchorage to Concrete Floor or Roof Slabs

Concrete expansion anchors are the most common type of hardware used to anchor items to a concrete slab on grade or to a structural floor slab. Most manufacturers require a minimum slab thickness on the order of 1.5 times the anchor embedment depth. For heavy loads or concrete slabs less than 4 inches thick, it may be preferable to use through-bolts.

HARDWARE AND PROCEDURES - RECOMMENDED

- Refer to discussion of expansion anchors under concrete wall anchorage details.
- **Do not cut reinforcing steel or tendons in concrete slabs or beams.** Locate the reinforcing steel, post-tensioning tendons, any embedded water pipes, and electrical conduit prior to drilling holes in concrete slabs.

- For anchorage to a concrete foundation pad, slab on grade, or suspended floor, check the drawings for the thickness of the concrete, or perform exploratory investigation to confirm the thickness. While short expansion bolts may be adequate to prevent sliding of squat equipment, longer bolts with greater embedment are generally needed to prevent the combination of sliding and overturning forces for items that are taller than they are wide.
- If equipment is resting on leveling bolts or must be level to allow for proper operation, then vertically slotted connections may be needed to allow for adjustment.

HARDWARE AND PROCEDURES - NOT RECOMMENDED

Anchors that have not been qualified for seismic applications should not be used unless they are specifically justified by a licensed professional and are permitted for use by the authority having jurisdiction.

6.6.4 Typical Shelf or Countertop Attachment Details

If important or essential contents are to be secured, then the shelf or mounting surface should be secured prior to anchoring nonstructural items. While standard desks and office tables are unlikely to overturn, they may slide during an earthquake. Desktop computers and printers can be anchored to the desk by means of hook-and-loop tape such as Velcro or by using various types of security devices designed to prevent theft.

HARDWARE AND PROCEDURES - RECOMMENDED

- Unanchored desks or tables may slide and pull on the electrical cords of office equipment, if the items are anchored to the tabletop. Electrical cords should have adequate slack to allow for movement of unanchored desks or tables.
- Loose shelves should be secured to the wall or to shelf brackets. Wood shelves that rest on wall-mounted brackets may be secured to the brackets with 1/2-inch long wood screws.
- Many types of vendor-supplied anchorage and security devices are available for computer equipment. These may also be adapted for other types of countertop equipment, such as medical or laboratory equipment. Heavy-duty hook-and-loop tape with adhesive backing can be purchased at most hardware and fabric stores and can readily be cut into strips.
- Desktop computer equipment usually consists of several independent components. If items are stacked, then make sure that each component is anchored to the one beneath it and that the bottommost item is anchored to the desk. For tall configurations of

items that do not have to be moved frequently, it may be more advantageous to tie an assembly of components together using nylon strap and then to anchor the base to the desktop.

- For light and nonessential items on shelves or countertops, a 1- to 2-inch lip secured to the edge of the counter or shelf may be adequate to prevent miscellaneous items from falling. In this case, individual items need not be anchored.

6.6.5 Purchasing

In some instances, it is easier to install nonstructural anchorage details for newly purchased equipment than for existing equipment. Many items are available off the shelf or can be special-ordered with seismic attachment provisions from the manufacturer. Some file cabinets come with predrilled holes for floor anchorage and strong latches on the drawers. Installing a strong shelf over the top of a bank of file cabinets that will line a wall or using other architectural ways to provide built-in restraint can be cost-effective and have a non-seismic benefit. Battery racks, industrial storage racks, and computer access floors that meet seismic requirements specified in the building code can be ordered. It is always useful to inquire about the availability of seismic attachment provisions when purchasing new equipment.

6.6.6 Patching, Painting, and Corrosion Protection

Most of the details shown here assume that the nonstructural component in question is situated in a dry, interior location. In these locations, some cosmetic patching and painting may be desirable, primarily for aesthetic reasons.

For basements, roofs, or other exterior locations, it is important to provide adequate protection from weathering and corrosion. If attachment details perforate a roof membrane, then appropriate sealants or localized repair will be needed, in order to avoid roof leakage. If expansion anchors or other steel hardware will be exposed to moist conditions or weathering, then either stainless steel or galvanized hardware should be selected to avoid corrosion and deterioration. Many types of paints and coatings are available that will help retard corrosion. Exterior earthquake protection devices may need periodic maintenance to avoid deterioration.

In cases where a chain, latch, or tether is installed and users must remove and replace some hardware whenever they need to use the item, it may be helpful to select a bright or distinctive paint color as a reminder that the seismic restraint, chain, or hook needs to be refastened.

6.6.7 Safety Precautions

As with any type of construction work, there are safety precautions that must be followed while installing nonstructural attachment details. Employers and the skilled trades must comply with numerous local, state, and federal safety regulations and follow guidelines established for specific trades or industries. The following list is not comprehensive but is a brief list of safety precautions that merit emphasis in connection with the nonstructural attachment details shown here.

PROCEDURES - RECOMMENDED

- The individuals installing seismic mitigation measures should have adequate training and supervision. Office workers or volunteers may not have the necessary background.
- Electrical hazards are present around any equipment supplied with electrical power. See FEMA 413, *Installing Seismic Restraints for Electrical Equipment* (FEMA, 2004) www.fema.gov/library/viewRecord.do?id=1436.
- Mechanical and electrical hazards are present around machinery that is operating. See FEMA 412, *Installing Seismic Restraints for Mechanical Equipment* (FEMA, 2002), www.fema.gov/library/viewRecord.do?id=1557.
- For guidance on bracing ducts and piping, see FEMA 414, *Installing Seismic Restraints for Duct and Pipe* (FEMA, 2004) www.fema.gov/library/viewRecord.do?id=1437.
- All power to energized equipment must be turned off and verified as energized by a qualified electrician
- Drilling holes into metal cabinets containing electrical components or piping may void the equipment warranty, create an electrical safety hazard or damage the equipment. Care should be taken to protect the equipment when drilling holes and that no debris has fallen into energized portions of the equipment.

6.6.8 Electrical Danger Warnings and guidelines

- Only qualified personnel familiar with proper voltage equipment are to perform work described in this set of instructions. Workers must understand the hazards involved in working with or near electrical circuits.
- Perform work only after reading and understanding all of the installation instructions in this manual and the manufacturer's literature.
- Turn off all power-supplying equipment before working on or inside equipment.
- Always use a properly rated voltage sensing device to confirm that the power is off.

- Beware of potential hazards. Wear Personal Protective Equipment as required by NFPA-70E, *Standard for Electrical Safety in the Workplace* (2009), and take adequate safety precautions.
- Replace all devices, doors, and covers before turning on the power to the equipment.
- All activities must be performed by qualified personnel in accordance with local codes.
- Handle equipment carefully and install, operate, and maintain it correctly in order for it to function properly. Neglecting fundamental installation and maintenance requirements may lead to personal injury, as well as damage to electrical equipment or other property.
- Heavy equipment should be stabilized with straps and other tie-downs to reduce the possibility of tipping.
- Spreader bars must be evaluated by the appropriate design professional prior to lifting.
- When lifting, do not pass ropes or cables through lift holes. Use slings with safety hooks or shackles.
- Damaged vent housings can constrict proper air flow and expose the interior of electrical voltage compartments to weather.
- Do not make any modifications to the equipment or operate the system with interlocks and safety barriers removed. Contact the manufacturer's representative for additional instructions if the equipment does not function as described in this manual.
- Complete seismic installation and proper inspection of work prior to enabling the circuit breakers.
- Use out-of-service tags and padlocks when working on equipment. Leave tags in place until the work is completed and the equipment is ready to be put back into service.
- Restore all seismic restraints removed for maintenance to their original installation configuration and torque all bolts and anchors to their proper values.
- Carefully inspect the work area and remove any tools and objects left inside the equipment.
- Remove all tools, lifting assembly, and miscellaneous items left on the equipment prior to enabling the circuit breaker.
- All instructions provided in this manual and by the manufacturer are written with the assumption that the customer has taken the above measures before performing any maintenance or testing

These electrical danger warnings and guidelines were originally developed for FEMA 413; refer to FEMA 412, 413, and 414 for additional warnings regarding the installation of bracing or anchorage details for MEP equipment, ducts, and piping.

7. POST-EARTHQUAKE DATA COLLECTION

This chapter provides motivation for collection of post-earthquake nonstructural component data and resources for conducting systematic collection of data for two selected nonstructural components.

There have been no publically available systematic, quantitative post-earthquake investigations of nonstructural damage. This is due to the following:

- Focus has been on structural damage;
- Nonstructural damage is perishable since it is cleaned up immediately, leaving little evidence of the original damage;
- Access to the interiors of buildings is limited because the buildings may contain proprietary information or damage that owners do not want to publically share;
- There are many different types of nonstructural components and it is extremely time consuming and complicated to obtain information in sufficient quantity and detail to draw meaningful conclusions on which to change or validate design and/or construction practices; and
- No one has the time or resources to do this.

However, until comprehensive nonstructural damage information is available, the practice will continue to rely on an incomplete understanding of the performance of some nonstructural components and base the designs on standards of practice that may be lacking or even incorrect.

Collection of these data is essential to advancing the protection of nonstructural components. In an effort to provide an initial data collection tool, data collection forms for two of nonstructural components have been developed for use in immediate post-earthquake situations: one for suspended acoustic tile ceilings and one for metal stud partitions. The forms are provided in Appendix F along with instructions. These forms are intended to serve as a starting point for data collection subject to revision and refinement as they are used in the field. Other similar forms can be developed for other systems and components when resources become available.

A. SPECIFICATION

This appendix contains Specification Section 130541, Seismic Restraint Requirements for Nonstructural Components. This Section is intended to aggregate requirements for seismic restraint of nonstructural components and should be cross referenced from each specification section that includes nonstructural components requiring seismic protection. This specification has been written to address nonstructural components for which the Contractor is assigned responsibility for both design and construction. Items that have been explicitly designed by the design team and included on the drawings may be removed from this section, or the relevant section may be modified to indicate that the Contractor is required to furnish and install restraints only.

The specification is intended to be used in conjunction with the responsibility matrices provided in Appendix B to facilitate compliance with nonstructural performance objectives.

The Section is provided as a Microsoft Word file (.doc) file for download here and should be customized for use in projects.

SECTION 130541

SEISMIC RESTRAINT REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS

[NOTE TO SPECIFIER: This section is intended to aggregate requirements for seismic restraint of nonstructural components. It should be cross referenced from each specification section that includes nonstructural components requiring seismic protection. This specification has been written to address nonstructural components for which the Contractor is assigned responsibility for both design and construction. Items that have been explicitly designed by the design team and included on the drawings may be removed from this section, or the relevant section may be modified to indicate that the Contractor is required to furnish and install restraints only.]

PART 1 - GENERAL

1.1 DESCRIPTION

A. Provide seismic restraint of nonstructural components to withstand seismic forces and seismic deformations without displacing or overturning. For designated nonstructural components, provide installations capable of providing post-earthquake functionality.

B. Work in this section includes furnishing and installing complete seismic restraint systems. Work in this section may also include the seismic restraint design and/or equipment/product certifications to be submitted for review by the registered design professional.

1.2 SCOPE

A. The architectural, mechanical, electrical, and plumbing components and systems identified on the following Responsibility Matrix shall be designed and constructed for seismic demands.

[NOTE TO SPECIFIER: Insert the Responsibility Matrix appropriate for the project Seismic Design Category (see Section 1.3A). Explicitly list those components requiring seismic design, specify each component importance factor, I_p, identify the parties responsible for design, preparation of shop drawings and seismic calculations and indicate which components require Special Seismic Certification.]

Figure A-1 Screenshot showing Specification Section 130541, Seismic Restraint Requirements for Nonstructural Components.

B. RESPONSIBILITY MATRIX

This appendix contains responsibility matrix templates for the seismic protection of nonstructural components. The templates are to be used for assigning responsibility for design, construction, and inspection of nonstructural installations governed by ASCE/SEI 7-10. Three separate templates are provided for Seismic Design Categories B, C, and D/E/F, respectively. In addition, a Basic Form is provided for general use. The matrices are intended to be used in conjunction with the construction specification provided in Appendix A.

The matrices are provided as a Microsoft Excel file (.xls) file for download here and should be customized for use in projects.

.

	A	B	C	D	E	F	G	H	I	J
1		RESPONSIBILITY MATRIX								
2		FOR THE SEISMIC PROTECTION OF NONSTRUCTURAL COMPONENTS								
3		SEISMIC DESIGN CATEGORY B								
4										
5		NONSTRUCTURAL COMPONENTS								
6		General categories shown with sample entries (in blue); insert line items for project specific components	Is Seismic Design Required? (yes/exempt)	Component Importance Factor, Ip (See Note 1)	Party Responsible for Design of Seismic Details (See Note 2)	Party Responsible for Preparation of Seismic Shop Drawings (See Note 2)	Party Responsible for Preparation of Seismic Calculations (See Note 2)	Is Special Seismic Certification Required? (See Note 3)	Is seismic design being handled as a Deferred Approval?	Party Responsible for Site Inspection of Installed Component/System
7	ITEM	DESIGNATED SEISMIC SYSTEMS (See Note 1)	Exempt	Ip=1.5				No		
8	S.1	**Component required to function for life-safety purposes after an earthquake, including fire protection sprinkler systems and egress stairways. (per 13.1.3.1)**	**Exempt per 13.1.4.2**							
9										
10	S.2	**Component conveys, supports or contains toxic or explosive substances. (per**	**Exempt per 13.1.4.2**							
11										
12	S.3	**Component in or attached to Risk Category IV structure and is needed for continued operation of the facility or its failure could impair the continued**	**NA**							
13										
14	Note	**Systems in Seismic Design Category B (other exemptions may apply, see ASCE 7-10)**	**Exempt**							
15		Mechanical and electrical components in Seismic Design Category B are exempt from the requirements of Chapter 13 of ASCE 7.	Exempt per 13.1.4							
16										
17										
18	ITEM	STANDARD NONSTRUCTURAL COMPONENTS		Ip=1.0 (UON)						
19		ARCHITECTURAL COMPONENTS								
20	A.1	**Exterior Wall Components**	**Exempt**							
21										
22	A.2	**Interior Partitions**	**Exempt**							
23										
24	A.3	**Ceilings**	**Exempt**							

Figure B-1 Screenshot showing Responsibility Matrix for the Seismic Protection of nonstructural Components, Seismic Design Catergory B worksheet.

C. NONSTRUCTURAL INVENTORY FORM

The intent is that Appendices C, D and E be used together as tools for the facility survey. The first step is to review the map in Figure 3.2.1-1 and discussion in Section 1.3 to see if nonstructural hazard mitigation is a concern for the facility in question. If so, then Appendices C and D can be used in tandem to perform the survey. Risk ratings from Appendix E could be added to the inventory form during the field survey or added later in order to help prioritize the items in the list.

The questions in Appendix D are stated in such a way that the answer "No" or "Unknown" indicates that the component may be noncompliant and likely to pose a nonstructural earthquake hazard. All of the noncompliant components should be entered as individual line items on the facility inventory form in this Appendix. As shown below, the form provides columns for the following information:

- Priority: This can be added at the end after the priorities have been established.
- Nonstructural Item: Name or description of nonstructural component.
- Location: Information such as building, floor, or room number.
- Quantity: Number of items, lineal feet, or square feet.
- Risk Rating for Life Safety (LS), Property Loss (PL) and Functional Loss (FL) from Appendix E.
- Notes: Space for comments regarding the current condition, presence or absence of anchorage details, proximity to other hazardous items, issues with secondary damage such as leaks or hazardous materials release, and whether the component in question is important for functionality of the facility. This might also include a photo number if photos of each item are taken to assist with the survey.

The inventory form provided here has been adapted from the spreadsheet provided by the U.S. Bureau of Reclamation on their website under the heading "Online Orders/Free Tools," http://www.usbr.gov/ssle/seismicsafety/onlineorders.html. The website contains two types of downloadable survey forms: one in spreadsheet format (Microsoft Excel) and one in database format (Microsoft Access). Both of these forms have built-in sorting algorithms so that components with high risk in any category can be shifted to the top of the list. These sorting criteria may be adjusted to suit individual needs. Survey forms can be customized to include cost data, which may be useful for prioritization and planning. Proprietary forms are also available for purchase from specialty vendors.

PRIORITIZED INVENTORY										Rank by LS	Rank by Highest Rank
ID	Description	Location	Quantity	Units	LS	PL	LF	Detail Type	Notes	Rank by PL	
					"H", "M", or "L"			NE, PR, ER		Rank by LF	
1	Bookcase in the south east corner	Room 13	2	each	H	M	M	NE	The two wooden bookcases are unanchored an could tip over during an earthquake blocking egress. Relocate the bookcases away from the doorway or anchor them to the supporting floor or adjacent wall.		
6	Computer monitor	04-N3	1	each	H	H	L	NE	Equipment stored less than four feet above the floor, like this computer monitor, is not a significant life safety hazard. However consideration should be made to securing these types of equipment to the desk top or adjacent wall.		
82	Bookcase	02-12	3	each	H	M	M	NE	Tall shelving or bookcases that have width to height ratios greater than four should be attached to the supporting floor or adjacent wall.		
182	Unreinforced Masonry parapet	South Elevation	50	LF	H	H	L	ER			
13	File cabinets	04-W4	3	each	M	M	M	NE	These flat files are three individual units stacked on top of each other. Without lateral restraints, they can easily slide off each other.		
16	Hot water heater	04-W7	1	each	M	H	L	PR	Gas hot water heaters should be anchored to the floor or adjacent wall to prevent tipping and damage to water and gas lines.		
65	Vending machine	02-15	1	each	M	M	L	NE			
83	Suspended ceiling	02-12	150	SF	M	M	M	PR	The suspended ceiling tiles are supported vertically to the roof structure. There are no lateral tie wires to compensate for lateral loads due to seismicity.		
85	Natural gas supply line	02 North Elevation	200	each	M	M	M	ER	Each gas line that enters the building should have an automatic shutoff valve to prevent escaping gas from feeding a potential fire.		
138	Credenza	04-N4	1	each	M	M	L	NE	The credenza should be anchored to the desk top or adjacent wall to prevent a potential falling hazard.		
63	Computer cabinet	02-14a	1	each	L	H	M	NE	Computer hub should be anchored to the floor or adjacent wall to limit potential damage.		
86	Communication hub	04-W8	1	each	L	L	L	NE	The communication equipment should be stored inside of protective cabinets to prevent potential damage from falling debris.		
178	Desktop computer with monitor	04-E110	2	each	L	M	L	NE	Computers could be placed on the floor to limit potential damage to stored data or the computer's electrical components. The monitor should also be anchored to the desk.		

Figure C-1 Sample inventory checklist for a facility located in an area with Moderate seismic risk. The sorting algorithm of the spreadsheet makes this a useful tool for prioritization. The electronic file is free to download from the U.S. Department of the Interior Bureau of Reclamation's website, http://www.usbr.gov/ssle/seismicsafety/onlineorders.html.

D. CHECKLIST OF NONSTRUCTURAL SEISMIC HAZARDS

This checklist is intended to be used in surveying buildings to assess whether the nonstructural elements (architectural, MEP, FF&E, or contents) pose a danger to the building occupants or are likely to cause financial loss or interruption following an earthquake.

This checklist of nonstructural hazards is intended for use in areas where seismic hazards are a significant concern. Review the discussion in Section 1.3 for the applicability of these nonstructural guidelines and the sidebar in Section 5.3.1 for rules regarding exemptions from the nonstructural provisions in ASCE/SEI 7-10 *Minimal Design Loads for Buildings and Other Structures* (ASCE, 2010) that apply to new construction.

The form includes eight columns marked as follows:

ITEM NO.: ID number to indicate the type of component (architectural, MEP, FF&E or contents) and the subgroup. These numbers are based on the section or subsection in this text and as shown in the tables in Chapter 6.

COMPONENT NAME(S): Name or description of item.

PRINCIPAL CONCERNS: List of problems often associated with this type of item such as falling hazard, water or fuel leakage, broken glass. These concerns should be taken into account when answering the checklist questions. For example, the primary concern for adhered veneer is that it may pose a falling hazard. If a facility has adhered veneer, but only at the base of the building below 6 ft, then this might be checked “Compliance,” if the purpose of the survey is to identify life safety hazards or might be rated “Noncompliance,” if the survey is also intended to help control property damage and limit losses.

EXAMPLE: Example number. All examples, which contain photos and detailed drawings when applicable, can be found in Chapter 6.

COMPLIANCE (C): The questions in this form have been stated in such a way that an affirmative answer indicates that the item is not likely to pose a nonstructural hazard.

NONCOMPLIANCE (NC): The questions in this checklist are stated in such a way that the answer "No" or “Unknown” indicates that the component may be noncompliant and likely to pose a nonstructural earthquake hazard. All of the noncompliant components should be entered as individual line items on the facility inventory form in Appendix A. Comments should

be entered in the survey form noting the location, condition, presence or absence of anchorage details, proximity to other hazardous items, issues with secondary damage such as leaks or hazardous materials release, and whether the component in question is important for functionality of the facility.

NOT APPLICABLE (N/A): This column should be checked if none of the listed items are present and has been included, so that it is clear that the item was not missed or overlooked when performing the survey.

CHECKLIST QUESTIONS: Questions are all "Yes-No" questions, which are answered by checking the appropriate box from among the previous three columns.

6.3	Architectural Components						
Item No.	**Component Name**	**Principal Concerns**	**Example**	**C**	**NC**	**NA**	**Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)**
6.3.1	**Exterior Wall Components**						*[Exterior falling hazards are a primary concern, especially items situated above 10 feet and items that may fall over exits, walkways, or sidewalks.]*
	Adhered veneer	Falling hazard	6.3.1.1				Is the adhered veneer adequately attached to the structure? [This includes relatively thin sections of tile, masonry, stone, terra cotta, ceramic tile, glass mosaic units, stucco, or similar materials attached to a structural wall or framework by means of an adhesive].
							Based on visual observations and/or tapping, is the veneer free of cracked or loose sections that may fall during an earthquake?
	Anchored veneer	Falling hazard	6.3.1.2				Is the anchored veneer adequately attached to the structure? [This includes thicker masonry, stone, or stone slab units that are attached to the structure by mechanical anchors].
							Is the masonry or other veneer supported by shelf angles or other elements at each floor?
							Is the masonry or other veneer connected to a structural back-up wall at adequate spacing?
							Has the veneer been adequately maintained? Are the anchors in good condition, free of significant corrosion, and inspected regularly?
	Prefabricated panels	Falling hazard, damage to panels and connections, broken glass	6.3.1.3				Were the panels and connections designed by an architect or engineer to accommodate the expected seismic distortion of the surrounding structure?
							Are prefabricated cladding panels detailed to allow relative movement between the panel and the structure?
							Are prefabricated panels supported for vertical loads with at least two connections per panel?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are prefabricated panels supported for out-of-plane loads with at least four connections per panel?
							Have the panels been adequately maintained? Are the panel connections in good condition, free of significant corrosion, and inspected regularly?
							Are there adequate separations between panels so they will not come into contact with each other during an earthquake?
	Glazing exterior wall system	Falling hazard, broken glass	6.3.1.4				Is it known that the glazing was designed by an architect or engineer to accommodate the expected seismic distortion of the surrounding structure?
							Do large window panes and storefront windows have safety glass? [All exterior glazing should be laminated, annealed or laminated heat-strengthened safety glass or other glazing system that will remain in the frame when the glass is cracked. This is particularly important for glazing located over 10 feet above an exterior walking surface].
	Glass blocks	Falling hazard, broken glass	6.3.1.5				Are partial-height glass block walls laterally braced to the structure?
							Is the glass block reinforced with panel anchors and panel reinforcing wire?
	Overhead glazing or skylights	Falling hazard, broken glass	6.3.1.6				Are transoms (glass panes over doors) made of safety glass?
							Are skylights made of safety glass or covered with shatter-resistant film?
							Are large panes made of safety glass or is it known whether the glazing assembly was designed by an architect or engineer to accommodate the expected seismic distortion of the surrounding structure?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
6.3.2	**Partitions**						
	Heavy	Falling hazard; collapse or spalling with debris in exitways; large cracks often mistaken for structural damage	6.3.2.1				Are block wall partitions reinforced? [This would include concrete masonry unit (CMU), brick, and hollow clay tile partitions. Most brick and hollow clay tile walls in pre-1933 buildings in California are unreinforced; unreinforced masonry partitions may still be found in current construction in other parts of the country.]
							Are unreinforced masonry walls braced at regular intervals? [In zones of low and moderate seismicity, are partitions braced at 10 foot intervals or less? In zones of high seismicity, are partitions braced at 6 foot intervals or less?]
							Are full-height CMU partitions detailed to allow sliding at the top?
	Light	Cracking of plaster or gypsum board; costly to patch and paint	6.3.2.2				Are partial-height stud wall partitions braced to the structure above the ceiling line?
							Are full-height stud wall partitions detailed to allow sliding at the top?
							If partitions function as lateral support for tall shelving or other nonstructural components, are these partitions adequately anchored or braced to the structure above the ceiling line?
	Glazed	Broken glass	6.3.2.3				Are interior glazed or glass block partitions laterally braced to the structure?
6.3.3	**Interior Veneers**						
	Stone and tile	Falling hazard, debris in exitways	6.3.3.1				Is the adhered veneer adequately attached to the structure?
							Is the anchored veneer adequately attached to the structure?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
6.3.4	**Ceilings, Soffits**						
	Suspended acoustic lay-in tile ceiling	Dropped acoustical tiles, perimeter damage, separation of runners and cross runners; falling hazard if grid and lights come down	6.3.4.1				Does the suspended ceiling have adequate diagonal bracing wires and compression struts to support seismic loads from the ceiling grid plus all lay-in items that do not have independent lateral supports?
							If the ceiling supports lay-in lighting or diffusers, do the lay-in items all have independent vertical supports consisting of wires located at least at two diagonally opposite corners?
							Do lay-in fixtures weighing over 50 pounds additionally have independent lateral bracing wires at all four corners?
							If located in a high seismic zone, is the suspended ceiling supported by a heavy duty ceiling grid with adequate capacity and does the grid include supplemental hanger wires at light fixtures or other mechanical items?
	Directly applied to structure	Falling hazard	6.3.4.2				Are decorative ceiling panels and/or latticework securely attached, particularly beneath exterior eves over exits?
							Are decorative finishes and/or latticework on beam soffits or beneath exterior eves securely attached, particularly over exits?
							For plaster ceilings or stucco soffits, is the wire mesh or wood lath securely attached to the structural framing above?
							Is the plaster or stucco in good condition and not deteriorated by water damage or corrosion?
	Suspended heavy ceilings	Falling hazard	6.3.4.3				If the suspended gypsum board ceiling extends over more than one level, does the suspended ceiling system have adequate diagonal bracing?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Is the suspended wire mesh or wood lath securely attached to the structural framing above?
							Is the plaster ceiling in good condition and not deteriorated by water damage?
6.3.5	**Parapets, Appendages, Roof Tiles**						
	Unreinforced masonry parapet	Falling hazard	6.3.5.1				Are unreinforced masonry parapets adequately braced? [If there is a local parapet ordinance, is it known if the bracing complies with the local ordinance?]
	Parapets, cornices, appendages	Falling hazard					Are parapets and cornices reinforced and adequately braced?
							Do other decorative elements and appendages have positive anchorage to the building?
							Are hanging appendages braced or secured with a safety cable?
6.3.6	**Canopies, Marquees, Signs**						
	Canopy, Marquees, Signs	Falling hazard	6.3.6.1				Are cantilevered elements braced to the structure with steel shapes, not chains, to provide restraint and prevent bouncing?
							Are exterior signs or billboards adequately braced and anchored?
							Are interior signs securely attached with positive connections?
	Flagpoles	Falling hazard					Are flagpoles securely attached to the structure?
6.3.7	**Chimneys and Stacks**						
	Unreinforced masonry chimney	Falling hazard	6.3.7.1				Is the brick chimney restrained with braces to the roof near the top of the chimney?
							Is the brick chimney anchored near the roof line?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Stacks	Falling hazard					Are stacks anchored to the supports or foundation by means of anchor bolts of adequate length and double nuts?
6.3.8	**Stairways**						
	Stairways		6.3.8.1				Do steel stairs in multistory buildings have sliding supports at one end that can accommodate the anticipated interstory displacements?
							Have any unreinforced masonry partitions, piping, or lighting in stairwells been removed, strengthened, encapsulated or braced, especially if the stairway is used as a primary exit route?
6.3.9	**Freestanding Walls or Fences**						
	Freestanding Walls or Fences	Falling hazard if over 4' tall	6.3.9.1				Were freestanding walls or fences designed by an architect/engineer to resist lateral forces?
							Are CMU walls adequately reinforced with vertical bars set in grout-filled cells and horizontal bars embedded in the mortar joints?
							Were CMU walls or fences built with adequate foundations to prevent them from tipping over in an earthquake?

6.4	Mechanical, Electrical and Plumbing Components						
Item No.	**Component Name**	**Principal Concerns**	**Example**	**C**	**NC**	**NA**	**Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)**
6.4.1	**Mechanical Equipment**						
	Boilers, furnaces, pumps and chillers (HVAC wet-side equipment)	Sliding, overturning, broken gas/fuel or exhaust lines, leaking fluids, loss of function	6.4.1.1				Are the boilers, pumps, chillers and similar wet-side HVAC equipment securely anchored to the floor or wall with adequately sized bolts?
							Do HVAC wet-side equipment items that are mounted on vibration isolators have adequate lateral restraint provided by snubbers, bumpers, or restrained vibration isolators?
							Are housekeeping pads under boilers and similar equipment anchored to the floor slab?
							Does the gas line have a flexible connection to the water heater or boiler that is able to accommodate movement?
							Are furnaces, and furnace or boiler bases, constructed without using unreinforced masonry?
	General manufacturing and process machinery	Falling hazards, hazardous material leaks or spills, loss of function	6.4.1.2				Is manufacturing and process machinery and related equipment, cranes, tanks, piping, chutes, and conveyors all adequately restrained and anchored, particularly items that may fall and injure workers, result in hazardous materials release, or create hazardous electrical conditions?
							Have all life safety hazards been addressed by bracing or anchoring clear falling hazards and other hazardous items?
							If immediate occupancy or operations is a project objective, has a design professional familiar with nonstructural anchorage of manufacturing and process machinery been engaged to perform a detailed survey of the plant?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	HVAC equipment with vibration isolation	Fall off isolators, overturning, broken gas/fuel or exhaust lines, leaking fluids, loss of function	6.4.1.3				Do HVAC dry-side equipment items such as air compressors, fans, blowers and filters that are mounted on vibration isolators have adequate lateral restraint provided by snubbers, bumpers, or restrained vibration isolators?
							If large equipment is mounted on a concrete housekeeping pad, is the pad adequately anchored into the structural slab?
							Do roof-mounted HVAC units that are mounted on vibration isolators have adequate lateral restraint provided by snubbers, bumpers, or restrained vibration isolators?
							For roof-mounted units, are the curbs supporting the vibration isolators securely attached to the structural roof framing?
	HVAC equipment without vibration isolation	Sliding, overturning, broken gas/fuel or exhaust lines, leaking fluids, loss of function	6.4.1.4				Is equipment (e.g. gas-fired boiler, commercial water heater, chiller, etc.) securely mounted to the floor, wall, or roof with adequately sized bolts?
							If large equipment is mounted on a concrete housekeeping pad, is the pad adequately anchored into the structural slab?
							Does the gas or fuel line have a flexible connection that is able to accommodate movement?
							For roof-mounted units, are the curbs supporting the vibration isolators securely attached to the structural roof framing?
							Are wall- or window-mounted window air conditioning units securely mounted to the wall or shelf?
	HVAC equipment	Falling or swinging	6.4.1.5				Is suspended equipment braced or anchored independently from the ductwork?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	suspended in-line with ductwork	hazard, separate from ductwork, loss of function					Does the equipment have flexible connections to gas, fuel, or electrical lines?
	Suspended equipment	Gas leak, falling hazard	6.4.1.6				Are the suspended room heaters, especially gas-fired ones, laterally supported?
							Are gas-fired heaters fitted with flexible gas connections?
6.4.2	**Storage Tanks and Water Heaters**						
	Structurally supported tanks and vessels	Tank or vessel rupture, pipe break	6.4.2.1				Is the tank securely attached to the supports?
							Are the tank supports braced in both directions?
							Are the tank supports attached with anchor bolts to concrete walls or foundation pad?
							Is the foundation large enough to keep the tank from sliding or tipping over?
							Is the wall strong enough to support the tank?
	Flat bottom tanks and vessels	Tank or vessel rupture, pipe break	6.4.2.2				Is the tank securely anchored to a concrete slab or foundation?
							Is the foundation large enough to keep the tank from sliding or tipping over?
	Compressed gas cylinders	Gas leak	6.4.2.3				Are all gas cylinders tightly secured with a chain near the top and bottom or otherwise restrained from movement in each direction?
							Are the chains or restraints securely anchored to a wall or counter with screws or bolts rather than clamps?
							If the gas cylinders are attached to piping, are the restraints adequate to prevent damage at the piping connections?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Water heaters	Gas leak, water leak, loss of function	6.4.2.4				Are the water heaters securely anchored to the floor or wall?
							Do the gas lines or electrical conduit and water lines have flexible connections to the water heater that are able to accommodate movement?
							Does the water heater meet the limitations for use of prescriptive restraints? Is the capacity less than 100 gallons and is there a structural wall within 12 inches?
							Does the wall have adequate strength to restrain the water heater?
6.4.3	**Pressure Piping**						
	Suspended pressure piping	Breaks, leaks, loss of function	6.4.3.1				Are the pipes laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
							Are the pipes free of asbestos insulation that could be damaged by movement in an earthquake?
							Are the pipes free of asbestos that would need to be abated before any retrofit work?
	In-line valves and pumps	Loss of function, leaks	6.4.3.2				Are the distribution pumps anchored, or are they mounted on vibration isolation springs with additional seismic lateral restraints?
							Are suspended valves and pumps adequately braced and anchored to structural elements?
	Flexible connections, expansion joints, seismic separations	Breaks, leaks, loss of function	6.4.3.3				Are flexible connections provided where piping connects to rigidly mounted equipment?
							Are flexible connections provided where pipes cross expansion joints or seismic separations between buildings?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are pipe penetrations through structural walls or framing members large enough to allow for some seismic movement?
	Pipe Risers	Breaks, leaks, loss of function	6.4.3.4				Are risers (vertical runs of piping) laterally restrained at each floor level or roughly at 20 foot intervals?
							For risers subject to thermal expansion and contraction, have the seismic supports been designed to allow ample thermal movement?
	Floor-mounted pipe supports	Breaks, leaks, loss of function	6.4.3.5				Are the pipes laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
	Roof-mounted pipe supports	Breaks, leaks, loss of function	6.4.3.6				Are the pipes laterally restrained at reasonable intervals in each direction and do the restraints appear adequate for the roof level? [Accelerations at the roof level are typically higher than at lower levels of a building.]
							Are the curbs and restraints securely attached to the structure and protected from weathering and corrosion?
	Wall-mounted pipe supports	Breaks, leaks, loss of function	6.4.3.7				Are the pipes laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
	Pipe penetrations	Breaks, leaks, loss of function	6.4.3.8				Are pipe penetrations through structural walls or framing members large enough to allow for some seismic movement or are the pipes restrained to prevent impact with the structural element?
6.4.4	**Fire Protection Piping**						
	Suspended fire protection	Damage to sprinkler	6.4.4.1				Are the fire sprinkler piping components laterally restrained in each direction?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	piping	heads, leaks, loss of function					Is the ceiling restrained so the ceilings won't break the sprinkler heads?
6.4.5	**Fluid Piping, not Fire Protection**						
	Hazardous materials	Breaks, leaks, hazardous materials release	6.4.5.1				Is the hazardous material piping laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
							Where required, does the hazardous material piping have double walls, secondary containment, leak detection systems or monitoring and are these systems designed for seismic loading?
							Do the pipes have flexible connections that are able to accommodate relative movement at locations where they are attached to rigidly mounted equipment or where they cross seismic separations?
							Does piping containing fuel or other hazardous materials have a seismic shut-off valve or excess flow valve?
							If the shut-off for the line is manual, is a wrench stored within easy reach?
	Nonhazardous materials	Breaks, leaks, loss of function	6.4.5.2				Is the piping laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
							Do the pipes have flexible connections that are able to accommodate relative movement at locations where they are attached to rigidly mounted equipment or where they cross seismic separations?
6.4.6	**Ductwork**						

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Suspended ductwork	Collapse, separation, leaking, fumes	6.4.6.1				Are the rectangular distribution ducts larger than 6 sq ft in cross sectional area laterally supported in each direction?
							Are circular ducts larger than 28 inches diameter laterally supported in each direction?
							Are the supports and hangers securely attached to the structure?
							Are the distribution ducts able to accommodate movement at locations where they cross separations between buildings?
	Air diffusers	Drop out of ceiling grid	6.4.6.2				Are the air distribution grills or diffusers anchored to adequately supported sheet-metal ducts or to the ceiling grid or wall?
							Do the diffusers have positive restraint, independent of the ceiling grid, such as at least two vertical hanger wires per diffuser?
6.4.7	**Electrical and Communications Equipment**						*Caution: Only qualified personnel should open access panels on electrical equipment.*
	Control panels, motor control centers, switchgear, etc.	Sliding or overturning, broken or damaged conduit or electrical bus	6.4.7.1				Are the control panels, motor control centers, switchgear and similar items all properly anchored to the floor or laterally supported by a structural wall?
							Do the walls used to support these electrical cabinets have adequate strength to restrain these items?
	Emergency generator	Failed vibration isolation mounts; broken fuel, signal, power and exhaust lines; loss of function	6.4.7.2				Is the emergency generator adequately secured, especially if mounted on motor vibration isolation springs?
							Is the concrete housekeeping pad adequately anchored to the structural slab?
							Is the diesel fuel tank adequately braced and anchored? (Refer to additional questions for structurally supported tanks and vessels).

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are the fuel lines, cooling water lines, and exhaust flues for the emergency generator attached with flexible connections that are able to accommodate relative movement at junctions to spring-mounted equipment, at building entry and exit points, and at expansion joints within the building?
							Have all the components of the emergency power generating system and the electrical distribution system been checked as part of this survey?
	Transformers	Sliding, oil leakage, bushing failure, loss of function	6.4.7.3				Are transformers properly anchored to the floor or wall?
	Batteries and battery rack	Batteries fall, rack tips; loss of emergency power	6.4.7.4				Are the batteries securely attached to the battery rack?
							Is the battery rack cross-braced in both directions?
							Does the battery rack have anchor bolts secured to a concrete foundation pad?
							Is the foundation large enough to keep the battery rack from sliding or tipping?
	Photovoltaic power systems	Falling hazard for roof mounted panels	6.4.7.5				Are the solar panels securely anchored to the roof?
							Is the piping laterally restrained?
	Communica-tions equipment	Sliding, overturning, or toppling leading to loss of function	6.4.7.6				Is the microwave communications equipment (antennae, receiver, transmitter, etc.) securely supported and/or anchored?
							Are the components of the public address system and phone system secured?
6.4.8	**Electrical and Communications Distribution Equipment**						

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Electrical raceways, conduit, cable trays	Electrical hazards, loss of function	6.4.8.1				Are the raceways, bus ducts, and cable trays all laterally braced, including both transverse and longitudinal braces at reasonable spacing?
							Are electrical cables or conduit able to distort at the connections with the equipment or where they cross seismic joints between buildings?
	Distribution panels	Electrical hazards, loss of function	6.4.8.2				Are the electrical distribution panels securely anchored to the floor or wall?
6.4.9	**Light Fixtures**						
	Recessed	Falling hazards	6.4.9.1				Are recessed lights securely attached to the ceiling grid to resist seismic shaking and is the ceiling grid adequately braced?
							Do the lay-in fluorescent light fixtures have positive support, independent of the ceiling grid, such as at least two diagonally opposite hanger wires per light fixture?
							Do lay-in fixtures weighing more than 50 pounds have independent lateral support?
							Are lens covers attached or supplied with safety devices?
	Surface-mounted	Falling hazards	6.4.9.2				Are spot lights or track lights securely attached to resist seismic shaking?
							Are exterior light fixtures properly supported or securely attached to the structure?
							Are emergency lights and exit lights mounted to protect them from falling off the wall or off shelf supports?
	Pendant light fixtures	Falling hazard, light fixture or	6.4.9.3				Do chandeliers or other hanging fixtures have safety cables to prevent them from impacting each other or a window?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
		unrestrained bulbs					Are lens covers attached or supplied with safety devices?
							Do pendant or stem light fixtures have safety cables so they will not fall if the fixture sways and breaks the stem connection, or are they braced to prevent swaying?
	Heavy light-fixtures	Falling hazards	6.4.9.4				Are heavy light fixtures, such as operating room lights, adequately braced and anchored to the structure independent of the ceiling system?
6.4.10	**Elevators and escalators**						*Caution: The moving parts or components of these systems need to be evaluated by qualified personnel. Inappropriate seismic restraints may compromise the safe operation of these systems.*
	Hydraulic elevator	Loss of function	6.4.10.1				Are the components of the hydraulic system properly anchored?
	Traction elevator	Loss of function, counter-weights out of guide rails, cables out of sheaves, dislodged equipment	6.4.10.2				Are the cables installed in such a way that they are protected against misalignment during an earthquake?
							Is the elevator cab properly attached to the guide rails?
							Are the counterweights properly attached to the guide rails?
							Are the guide rails securely attached to the building?
							Are the motor and motor control cabinets properly anchored?
							Is the elevator equipped with a seismic switch?
	Escalators	Loss of function	6.4.10.3				Is the escalator control equipment securely anchored?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Is it known if the escalator was designed by an engineer to accommodate relative movement between floors during an earthquake?
							Is the control equipment for the moving walkway properly anchored?
6.4.11	**Conveyors, material handling**						
	Conveyors	Loss of function, falling hazard if elevated, contents fall	6.4.11.1				Are supports for the conveyors properly anchored to the floor or wall?
							Is the conveyor control equipment properly anchored?

6.5	Furniture, Fixtures & Equipment and Contents						
Item No.	**Component Name**	**Principal Concerns**	**Example**	**C**	**NC**	**NA**	**Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)**
6.5.1	**Storage racks**						
	Light duty shelving	Contents fall, shelves damaged	6.5.1.1				Are tall shelving units securely anchored to the floor or walls?
							If walls are used for lateral support, has the capacity of the walls been checked for adequacy to restrain the shelving?
							Are heavily loaded shelving units supported in both directions?
							For shelving units significantly taller than wide, are large anchor bolts used to anchor each leg to a concrete slab?
							Are breakable items secured to the shelves, or are they stored in stable units (e.g., are they shelved in the original packing boxes, or are small items shrink-wrapped together)?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Industrial storage racks	Contents fall, racks damaged	6.5.1.2				Are industrial storage racks braced and anchored to a concrete floor slab or concrete walls?
							If walls are used for lateral support, has the capacity of the walls been checked for adequacy to restrain the shelving?
							Has the capacity of the concrete floor slab been checked for adequacy to resist uplift of the storage racks?
							Are the racks equipped with dampers, base isolation, or other specialized seismic restraint systems?
6.5.2	**Bookcases, Shelving**						
	Bookshelves	Contents fall, shelving damaged	6.5.2.1				Are bookshelves 5' or taller properly anchored with brackets to a solid wall or studs, or anchored to the floor, particularly if they are located next to a bed or desk or where they could block an exit?
							Does the wall or partition used to anchor the book shelves have adequate strength to support seismic loading from the shelving?
							Are bookshelves fitted with edge restraints or elastic cords to keep books from falling?
							Are large and heavy books located on the lowest shelves?
	Library and other shelving	Contents fall, shelving damaged	6.5.2.2				Is it known if the lateral supports for the library stacks and shelving have been designed by an architect or engineer?
							Are library shelving and stacks properly braced and anchored to the floor and walls, including bracing to the floor above if shelving is tall and slender that tie the shelving units together?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							If all shelving units are not independently braced or anchored, are adjacent units fastened together with bolts or other mechanical fasteners?
							Do walls or partitions used to anchor library stacks have adequate strength for the imposed lateral loads?
							Are bookshelves fitted with edge restraints or elastic cords to keep books from falling?
							Are large and heavy books located on the lowest shelves?
							Are rare or fragile books given extra protection to prevent falling and water damage?
6.5.3	**Computer and Communications Equipment**						
	Computer access floors and equipment	Collapse, separation between modules, loss of function	6.5.3.1				Are the support pedestals for computer access floors anchored to the floor and braced with diagonal steel members, or is it verified that the vertical pedestals are a seismically qualified model, installed in accordance with the manufacturer's recommendations?
							Do cable openings in the access floor have edge guards to prevent equipment legs from sliding into the openings
							Are computers, tape racks, and associated equipment that are about twice as tall as wide, anchored, tethered, and/or laterally supported?
							Does heavy computer equipment have supports which are braced and anchored to the structural floor slab independently of the computer access floors?
							Is computer cabling long enough to accommodate lateral movement within the building?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Computer and communication racks	Lost data or damaged equipment may cause downtime	6.5.3.2				Is computer information vital to operations backed up and stored off-site?
							Is critical computer and communications equipment securely anchored to the rack?
							Are computer and communication racks securely anchored to the floor or wall?
							Is sensitive computer or communications equipment located out of range of fire sprinkler heads or joints in the sprinkler pipes where they are less prone to water damage if the sprinkler lines break?
	Desktop computers and accessories	Falling hazard, lost data or damaged equipment may cause downtime	6.5.3.3				Are computers and monitors anchored to desktops?
							Are desktop or countertop computers and printers mounted with positive restraint, resting on high-friction rubber pads, or located far enough from the edges of desks and tables to prevent them from sliding and falling in an earthquake?
	Televisions and video monitors, wall-mounted	Falling hazard	6.5.3.4				Are wall- or overhead-mounted television sets, video monitors, surveillance cameras or sound system speakers securely braced and anchored to the wall or ceiling or equipped with safety cables?
6.5.4	**Hazardous materials storage**						
	Hazardous materials storage	Hazardous material release, mixing of incompatible substances	6.5.4.1				Are chemical supplies secured with shelf lips several inches high, or are they stored in "egg crate" containers in drawers, so that the containers will not overturn or fall and spill?
							Are chemicals stored in accordance with manufacturers' recommendations?
							Are incompatible chemicals stored at an appropriate distance from one another so that they will not mix if the containers are broken?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are the chemicals in each cabinet catalogued properly and marked clearly?
							Are Material Safety Data Sheets (MSDSs) stored in a location separate from the chemicals?
							Are cabinets for hazardous materials securely attached to the floor or to a sturdy wall?
							Has asbestos insulation been removed, or has it been encapsulated to reduce the possibility of damage in an earthquake?
							Is the facility free of asbestos that would need to be abated before any retrofit work?
6.5.5	**Miscellaneous FF&E**						
	File cabinets	Cabinets fall, may block exits, contents spill	6.5.5.1				Do the file cabinet drawers or doors latch securely?
							Are tall file cabinets anchored with wall brackets to a solid wall or studs, anchored to the floor, or bolted to one or more adjacent cabinets to form a more stable configuration, i.e., a larger "footprint"?
							Are unanchored cabinets located so that they will not fall or slide and block a door or exit?
	Demountable partitions	Collapse, block exit path	6.5.5.2				Are demountable partitions attached to each other and arranged in a stable layout with many perpendicular wall segments?
							Are partial-height partitions anchored to the floor?
							If tall shelving or cabinets are located next to the partitions, can these items be moved or independently anchored to the floor or structure?
	Miscellaneous furniture and fixtures	Falling hazard	6.5.5.3				Are tall items located near beds or desks securely anchored to a wall with adequate capacity?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are large kitchen and laundry equipment all securely anchored to the floor, wall, or countertop with adequate capacity?
							Are vending machines tethered a column or wall to prevent tipping and sliding?
							Are unanchored furnishings located where they cannot slide or overturn to block corridors or doors?
							Are heavy wall pictures and other wall hangings well anchored to the studs or structural framing?
							Are heavy hanging plants secured to prevent falling or impact with windows?
							Are personal or storage lockers and vending machines anchored and laterally supported, or are they clear of exits?
6.5.6	**Miscellaneous Contents**						
	Shelf-mounted items	Contents fall, items broken or mixed	6.5.6.1				Are valuable or fragile items protected against tipping or falling off shelving?
							Are the drawers and cabinet doors latched securely, e.g., with special latches or baby-proof hardware that will not fly open in an earthquake?
							Are rare or valuable items (rare books, museum collections, medical records) given extra protection against falling and water damage?
							Are heavy potted plants on file cabinets or tall shelves restrained to prevent falling?
	Desktop, countertop items		6.5.6.2				Is radio equipment restrained to keep it from sliding off shelving or tabletops?
							Is important equipment restrained to keep it from sliding off shelving or tabletops?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are fax machines restrained or placed far enough from the edge that they will not slide and fall off?
							Is the public address system restrained to prevent the equipment from sliding and falling off the shelving?
	Fragile artwork	Loss of rare or expensive art objects, falling hazards	6.5.6.3				Are heavy sculptures anchored to prevent overturning during an earthquake?
							Are heavy wall-mounted paintings, mirrors, or other wall hangings well anchored to structural studs or framing?
							Do hanging sculptures or mobiles have a safety cable to prevent them from swinging excessively, impacting windows or other artwork, or falling?
							Are fragile items restrained by mono-filament lines, hook and loop material, Plexiglas display cases, or some other seismic safety device?
	Fire extinguisher and cabinet		6.5.6.4				Are the fire extinguisher cabinets and/or hose cabinets securely mounted?

	Emergency Systems						
Item No.	**Component Name**	**Principal Concerns**	**Example**	**C**	**NC**	**NA**	**Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)**
	Emergency Egress						*Emergency system components were not covered in the body of the document but are an important consideration for providing earthquake safety.*
	Emergency Egress	Exit doors jammed, corridors blocked, no emergency lighting, falling hazards	6.6.1.1				If primary exit doors are heavy metal fire doors that might jam if the building racks during an earthquake, is there a crowbar or sledgehammer located near the exit to facilitate emergency exiting?
							Do automatic doors with optical or floor sensors and mechanized roll-up doors have a manual override in case of a power outage after an earthquake?
							Are the building utilities and architectural finishes along egress routes (piping, ducts, ceilings, lights, partitions, etc.) braced or anchored adequately to prevent falling obstructions and to keep the egress routes clear after an earthquake?
							Are the furniture and contents along egress routes (desks, supply cabinets, shelving, etc.) braced or anchored adequately to prevent falling obstructions and keep the egress routes clear after an earthquake?
							Are unanchored furniture and contents along egress routes kept far enough from the exits so they will not fall or slide and obstruct the doors?
							Have any unreinforced masonry walls in stairwells, corridors, and elevator enclosures been removed, strengthened, or encapsulated to prevent collapse during an earthquake?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are parapets, canopies, veneers, cornices and any other ornamentation above building exits braced and anchored to prevent collapse?
							Are emergency lights and exit lights securely mounted to protect them from falling off walls or shelf supports during an earthquake?
							Are transoms, skylights, corridor glazing or glazing above exits made of safety glass or covered with shatter-resistant film?
							If the building has elevators, does the elevator have a seismic switch?
	Emergency Power Generation and Distribution System	Loss of function					Is the emergency generator adequately secured, especially if mounted on motor vibration isolation springs?
							Is the concrete housekeeping pad adequately anchored to the structural slab?
							Is the diesel fuel tank adequately braced and anchored?
							Are the batteries and battery racks adequately braced and anchored?
							Are the fuel lines, cooling water lines, and exhaust flues for the emergency generator attached with flexible connections that are able to accommodate relative movement at junctions to spring-mounted equipment, at building entry and exit points, and at expansion joints within the building?
							Have the transformer, MCC, switchgear and bus ducts been checked?
							Have all the components of the emergency power generating system and the electrical distribution system been checked as part of this survey?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Fire Detection and Protection System	Loss of function					Are fire and smoke detectors properly mounted?
							Is the control equipment for the fire alarm system and automatic fire doors securely anchored?
							Are the fire extinguisher cabinets and/or hose cabinets securely mounted?
							Are the fire extinguishers secured with quick-release straps?
							Are the fire sprinkler piping components laterally restrained in each direction?
							Is the ceiling restrained so the ceilings won't break the sprinkler heads?
							Are the distribution lines able to accommodate movement where they cross between buildings?
							Is the fire water pump anchored, or is it mounted on vibration isolation springs with additional seismic restraints?
							Is the emergency water tank or reservoir securely attached to its supports?
							Are the tank supports anchored to the floor and braced in both directions?
							Are the supports or braces properly anchored to the foundation?
							Are the smoke control fans properly supported and/or anchored?
							Are the fan control centers securely anchored?
	Emergency Supply Cabinet	Supplies inaccessible in emergency					Is the cabinet properly braced and anchored to the floor and/or walls?

E. Nonstructural Seismic Risk Ratings

The risk ratings that appear in this Appendix are provided as an aid to establishing priorities. Nonstructural components are organized by component type, and estimates of the potential risk posed by the component are given for different ground shaking intensities. Each component is rated for High (H), Moderate (M) or Low (L) potential risk to Life Safety, Property Loss, and Functional Loss. The seismic risk ratings are based on the following definitions and assumptions:

SHAKING INTENSITY: For a particular geographic location in the United States, the shaking intensity may be estimated by using the seismic map in Figure 3.2.1-1 that shows the areas that are likely to experience minimal, low, moderate, or high ground shaking during future probable maximum considered earthquake events that may affect the areas. The shaking intensity estimates based on the map in Figure 3.2.1-1 should be adequate for items situated at or near the ground in simple, nonessential facilities. For other situations, it may be advisable to choose the next higher shaking intensity or to seek the advice of professional consultants. Note that for areas with light shaking, a full blown upgrade of nonstructural components may not be warranted, unless an owner is particularly risk averse; the current code would not require many of the protective measures recommended herein, even for new construction.

LIFE SAFETY (LS) RISK: Risk of death or direct injury requiring hospitalization.. This does not include the overall impact on life safety systems in a building, such as loss of emergency power in a hospital or loss of fire detection or suppression capability. These disruptions of service are covered under Functional Loss below.

PROPERTY LOSS (PL) RISK: Risk of incurring a repair or replacement cost because of damage to the item. This property loss, as used here, includes the cost of fixing a broken pipe but not the indirect cost of water leakage damage, and includes the cost of repairing a computer but not the loss of business revenue computer downtime might cause. These indirect effects cannot be estimated here on a generic basis.

FUNCTIONAL LOSS (FL) RISK: Risk that the item will not function because it has been damaged. This includes some consideration of the impact of this loss of function of the component on the operation of an ordinary occupancy building. Not included are off-site functional impacts, such as the loss of function of a piece of equipment because of a city-wide

power outage. Outages of power, water, and other utility company or agency services are real problems to consider but are outside the scope of the item-by-item ratings here.

TYPE OF DETAIL: For components where an illustrated example is provided in Chapter 6, the detail type is indicated as Non-engineered (NE), Prescriptive (PR), or Engineering Required (ER). The example number (e.g. 6.3.1.1 for adhered veneer) is shown at the left.

ASSUMPTION 1: The risk ratings are based on the assumption that the item has been installed without seismic bracing, seismic anchorage, seismic restraint, or allowance for differential movements. In areas of the U.S. where seismic building code provisions have only recently been enforced, this assumption will be generally true. In areas of the western U.S. where seismic codes have been enforced for some time, this assumption may not always be true. Particularly in buildings constructed in the western states since the mid-1970s, some nonstructural items may be anchored or braced, but the assumption of unanchored and unbraced items will still be true for many items on these lists.

ASSUMPTION 2: The item is assumed to be located at or near the ground level, or in a low-rise building. The most common case of a relatively stiff low-rise building with structural walls is presumed in the ratings here. Items such as full-height partitions and glazing are more likely to be damaged in flexible buildings that experience large lateral deformations. Damage to items sensitive to imposed deformation will be greater in buildings or portions of buildings that are more flexible, such as mid- and high-rise buildings; flexible frame buildings without significant structural walls; "soft stories" of buildings with structural walls in most stories but with a story, typically the ground story, that is much less laterally stiff because of the absence of walls; and the "soft wall" sides of bearing wall buildings where there is little or no solid wall area, such as the face of a typical commercial storefront building.

ASSUMPTION 3: For building occupancy, an ordinary occupancy category is assumed. Thus, in the case of essential or specialized facilities, some nonstructural components would be rated differently. For example, in this appendix the risk ratings are given for shelving in an ordinary occupancy building, but the same shelving would be rated quite differently with regard to Life Safety risk in a lab, Property Loss risk in a museum, or risk of Functional Loss in a communications center.

For most of the nonstructural components listed below, the risk ratings for those components would be reduced significantly if the components were installed or retrofitted in accordance with recommendations of Chapter 6 or were installed within a seismically isolated building.

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.3	Architectural Components					
6.3.1	Exterior Wall Components[1]					
6.3.1.1	Adhered veneer	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.3.1.2	Anchored veneer	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.3.1.3	Prefabricated panels	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	M	
6.3.1.4	Glazed exterior wall system	Low	L	L	L	ER
		Mod	M	M	L	
		High	H	M	M	
6.3.1.5	Glass blocks	Low	L	L	L	ER
		Mod	M	M	L	
		High	H	H	M	
N/A	Overhead glazing or skylights	Low	L	L	L	
		Mod	H	M	L	
		High	H	M	M	
6.3.2	Partitions[2]					
6.3.2.1	Heavy (CMU, brick, hollow clay tile)	Low	L	L	L	ER
		Mod	H	H	H	
		High	H	H	H	
6.3.2.2	Light (partial- or full-height stud wall partitions)	Low	L	L	L	ER
		Mod	M	M	M	
		High	M	H	H	
6.3.2.3	Glazed	Low	L	L	L	ER
		Mod	M	M	L	
		High	M	H	M	
6.3.3	Interior Veneers[2]					
6.3.3.1	Stone and tile	Low	L	L	L	ER
		Mod	H	H	M	
		High	H	H	M	
6.3.4	Ceilings					
6.3.4.1	Suspended acoustic lay-in tile	Low	L	L	L	PR

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
	ceiling	Mod	L	M	M	
		High	M	H	H	
6.3.4.2	Directly applied to structure	Low	L	L	L	
		Mod	M	M	M	NE
		High	M	H	H	
N/A	Soffits (stucco, gypsum board, plaster)	Low	L	L	L	
		Mod	M	M	M	
		High	H	H	H	
6.3.4.3	Suspended heavy ceilings	Low	L	L	L	
		Mod	M	M	M	PR
		High	H	H	H	
6.3.5	**Parapets, Appendages, Roof Tiles**					
6.3.5.1	Unreinforced masonry parapet	Low	M	M	L	
		Mod	H	H	L	ER
		High	H	H	L	
N/A	Parapets, cornices, decoration	Low	M	M	L	
		Mod	H	H	L	
		High	H	H	L	
N/A	Hanging appendages	Low	L	L	L	
		Mod	H	H	L	
		High	H	H	M	
N/A	Clay roof tiles[1]	Low	L	L	L	
		Mod	L	M	L	
		High	M	H	M	
6.3.6	**Canopies, Marquees, Signs**					
6.3.6.1	Canopies, Marquees, Signs	Low	L	L	L	
		Mod	H	H	L	ER
		High	H	H	M	
N/A	Heavy signs or exterior billboards	Low	L	L	L	
		Mod	H	H	L	
		High	H	H	L	
N/A	Flagpoles	Low	L	L	L	
		Mod	L	L	L	
		High	M	L	L	
6.3.7	**Chimneys and Stacks**					
6.3.7.1	Unreinforced masonry chimney	Low	L	L	L	
		Mod	M	M	L	ER

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
		High	H	M	M	
N/A	Stacks, small	Low	L	L	L	
		Mod	M	M	L	
		High	H	M	M	
6.3.8	**Stairways**					
6.3.8.1	Stairways	Low	L	L	L	
		Mod	H	M	M	ER
		High	H	M	H	
6.3.9	**Freestanding Walls or Fences**					
6.3.9.1	Freestanding Walls or Fences	Low	L	L	L	
		Mod	L	L	L	PR
		High	M	H	M	
6.4	**Mechanical, Electrical, & Plumbing Components**					
6.4.1	**Mechanical Equipment**					
6.4.1.1	Boilers, furnaces, pumps and chillers (HVAC wet side)	Low	L	L	L	
		Mod	L	L	L	ER
		High	M	M	H	
N/A	Boilers and furnaces (rigid mount)	Low	L	L	L	
		Mod	L	L	L	
		High	M	M	M	
N/A	Chillers	Low	L	L	L	
		Mod	L	L	L	
		High	L	M	H	
N/A	Heat pumps or heat exchangers	Low	L	L	L	
		Mod	L	L	L	
		High	L	M	M	
6.4.1.2	General manufacturing and process machinery	Low	L	L	L	
		Mod	M	M	M	ER
		High	M	H	H	
6.4.1.3	HVAC equipment with vibration isolation	Low	L	L	L	
		Mod	L	M	L	ER
		High	L	M	M	
N/A	Fans, blowers, filters	Low	L	L	L	
		Mod	L	M	L	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
		High	L	M	M	
N/A	Air compressors	Low	L	L	L	
		Mod	L	M	L	
		High	L	M	M	
N/A	Roof mounted HVAC units	Low	L	M	L	
		Mod	L	M	L	
		High	M	H	M	
N/A	Roof mounted equipment, vents or flues	Low	L	L	L	
		Mod	L	M	L	
		High	M	M	M	
6.4.1.4	HVAC equipment without vibration isolation (rigid mount)	Low	L	L	L	ER
		Mod	L	L	L	
		High	L	M	M	
N/A	Wall-mounted room air conditioning units	Low	L	L	L	
		Mod	M	M	L	
		High	M	M	L	
6.4.1.5	HVAC equipment suspended in-line with ductwork	Low	L	L	L	ER
		Mod	L	M	L	
		High	L	M	M	
6.4.1.6	Suspended equipment	Low	L	L	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.4.2	**Storage Tanks and Water Heaters**					
6.4.2.1	Structurally supported tanks and vessels	Low	L	L	L	ER
		Mod	M	H	M	
		High	M	H	M	
N/A	Diesel fuel tank	Low	L	L	L	
		Mod	H	H	L	
		High	H	H	M	
N/A	Propane tank	Low	L	L	L	
		Mod	H	H	M	
		High	H	H	M	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.4.2.2	Flat bottom tanks and vessels	Low	L	L	L	
		Mod	M	H	M	ER
		High	M	H	M	
6.4.2.3	Compressed gas cylinders (oxygen, CO_2, ammonia, etc.)	Low	L	L	L	
		Mod	M	M	L	NE
		High	H	M	M	
6.4.2.4	Gas water heaters	Low	L	L	L	
		Mod	M	H	L	PR
		High	H	H	L	
6.4.3	**Pressure Piping**					
6.4.3.1	Suspended pressure piping	Low	L	L	L	
		Mod	M	M	M	ER
		High	M	H	M	
6.4.3.2	In-line valves and pumps	Low	L	L	L	
		Mod	M	M	M	ER
		High	M	M	M	
6.4.3.3	Flexible connections, expansion joints and seismic separations	Low	L	L	L	
		Mod	M	M	M	ER
		High	M	M	M	
6.4.3.4	Pipe Risers	Low	L	L	L	
		Mod	L	M	M	ER
		High	M	M	M	
6.4.3.5	Floor-mounted supports	Low	L	L	L	
		Mod	L	M	M	ER
		High	M	M	M	
6.4.3.6	Roof-mounted supports	Low	L	L	L	
		Mod	L	M	M	ER
		High	M	M	M	
6.4.3.7	Wall-mounted supports	Low	L	L	L	
		Mod	M	M	M	ER
		High	M	M	M	
						ER
6.4.4	**Fire Protection Piping**					
6.4.4.1	Suspended fire protection	Low	L	M	M	ER

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
	piping					
		Mod	L	H	H	
		High	M	H	H	
6.4.5	**Fluid Piping, not Fire Protection**					
6.4.5.1	Hazardous materials	Low	L	L	L	
		Mod	H	H	H	ER
		High	H	H	H	
N/A	Fuel line	Low	L	L	L	
		Mod	H	H	L	
		High	H	H	M	
6.4.5.2	Nonhazardous materials	Low	L	L	L	
		Mod	M	M	M	ER
		High	M	M	M	
6.4.6	**Ductwork**					
6.4.6.1	Suspended Ductwork	Low	L	L	L	
		Mod	L	L	L	ER
		High	M	M	L	
6.4.6.2	Air diffuser	Low	L	L	L	
		Mod	M	M	L	NE, ER
		High	M	HM	L	
6.4.7	**Electrical and Communications Equipment**					
6.4.7.1	Control panels, motor control centers and switchgear	Low	L	L	L	
		Mod	L	L	L	ER
		High	M	M	M	
6.4.7.2	Emergency generator	Low	L	L	M	
		Mod	L	M	H	ER
		High	L	H	H	
6.4.7.3	Transformers	Low	L	L	L	
		Mod	L	L	L	ER
		High	M	M	M	
6.4.7.4	Batteries and battery rack	Low	L	L	L	
		Mod	L	H	M	ER
		High	L	H	H	
6.4.7.5	Photovoltaic power systems (Solar panels)	Low	L	L	L	
		Mod	L	L	L	ER

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
		High	M	M	L	
6.4.7.6	Communication antennae	Low	L	L	L	ER
		Mod	L	M	L	
		High	M	H	M	
6.4.8	**Electrical and Communications Distribution Equipment**					
6.4.8.1	Electrical raceways, conduit, and cable trays	Low	L	L	L	ER
		Mod	L	M	M	
		High	M	M	M	
6.4.8.2	Distribution panels	Low	L	L	L	ER
		Mod	L	L	L	
		High	M	M	M	
6.4.9	**Light Fixtures**					
6.4.9.1	Recessed	Low	L	L	L	PR
		Mod	H	L	L	
		High	H	M	M	
6.4.9.2	Surface-mounted lighting	Low	L	L	L	PR
		Mod	H	L	L	
		High	H	M	M	
6.4.9.3	Pendant light fixtures	Low	L	L	L	NE
		Mod	H	L	L	
		High	H	M	M	
6.4.9.4	Heavy light fixtures	Low	L	L	L	NE
		Mod	H	L	L	
		High	H	M	M	
N/A	Exterior lighting	Low	L	L	L	
		Mod	M	L	L	
		High	M	M	M	
6.4.10	**Elevators and Escalators**					
6.4.10.1	Hydraulic Elevator (cab and elevator equipment)	Low	L	L	L	ER
		Mod	L	M	M	
		High	M	M	M	
6.4.10.2	Traction Elevator (elevator cab and shaft doors)	Low	L	L	L	ER
		Mod	L	M	M	
		High	M	M	H	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
N/A	Cables, counterweights and guide rails (for cable-traction system)	Low	L	L	L	
		Mod	H	M	M	
		High	H	M	M	
N/A	Elevator motor and motor control cabinets	Low	L	L	L	
		Mod	L	M	M	
		High	L	H	M	
6.4.10.3	Escalator	Low	L	L	L	
		Mod	M	M	M	ER
		High	H	H	H	
6.4.11	**Conveyors**					
6.4.11.1	Conveyors	Low	L	L	L	
		Mod	L	M	M	ER
		High	M	M	M	
6.5	**Furniture, Fixtures, & Equipment**					
6.5.1	**Storage racks**					
6.5.1.1	Light duty shelving	Low	L	L	L	
		Mod	H	M	M	NE, ER
		High	H	M	M	
6.5.1.2	Industrial storage racks	Low	L	L	L	
		Mod	H	M	M	ER
		High	H	H	M	
6.5.2	**Bookcases, Shelving**					
6.5.2.1	Bookshelves	Low	L	L	L	
		Mod	H	M	M	NE
		High	H	M	M	
6.5.2.2	Library and other helving	Low	L	L	L	
		Mod	H	M	M	ER
		High	H	M	M	
6.5.3	**Computer & Communications Equipment**					
6.5.3.1	Computer access floors	Low	L	L	L	
		Mod	L	L	M	ER
		High	M	H	H	
N/A	Large computer equipment	Low	L	L	L	
		Mod	L	M	M	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
		High	M	H	M	
N/A	Computer networks, data storage	Low	L	L	L	
		Mod	L	M	H	
		High	L	H	H	
N/A	Computer cabling	Low	L	L	L	
		Mod	L	L	L	
		High	L	L	L	
6.5.3.2	Computer and communication racks	Low	L	L	L	NE
		Mod	L	H	M	
		High	M	H	M	
6.5.3.3	Desktop computers and accessories	Low	L	L	L	NE
		Mod	L	H	M	
		High	L	H	M	
6.5.3.4	Television and video monitors, cameras, wall-mounted	Low	L	L	L	NE
		Mod	H	H	L	
		High	H	H	L	
N/A	Suspended speakers in conference room or auditorium	Low	L	L	L	
		Mod	M	M	L	
		High	H	H	L	
6.5.4	**Hazardous materials storage**					
6.5.4.1	Hazardous materials storage, cabinet and contents	Low	L	L	L	NE
		Mod	H	M	H	
		High	H	M	H	
N/A	Chemical, laboratory, medical supplies	Low	L	L	L	
		Mod	H	M	L	
		High	H	M	M	
N/A	Asbestos	Low	L	M	M	
		Mod	L	H	H	
		High	L	H	H	
6.5.5	**Miscellaneous FF&E**					
6.5.5.1	File cabinets, tall vertical or	Low	L	L	L	NE

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
	lateral files					
		Mod	M	M	M	
		High	H	M	M	
6.5.5.2	Demountable partitions	Low	L	L	L	
		Mod	L	L	L	NE
		High	M	M	M	
6.5.5.3	Miscellaneous furniture under 4' tall	Low	L	L	L	
		Mod	L	L	L	NE
		High	L	L	L	
N/A	Large kitchen or laundry equipment	Low	L	L	L	
		Mod	M	M	L	
		High	M	H	M	
N/A	Lockers, vending machines	Low	L	L	L	
		Mod	H	M	L	
		High	H	M	L	
N/A	Freestanding wood stove (wood, pellet, or gas-fired)	Low	L	L	L	
		Mod	M	M	M	
		High	H	H	H	
6.5.6	**Miscellaneous Contents**					
6.5.6.1	Shelf-mounted items	Low	L	L	L	
		Mod	M	M	L	NE
		High	H	M	M	
N/A	Especially valuable or fragile merchandise	Low	L	M	L	
		Mod	L	H	L	
		High	L	H	L	
N/A	Potted plants or indoor landscaping resting on shelves above the floor	Low	L	L	L	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
		Mod	L	L	L	
		High	M	L	L	
6.5.6.2	Desktop, countertop items	Low	L	L	L	
		Mod	L	M	L	NE
		High	L	H	M	
6.5.6.3	Fragile artwork	Low	L	L	L	
		Mod	L	H	L	NE
		High	L	H	L	
N/A	Tall sculptures (over 5 ft)	Low	L	L	L	
		Mod	M	M	L	
		High	H	H	L	
6.5.6.4	Fire extinguisher and cabinet	Low	L	L	L	
		Mod	M	H	L	NE
		High	M	H	L	

Footnotes:

1. Ratings for exterior components assume an entrance or walkway is located near the exterior wall. At locations where there is limited access, the life safety risk would be low.
2. Ratings assume component is located in a corridor or along the path of egress.

A. SPECIFICATION

This appendix contains Specification Section 130541, Seismic Restraint Requirements for Nonstructural Components. This Section is intended to aggregate requirements for seismic restraint of nonstructural components and should be cross referenced from each specification section that includes nonstructural components requiring seismic protection. This specification has been written to address nonstructural components for which the Contractor is assigned responsibility for both design and construction. Items that have been explicitly designed by the design team and included on the drawings may be removed from this section, or the relevant section may be modified to indicate that the Contractor is required to furnish and install restraints only.

The specification is intended to be used in conjunction with the responsibility matrices provided in Appendix B to facilitate compliance with nonstructural performance objectives.

The specification is also provided as a Microsoft Word file (.doc) file for download on this CD-ROM and should be customized for use in projects.

SECTION 130541

SEISMIC RESTRAINT REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS

[NOTE TO SPECIFIER: This section is intended to aggregate requirements for seismic restraint of nonstructural components. It should be cross referenced from each specification section that includes nonstructural components requiring seismic protection. This specification has been written to address nonstructural components for which the Contractor is assigned responsibility for both design and construction. Items that have been explicitly designed by the design team and included on the drawings may be removed from this section, or the relevant section may be modified to indicate that the Contractor is required to furnish and install restraints only.]

PART 1 - GENERAL

1.1 DESCRIPTION

A. Provide seismic restraint of nonstructural components to withstand seismic forces and seismic deformations without displacing or overturning. For designated nonstructural components, provide installations capable of providing post-earthquake functionality.

B. Work in this section includes furnishing and installing complete seismic restraint systems. Work in this section may also include the seismic restraint design and/or equipment/product certifications to be submitted for review by the registered design professional.

1.2 SCOPE

A. The architectural, mechanical, electrical, and plumbing components and systems identified on the following Responsibility Matrix shall be designed and constructed for seismic demands.

[NOTE TO SPECIFIER: Insert the Responsibility Matrix appropriate for the project Seismic Design Category (see Section 1.3A). Explicitly list those components requiring seismic design, specify each component importance factor, I_p, identify the parties responsible for design, preparation of shop drawings and seismic calculations and indicate which components require Special Seismic Certification.]

[NOTE TO SPECIFIER: The items listed above are generally consistent with the scope of items regulated by building codes per ASCE 7. Items not governed by Building Codes may be added to the scope to create a complete project-specific list (for example, shelf- and counter-mounted contents may be excluded completely or may be excluded except for designated items). It is the responsibility of the design team to create the list and identify the party/parties responsible for verifying compliance with this specification section.]

1.3 DEFINITIONS

1. Professional Engineer - A professional engineer is one who is legally qualified to practice in the jurisdiction where the Project is located, who is experienced in providing

engineering services of the kind indicated, and is registered with the state where the Project is located.

2. Seismic Forces: Forces acting in any direction on a nonstructural component and related system due to the action of an earthquake as defined in the Building Codes currently in effect where the Project is located.

3. Seismic Deformations: Drifts, deflections and seismic relative displacements determined in accordance with the applicable seismic requirements of the Building Codes currently in effect where the Project is located.

4. Restraint/Bracing: Bracing or anchorage used to limit movement under seismic forces. Cables or rigid elements (strut, pipe, angles, etc) used to resist forces by uniaxial tension or compression. The term “bracing” may also be used to describe design to resist lateral forces through the use of wall or frame elements.

5. Support: Elements used to support the weight (gravity load) of an item. Where the support is located at a seismic brace, the element may also resist tension/compression reactions from the restraint system.

6. Anchorage: Connection to structure typically through the use of welding, bolts, screws, post-installed anchors or other fasteners selected to meet the Building Codes currently in effect where the Project is located.

7. Designated Seismic System: Those architectural, electrical and mechanical systems and their components that require seismic design in accordance with ASCE 7 and for which the component importance factor, I_p, is 1.5 according to ASCE 7 or listed as 1.5 in Section 130541.1.2.

8. Inspection Body: Organization or individual accredited to ISO 17020 and regularly engaged in factory inspection services for seismic restraint of non-structural components and equipment.

9. Special Inspector: An IAS accredited IBC special inspection agency or qualified professional engineer who demonstrates competence, to the satisfaction of the building official (or Authority Having Jurisdiction [AHJ]), for inspection of the designated seismic systems. The owner or the registered design professional in responsible charge acting as the owner’s agent shall employ one or more special inspectors to provide periodic inspections during installation of designated seismic systems.

10. AHJ: Authority Having Jurisdiction – The governmental agency or subagency that regulates the construction process. This may be a local building department, state agency, federal entity or other body or bodies having statutory authority.

11. OSHPD: California Office of Statewide Health, Planning and Development

12. ICC-ES: International Code Council Evaluation Service

13. IAS: International Accreditation Service, Inc.

14. IBC: International Building Code

15. VISCMA: Vibration Isolation and Seismic Control Manufacturers Association

1.4 RELATED SECTIONS

[NOTE TO SPECIFIER: List all sections of the specifications that have related requirements governing installation. The following sections follow the Construction Specifications Institute format for "[Sound], Vibration, and Seismic Control." To avoid confusion and inconsistent design criteria, it is recommended that all seismic design criteria be aggregated in this section or that care is taken to ensure that seismic design criteria for all components are consistently addressed.]

A. Coordinate and comply with the requirements of the following:
1. Section XXX – Vibration and seismic controls for fire suppression piping and equipment
2. Section XXX – Vibration and seismic controls for plumbing piping and equipment
3. Section XXX – Vibration and seismic controls for HVAC duct, piping and equipment
4. Section XXX – Vibration and seismic controls for electrical systems and equipment
5. Section XXX –Vibration and seismic controls for communications systems and equipment
6. Section XXX – Vibration and seismic controls for electronic safety and security
7. Section XXX – Vibration and seismic controls for communications systems
8. Section XXX – Vibration and seismic controls for medical gas piping and equipment

1.5 APPLICABLE PUBLICATIONS

A. The most recent edition of publications listed below (including amendments, addenda revisions, supplements and errata) form a part of this specification to the extent referenced unless otherwise noted. The publications are referenced in text by basic designation only.

[NOTE TO SPECIFIER: Verify and edit applicable publications to indicate all referenced guidelines/standards. Where the most recent edition does not apply, provide specific instruction.]

B. American Concrete Institute (ACI):
1. 355.2 Qualification for Post-Installed Mechanical Anchors in Concrete and Commentary
2. 318 Appendix D Anchoring to Concrete

C. American Institute of Steel Construction (AISC): Load and Resistance Factor Design American Society of Civil Engineers Minimum Design Loads for Building and Other Structures

D. American Society for Testing and Materials (ASTM):
1. A/36/A36M Standard Specification for Carbon Structural Steel
2. A/53/A53M Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless

3. A307 Standard Specification for Carbon Steel Bolts and Studs; 600,000 PSI Tensile Strength
4. A325 Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength
5. A325M Standard Specification for High-Strength Bolts for Structural Steel Joints (Metric)
6. A490 Standard Specification for Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength
7. A490M Standard Specification for High-Strength Steel Bolts, Classes 10.9 and 10.9.3, for Structural Steel Joints (Metric)
8. A500/A500m Standard Specification for Cold-Form Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes
9. A501 Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing
10. A615/A615M Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
11. A992/A992M Standard Specification for Steel for Structural Shapes for Use in Building Framing
12. A996/A996M Standard Specification for Rail-Steel and Axel-Steel Deformed Bars for Concrete Reinforcement.
13. E488-96 Standard Test Method for Strength of Anchors in Concrete and Masonry Elements
14. E580 Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions

E. American National Standards Institute (ANSI) and Rack Manufacturers' Institute (RMI): Specification For The Design, Testing and Utilization of Industrial Steel Storage Racks (ANSI MH16.1)

F. American Welding Society (AWS):
1. AWS D1.1 Structural Welding Steel
2. AWS D1.3 Structural Welding Sheet Steel

G. International Code Council Evaluation Service (ICC-ES): Index of Reports can be found at http://www.icc-es.org/reports/index.cfm

H. National Fire Protection Association: Installation of Sprinkler Systems (NFPA-13)

I. OSHPD Code Application Notice 2-1708A.5 – Certification of Equipment and Nonstructural Components

J. Americal Society of Mechanical Engineers (ASME)
1. Standard B31 Standards for Pressure Piping

[NOTE TO DESIGNER AND SPECIFIER: Add additional local or statewide code references.]

1.6 REGULATORY REQUIREMENTS

A. Comply with the International Building Code (IBC) latest adopted Edition by the jurisdiction where the Project is located and applicable local and/or statewide adopted amendments.

B. Special Seismic Certification – Provide certification in accordance with IBC, Chapter 17 and ASCE 7 Chapter 13 requirements for designated seismic systems as indicated on the Responsibility Matrix.

[NOTE TO DESIGNER AND SPECIFIER: It is the project design professional's responsibility to identify components for which the Contractor is required to submit Special Seismic Certification. The "Responsibility Matrix" provided in Appendix B is provided as a tool to identify and track these items. (Note: Certification should be addressed by the design team prior to construction to ensure component has been certified or will be certified to suit the project schedule.)]

1.7 PROJECT SEISMIC DESIGN CRITERIA

A. Seismic Design Category – X

[NOTE TO DESIGNER AND SPECIFIER: Seismic Design Category is defined in ASCE 7 Table 11.6-1. It is dependent on the site seismicity and building occupancy. The project designer is responsible for identifying the building specific seismic design category.]

B. Seismic Design Force – Calculation of seismic design force shall be based on the requirements of Chapter 13 of ASCE 7 with the following seismic design parameters

1. S_{DS} = X.XX
2. $I_{building}$ = X
3. I_p = X.X (1.0 or 1.5 as indicated in ASCE 7 Section 13.1.3)
4. a_P, R_P = in accordance with ASCE 7 Tables 13.5-1 and 13.6-1
5. z = XX (roof elevation)
6. h_1 = XX (floor 1 elevation)
   h_2 = XX (floor 2 elevation)
   h_3 = XX (floor 3 elevation)
   etc.

C. Seismic Relative Displacement – Design shall accommodate seismic relative displacement of 0.02 times the story height in addition to thermal movement that may be present.

[NOTE TO DESIGNER AND SPECIFIER: Design for the maximum permitted code displacement as indicated in ASCE 7 Table 12.12-1. Alternatively, provide interstory drift for each story of the building based on project-specific structural analysis. For example, replace above requirement with: Use the following interstory drifts to compute the relative seismic displacement that the component must be designed to accommodate.

Δ1-2 = interstory drift between floors 1 and 2 = X.XX
Δ2-3 = interstory drift between floors 2 and 3 = X.XX
Δ3-Roof = interstory drift between floors 2 and 3 = X.XX]

D. Seismic Separation between Independent Structures – Components crossing seismic separations shall be designed to accommodate relative seismic movement between structures. Locations of seismic separations are shown on the drawings. Use the following to determine the range of movement required at each floor. Components shall be independently anchored to each structure.

1. $D_{A1\text{-}B1}$ = XX" (i.e. +/- xx"/2)
2. $D_{A2\text{-}B2}$ = XX" (i.e. +/- xx"/2)
3. $D_{A3\text{-}B3}$ = XX" (i.e. +/- xx"/2)
4. $D_{ARoof\text{-}BRoof}$ = XX" (i.e. +/- xx"/2)

[NOTE TO DESIGNER AND SPECIFIER: Provide seismic separation for each floor for each seismic joint based on project-specific structural analysis and as required by ASCE 7 Section 12.12-3. Alternatively, specify seismic separation based on maximum interstory drift permitted by code.]

[NOTE TO DESIGNER AND SPECIFIER: The following list contains a sample list of nonstructural components for which the contractor may be assigned responsibility for design and construction. Items that have been explicitly designed by the design team and included on the drawings should be identified as such on the Responsibility Matrix and may be removed from this section. Items for which seismic restraint is not required should be removed. Add additional items as required for project-specific scope.]

1.8 QUALITY CONTROL

A. Shop-Drawing Preparation:
   1. Seismic restraint shop drawings shall be prepared or their preparation shall be overseen by a professional engineer experienced in designing seismic restraints for nonstructural components as required by the authority having jurisdiction. The use of proprietary restraint systems with a certificate of compliance verified and listed by an IAS accredited inspection body is acceptable.

B. Seismic Calculations Preparation:
   1. Seismic restraint calculations shall be prepared and stamped by a registered professional engineer experienced in the area of seismic restraint for nonstructural components. Comply with the applicable code specified in Paragraph 1.6.

[NOTE TO SPECIFIER: If desired or required by the authority having jurisdiction, restrict design to professional engineers registered in the state where the project is located or to licensed Structural Engineers, or both.]

C. Special Seismic Certification of Mechanical and Electrical Equipment and Distribution Systems:
   1. Each manufacturer of designated seismic system components shall provide a certificate of compliance indicating that the component and its mounting system or anchorage have been tested or analyzed to withstand required seismic loads and maintain operability. Qualification shall be by an actual test on a shake table with three-dimensional shock tests, an analytical method using dynamic characteristics and forces and/or experience data based upon nationally recognized procedures acceptable to the authority having jurisdiction. Certificate must be verified by an IAS accredited inspection body or other independent inspection entity acceptable to the Authority Having Jurisdiction. Components shall be labeled with an identification applied on a product by the manufacturer that contains the name of the manufacturer, the function and performance characteristics of the product or material, and the name and identification of an accredited agency that indicates that the representative sample of the product or material and its testing have been evaluated and listed by an accredited inspection body agency.

      If a particular component has no manufacturer available that has been evaluated and listed by an accredited inspection body agency, then qualification must be by analysis performed be a professional engineer registered in the jurisdiction where the Project is located. Professional engineer must be approved by the authority having jurisdiction and experienced in providing engineering services of the kind indicated. Analysis must include an evaluation of stress and deflection developed through the entire load path from the center of applied seismic load to the equipment anchorage. Analysis must consider dynamic characteristics and the response spectrum required by code.

Special Seismic Certification for distribution systems such as piping and ductwork shall include a stress analysis of the pipe/duct, supports, bracing and anchors. The stress analysis shall include gravity and seismic demands and shall include an analytical assessment of connections and consideration of movement of points of attachment. The effects of in-line devices, where present, shall be considered in the analysis. Conformance with NFPA 13 2010 will satisfy Special Seismic Certification requirements for fire protection piping.

D. Coordination:
1. Do not install seismic restraints until seismic restraint submittals have been reviewed and accepted by the entity/entities identified on the Responsibility Matrix.
2. Verify that multiple systems installed in the same vicinity can be installed without conflict.
3. Verify tolerances between installed items to confirm that unbraced components will not come into contact with restrained equipment or structural members during an earthquake. When contact is possible, provide seismic restraint or provide justification to the satisfaction of the registered design professional in responsible charge of the project that contact will not cause unacceptable damage to the components in contact, their supports, finishes or other elements that are contacted.

[NOTE TO DESIGNER AND SPECIFIER: (1) The requirement to regulate tolerances between installed unbraced items may not be necessary to protect components and systems that are inherently rugged, lightweight or where contact is unlikely to cause unacceptable damage. Consider project specific requirements and those imposed by the authority having jurisdiction. (2) Where contact between adjacent items is specified, consider explicitly specifying tolerance for unbraced equipment. (3) See 3.9.D.9.(4) Unless otherwise specified, the Structural Engineer of Record is responsible for confirming that the structure is capable of supporting the gravity and seismic demands imposed by nonstructural components.]

PART 2 - PRODUCTS

2.1 STEEL

A. Structural steel: ASTM A36, A36M, A992

B. Structural tubing: ASTM A500, Grade B

C. Steel pipe: ASTM A53/A53M, Grade B

D. Bolts and nuts: ASTM, A307, A325, A325M, A490, A490M, ASTM A563

E. Lag bolts and screws: ASME B18.2.1 (ASME B18.2.3.8M), ASTM A563

F. Powder driven anchors: NES NER-272

G. Nails: ASTM F1667

2.2 LIGHT GAGE NON-LOAD BEARING METAL FRAMING

A. Metal studs: A653 Grade 33, ASTM A1011 Grade 33, ASTM A446 Grade A or D, or ASTM A570

B. Tie wires: ASTM A641/A641M

C. Screws for fastening to cold-formed metal framing: ANSI B18.6.4

2.3 WELDING

A. Welding filler metal: AWS A5.1

2.4 POST-INSTALLED ANCHORS

A. Expansion or sleeve anchors: Pre-qualified for use in seismic applications per ASTM E488

B. Adhesive anchors: Pre-qualified for use in seismic applications per ASTM E488

2.5 SEISMIC RESTRAINT CABLES

A. Prestretched galvanized carbon steel cable 7x19 strand core, ASCE-19, ASTM A-1023 1A, ASTM A-603 or stainless steel

2.6 CHANNEL STRUT AND FITTINGS

A. Strut: ASTM A 1011SS Gr 33 or ASTM A 653 Gr 33

B. Fittings: ASTM A 575, A 576, A36 or A 635

PART 3 - EXECUTION

3.1 CONSTRUCTION, GENERAL

A. For items identified in the Responsibility Matrix furnish and install supports, braces, connections, hardware and anchoring devices to withstand code-required seismic forces and seismic deformations without shifting or overturning. For components with Ip = 1.5, in addition to providing code-required seismic forces and deformations, provide installations capable of providing post-earthquake functionality.

B. Construct seismic restraints and anchorages that do not inhibit thermal expansion and contraction of distribution systems. Utilize ASME Standard B31 when utilizing common supports for both thermal and seismic loading.

C. Maintain fire ratings of assemblies as specified elsewhere or on the drawings in addition to compliance with the criteria set forth below.

[NOTE TO DESIGNER AND SPECIFIER: It is the structural engineer of record's responsibility to provide a structure capable of accommodating the design demands from nonstructural components. The submittal requirements of these specifications require the contractor to provide the numerical values of gravity and seismic forces imposed on the structure from components. The structural engineer of record must verify that the structure is capable of accommodating the demands. Any limitations of the structural system that would alter the manner or location in which components are supported or braced should be clearly shown on the drawings and/or described in the specifications below.]

3.2 NONSTRUCTURAL EXTERIOR WALL COMPONENTS

A. Nonstructural exterior wall framing
   1. Design framing to resist out-of-plane seismic design force, movement due to temperature changes and relative vertical movement between floors.
   2. Design framing to accommodate code-required interstory drift without damage that compromises the exterior wall water, moisture and thermal barriers.
   3. Design framing with sufficient out-of-plane stiffness to prevent damage to cladding or veneer when subjected to code-required out-of-plane forces.

B. Veneer
   1. Fasten veneer to substrate to accommodate out-of-plane seismic design force and deformation of supporting framing.
   2. Anchored veneer shall be detailed to prevent moisture penetration from weather that could corrode anchors.

C. Nonstructural prefabricated panels
   1. Design prefabricated panels and connections capable of resisting in-plane and out-of-plane forces and story drift deformations in accordance with ASCE-7.

D. Glazing
   1. Design glazing to resist out-of-plane seismic design force
   2. Design glazing to accommodate relative displacement to resist fallout as set forth in ASCE 7 Section 13.5.9.1 and not less than 0.5".
   3. Drift limit for glass components shall be determined in accordance with AAMA 501.6 or by engineering analysis.
   4. In lieu of calculations, compliance with design criteria may be established by testing in accordance with AAMA 501.4.

3.3 INTERIOR PARTITIONS

A. Heavy partitions (masonry, glass block, etc.):
   1. Design wall and connections to resist out-of-plane seismic design force.
   2. Provide connection detail between the building structure and heavy partition to accommodate seismic relative displacement between partition and structure.
   3. Maintain fire rating at connections in rated construction.

B. Light partitions (metal stud or wood stud):
   1. Design partitions to resist out-of-plane seismic design force. Design force shall be based on the weight of the partition framing, finishes, soffits, connected casework or equipment, and ceilings for which it provides bracing. Out-of-plane design force shall not be less than 5 psf.
   2. Design partitions to accommodate interstory drift.
   3. Fasten veneer to partition framing to resist code required forces and deformation of studs.
   4. Where partition does not extend to the structure, the partition height does not exceed 9 feet, the linear weight of the partition does not exceed the product of 10 pounds times the height in feet of the partition and the partition horizontal load does not exceed 5 psf, lateral bracing to the building structural is not required. For all other conditions, provide supplemental bracing or framing to resist out-of-plane seismic design force. Such bracing or framing shall be independent of splayed wire ceiling bracing. Design wall bracing or framing for compatibility with ceiling deflection requirements, fire ratings and architectural treatments.

3.4 CEILINGS

A. Suspended acoustic tile ceilings:
   1. Design and install ceiling in accordance with ASTM E580.

2. For Seismic Design Categories D, E and F, provide bracing at regular intervals to resist code design forces and limit vertical and lateral movement. Suspended ceilings with areas less than or equal to 144 square feet and that are surrounded by walls or soffits that are laterally braced to the structure above are exempt from seismic design requirements.
3. Where ceilings are unbraced or splayed wire bracing is used to resist seismic forces and limit lateral deflections, provide 1 inch clearance around all penetrations through the ceiling sprinkler drops. If flexible sprinkler drops are used and have been certified to accommodate 1 inch of movement, the 1 inch clearance requirement may be waived.
4. Provide independent support of lighting fixtures, diffusers, cable trays, electrical conduit and other ceiling appurtenances.
5. Ceiling system design load Wp shall be taken as not less than 4 psf.

B. Ceilings directly fastened to structural framing or furred with materials that are directly applied to structural framing
1. Fasten ceiling to framing to resist the vertical seismic design forces and the weight of the ceiling and all connected light fixtures, sprinklers, HVAC appurtenances.

3.5 PARAPETS, ROOF SCREEN WALLS, APPENDAGES, CANOPIES, MARQUEES, SIGNS, CHIMNEYS, AND STACKS

A. Exterior appendages
1. Design component and connections to resist out-of-plane seismic design force and code wind force.
2. Design and provide supplementary framing and/or backing as required to support and anchor to structural framing.
3. Provide details that do not compromise water, moisture and thermal barriers.

3.6 ACCESS FLOORS

1. Provide restraint to resist seismic design force in any direction. Use components that have been tested in accordance with CISCA “Recommended Test Procedures for Access Floors.”
2. The use of adhesive-only anchorage of pedestals is prohibited in Seismic Design Categories D through F.

3.7 STAIRWAYS

A. Stairs (including treads, risers, landings and enclosures)
1. Design components and connections to resist seismic design force
2. Design stairs to accommodate interstory drift. Acceptable means shall include isolating the stair from experiencing internal stresses due to interstory drift or provide substantiating evidence to demonstrate that stair can accommodate interstory drift.
3. Design and provide supplementary framing as required to support and anchor to structural framing.
4. Design components and connections to maintain fire rating when subjected to seismic design forces and deformations.

3.8 FREESTANDING WALLS OR FENCES

A. Freestanding walls and fences:
1. Design wall/fence and foundation capable of resisting out-of-plane seismic design force and code wind forces including out-of-plane forces.

3.9 MECHANICAL AND PLUMBING COMPONENTS

A. Floor and base-mounted mechanical equipment (boilers, furnaces, pumps, chillers, manufacturing, process machinery, etc.), vibration isolated equipment and associated system vibration and seismic controls for connections.
   1. Design equipment anchorage to resist seismic design force in any direction.
   2. Design vibration and seismic controls for equipment to include base and isolator requirements.
   3. Provide flexible connection between equipment and interconnected piping.
   4. Where equipment is mounted on vibration isolators and restraints, use isolators and restraints designed for amplified code forces per ASCE 7 and with demonstrated ability to resist required forces including gravity, operational and seismic forces.
   5. Provide supplemental steel or concrete base as required for mounting equipment on isolators. Where equipment is not designed to be point loaded, provide base capable of transferring gravity and seismic demands from equipment to isolator base plate anchorage.
   6. Where concrete floor thickness is less than required for expansion anchor installation per ICC-ESR, install through bolt in lieu of expansion anchor. Where timber/wood floor or other substrate is inadequate for installation of lag bolts, screws or other mechanical fasteners, furnish and install supplemental framing or blocking to transfer loads to structural elements.

B. Suspended mechanical equipment
   1. Design support and bracing to resist seismic design force in any direction.
   2. Provide flexible connection between equipment and interconnected piping.
   3. Brace equipment hung from spring mounts using cable or other bracing that will not transmit vibration to the structure.
   4. As an alternate to project-specific design of seismic bracing, use of proprietary restraint systems with a certificate of compliance verified and listed by an accredited inspection body is acceptable. Use of a certified product does not preclude the requirement for shop drawings.

[NOTE TO DESIGNER AND SPECIFIER: The California Office of Statewide Health Planning and Development (OSHPD) runs a "Preapproval" program in which it conducts an internal technical review of proprietary components or system seismic design submittals and approves them for use in California hospitals. OSHPD preapprovals are accepted by some jurisdictions.]

C. Wall-mounted mechanical equipment
   1. Design support and bracing to resist seismic design force in any direction.
   2. Install backing plates or blocking as required to deliver load to primary wall framing members. Do not anchor to gypsum wallboard, plaster or other wall finish that has not been engineered to resist imposed loads.

D. Piping
   1. Provide seismic bracing for piping as required by Section 1.2.
   2. Provide supports, braces and anchors to resist gravity and seismic design forces.
   3. Design piping and piping risers to accommodate interstory drift.
   4. Provide flexible connections between floor-mounted equipment and suspended piping; between unbraced piping and restrained suspended items; as required for thermal movement; at building separations and seismic joints; and wherever relative differential movements could damage pipe in an earthquake.
   5. Brace resiliently-supported pipe with cable bracing or alternate means designed to prevent transmission of vibrations and noise to structure.
   6. Brace every run (5' or more in length) with two transverse and one longitudinal bracing locations. For pipes and connections constructed of ductile materials (copper, ductile iron, steel or aluminum and brazed, welded or screwed connections) provide transverse

bracing at not more than 40 feet on center and longitudinal bracing at spacing not more than 80 feet on center. For pipes and their connections constructed of nonductile materials (cast iron, no-hub pipe and plastic or non-UL listed grooved coupling pipe), provide transverse bracing at not more than 20 feet on center and longitudinal bracing at spacing not more than 40 feet on center. Alternatively, explicitly design piping and connections to resist gravity and seismic forces and seismic deformations.

[NOTE TO DESIGNER AND SPECIFIER: Add additional pipe types or alternate requirements as required to cover project specific scope and performance requirements.]

7. Provide lateral restraint for risers at not more than 30 feet on center or as required for horizontal runs, whichever is less.
8. Where piping is explicitly exempt from seismic bracing requirements, provide flexible connections between piping and connected equipment, including in-line devices such as VAV boxes and reheat coils.
9. Where piping is explicitly exempt from seismic bracing requirements, install piping such that swinging of the pipes will not cause damaging impact with adjacent components, finishes or structural framing. This will be considered satisfied if there is horizontal clear distance of at least 2/3 the hanger length between subject components. If swinging of exempted piping can cause damaging contact with adjacent components, finishes or structural framing, add swing restraints as required to eliminate contact.

[NOTE TO DESIGNER AND SPECIFIER: The concern for damage caused by unbraced pipes should be considered on a project specific basis. ASCE 7 13.6.8 allows pipe bracing to be omitted if "high deformability piping is used; (and) provisions are made to protect the piping in the event of such impact." The measures described above are one way to meet these requirements. In many jurisdictions, this is not a focus of concern.]

10. As an alternate to project-specific design of seismic bracing, use of proprietary restraint systems with a certificate of compliance verified and listed by an accredited inspection body is acceptable. Use of a certified product does not preclude the requirement for shop drawings.

[NOTE TO DESIGNER AND SPECIFIER: The California Office of Statewide Health Planning and Development (OSHPD) runs a "Preapproval" program in which it conducts an internal technical review of proprietary components or system seismic design submittals and approves them for use in California hospitals. OSHPD preapprovals are accepted by some jurisdictions.]

11. Re-use of existing hangers: Where pipes are being installed in existing facilities, the re-use of existing hangers at locations of seismic bracing will be judged on a case-by-case basis by the registered project design professional. Unless otherwise shown on the drawings, it shall be assumed that all hangers supporting new piping and located at a seismic brace will be installed new.

E. Ductwork

1. Provide seismic bracing for ducts with cross sectional area greater than 6 square feet (independent of the duct contents) and for ducts containing hazardous materials.
2. Provide supports, braces and anchors to resist gravity and seismic design forces.
3. Design ducts and duct risers to accommodate interstory drift.
4. Provide independent support for in-line devices weighing more than 20 pounds. Provide independent support and bracing for all in-line devices weighing more than 75 pounds. Unbraced piping attached to braced in-line equipment shall be provided with adequate flexibility to accommodate differential displacements.

5. Appurtenances such as dampers, louvers and diffusers shall be positively attached to the ductwork with mechanical fasteners.
6. Duct supports shall be designed to resist not less than 150% of the weight of the duct. For seismic design categories D, E and F, ducts weighing over 10 plf shall not be hung using power driven fasteners.
7. As an alternate to project-specific design of seismic bracing, use of proprietary restraint systems with a certificate of compliance verified and listed by an IAS accredited inspection body or otherwise accepted by the Authority Having Jurisdiction is acceptable. Use of a certified product does not preclude the requirement for shop drawings.

[NOTE TO DESIGNER AND SPECIFIER: The California Office of Statewide Health Planning and Development (OSHPD) runs a "Preapproval" program in which it conducts an internal technical review of proprietary components or system seismic design submittals and approves them for use in California hospitals. OSHPD preapprovals are accepted by some jurisdictions. "Preapproved by OSHPD" may be added to item 7 after "IAS accredited inspection body" if desired.]

F. Tanks
1. Design tank anchorage to resist seismic design force.
2. Design tank legs or supporting structure to resist seismic design force.
3. Provide flexible connections between tank and interconnected piping.

G. Fire suppression equipment and piping
1. See requirements for suspended piping.
2. See requirements for floor-mounted and wall-mounted equipment.
3. Satisfy requirements of NFPA 13 and the force and displacement requirements of ASCE 7. All components shall be UL listed.
4. Provide end of line restraint as required by NFPA 13.

3.10 ELECTRICAL EQUIPMENT

A. Electrical equipment
1. Design equipment to resist seismic design force in any direction
2. Batteries on racks shall be provided with acid resistant and corrosion resistant wrap-around restraints or shall be otherwise prevented from movement within battery rack. Racks shall be designed to resist seismic design force.
3. Electrical cabinet design shall comply with the applicable National Electrical Manufacturers Association (NEMA) standards.
4. Supports shall be designed to accommodate the seismic relative displacement between points of support.
5. Where equipment is mounted on vibration isolators and restraints, use isolators and restraints designed for amplified code forces and with demonstrated ability to resist required forces including gravity, operational and seismic forces.

B. Conduit, cable tray, bus duct, raceways, bundled cabling
1. Provide supports and anchoring so that, upon application of seismic forces and deformations, conduit/cable tray/bus duct/raceway/bundled cabling will not displace sufficiently to cause damage to wires, connections, adjacent or connecting equipment, building members or finishes.
2. Provide seismic bracing of conduit/cable tray/bus duct/raceway/bundled cabling to resist gravity and seismic design forces.
3. Provide gravity support for conduit/cable tray/bus duct/raceway/bundled cabling that is independent of suspended ceiling framing.
4. Design conduit/cable tray/bus duct/raceway/bundled cabling to accommodate interstory drift.

5. As an alternate to project-specific design of seismic bracing, use of proprietary restraint systems with a certificate of compliance verified and listed by an accredited inspection body is acceptable. Use of a certified product does not preclude the requirement for shop drawings.

   [NOTE TO DESIGNER AND SPECIFIER: The California Office of Statewide Health Planning and Development (OSHPD) runs a "Preapproval" program in which it conducts an internal technical review of proprietary component or system seismic design submittals and approves them for use in California hospitals. OSHPD preapprovals are accepted by some jurisdictions.]

6. Provide flexible connections wherever relative differential movement could damage conduit/cable tray/bus duct/raceway/bundled cabling in an earthquake.

C. Light fixtures
   1. Design fixture connections to resist seismic design force.
   2. For lights in suspended ceilings:
      a. For lights weighing 56 pounds or less, provide positive mechanical connection between fixtures and ceiling framing to resist seismic design force and gravity load. Provide 2 independent wires at diagonally opposite corners connected to structural framing. For lights weighing more than 56 pounds, provide independent support and bracing.
   3. For lights in light framed ceilings and walls:
      a. For lights weighing 56 pounds or less, provide positive mechanical connection between the fixture and the ceiling/wall framing capable of resisting required gravity and seismic demands. Provide ceiling and wall framing capable of delivering demands from the light fixture to the structure.
   4. For pendant mounted fixtures:
      a. Verify that fixture will not displace in such a manner as to hit adjacent lighting and/or architectural elements or other suspended items. Connection to the structure shall allow a 360 degree range of motion. If pendant fixture could come in contact another item when swinging in a 45 degree arc from vertical in any direction, provide bracing to limit movement and avoid interaction. Design load shall be 1.4 times the operating weight acting down with a simultaneous horizontal load of 1.4 times the operating weight.

D. Communication systems including alarm systems
   1. See requirements for electrical equipment and conduit, cable tray, bus duct, raceways, bundled cabling.

3.11 TRANSPORTATION COMPONENTS

A. Elevator and escalators
   1. Design for conformance with seismic requirements of ASME A17.1.
   2. Design to resist seismic design force specified herein. The more stringent design force shall govern.
   3. Elevator/escalator equipment and controller supports and attachments shall be designed to resist seismic design force.
   4. Elevators travelling with a speed of 150 ft/min or greater shall be provided with a seismic switch in accordance with ASCE 7.
   5. Provide retainer plate at the top and bottom of the car and counterweight.

3.12 STORAGE RACKS AND SHELVING

A. Light duty storage racks and shelving
   1. Provide restraint to resist seismic design force in any direction.

2. Where restraint is provided by anchorage to a wall, verify that wall has adequate strength to resist anchor demands. Install backing plates or blocking as required to deliver load to primary wall framing members. Do not anchor directly to gypsum wallboard, plaster or other wall finish that has not been engineered to resist imposed loads.

B. Industrial storage racks

1. Design for conformance with latest version of Rack Manufacturers Institute (RMI) Specification for the Design, Testing and Utilization of Industrial Steel Storage Racks and the seismic design requirements of ASCE 7. Where design criteria conflict, the more stringent shall apply.

3.13 TELEVISIONS, MONITORS

1. Design support and bracing for wall-mounted and suspended televisions/monitors to resist seismic design force in any direction.
2. Where restraint is provided by anchorage to a wall, verify that was has adequate strength to resist anchor demands. Install backing plates or blocking as required to deliver load to primary wall framing members. Do not anchor directly to gypsum wallboard, plaster or other wall finish that has not been engineered to resist imposed loads.
3. Use mounting brackets certified for resistance to seismic loads.

[NOTE TO DESIGNER AND SPECIFIER: 1. These provisions address wall-mounted and suspended televisions/monitors. If large or critical monitors are counter-mounted, specific seismic restraint provisions could be added to restrain them. 2, The California Office of Statewide Health Planning and Development (OSHPD) runs a “Preapproval” program in which it conducts an internal technical review of proprietary component or system seismic design submittals and approves them for use in California hospitals. OSHPD preapprovals for television mounting brackets are accepted by some jurisdictions and may be a useful source for selecting and specifying mounting hardware.]

3.14 DESKTOP COMPUTERS

1. Provide straps, high friction pads, snubbers or other mechanisms as required to resist seismic design forces.
2. All connections shall be readily demountable and shall not damage computer housing.

[NOTE TO DESIGNER AND SPECIFIER: Desktop computers are not regulated by the building code. The need for restraint should be considered on a project-by-project basis.]

3.15 COMPUTER AND COMMUNICATIONS RACKS, CABINETS AND BOARDS

1. Design equipment anchorage to resist seismic design force in any direction
2. Where cable tray is connected to the top of racks or cabinets, design seismic restraint to include the tributary weight of the cable tray and components.
3. Interconnect adjacent cabinets to cause them to respond together when resisting lateral forces.
4. Where equipment is supported on raised access flooring, provide bracing and anchorage to the supporting floor below.

[NOTE TO DESIGNER AND SPECIFIER: There are many approaches to providing seismic restraint for computer and communications equipment. Where specific design requirements are desired, they should be clearly specified. For example, the use of isolation bases or independent support frames may be specified.]

3.16 KITCHEN EQUIPMENT

1. Design equipment anchorage to resist seismic design force in any direction.
2. Connections shall enable the equipment to be readily disengaged to enable the equipment to be relocated for cleaning.
3. Provide flexible connections between connected piping and kitchen equipment. If kitchen equipment is restrained with removable "tethers," provide sufficient flexibility in connections to accommodate full range of movement associated with tether.

3.17 DEMOUNTABLE PARTITIONS

1. Use system engineered for use in regions of seismicity. Anchor to structure to resist seismic design force in any direction.

3.18 SHELF- AND COUNTER-MOUNTED CONTENTS

1. Provide straps, mechanical barriers, high friction pads, snubbers or other mechanisms as required to resist seismic design forces.
2. All connections shall be readily demountable and shall not damage or permanently alter contents.
3. Restraints shall not prevent items from being added to or removed from shelf or counter.

[NOTE TO DESIGNER AND SPECIFIER: Shelf- and counter-mounted contents are not regulated by the building code. The need for restraint should be considered on a project-by-project basis.]

3.19 FIELD QUALITY CONTROL

Provide a quality assurance plan as required by ASCE 7, Appendix 11A for installation of the following per IBC Chapter 17. Reference 130541.1.3 for the definition of special inspector. A minimum of 3 special inspections shall be performed (pre-construction, mid-construction, and final inspection):

1. Seismic Design Category C
   a. Heating, ventilating and air-conditioning (HVAC) ductwork containing hazardous materials or smoke control and anchorage of such ductwork.
   b. Piping systems and mechanical units containing flammable, combustible or highly toxic materials.
   c. Anchorage of electrical equipment used for emergency or standy power systems.
   d. Vibration-isolated systems and associated seismic restraints where indicated on the construction documents or submittals. All restraints require a nominal clearance of 0.25" or less between the equipment support frame and restraint.
2. Seismic Design Category D
   a. All systems required for Seismic Design Category C
   b. Exterior wall panels and their anchorage
   c. Suspended ceiling system and their anchorage
      1) Verify member type and size, verify that bracing elements such as splayed wires and compression struts are installed as detailed; test anchorage to structure
   d. Steel storage racks 8' or higher

1) Verify that connections of the racks to the structure are installed as detailed on the drawings. Spot check the connection of horizontal beams to uprights verifying fastener tightness

e. Access floors
1) Verify that anchorage matches detail on the drawings
2) Verify connection of access floor framing to support posts
3) Inspect installation of post-installed anchors
4) Test post installed anchors

3. Seismic Design Categories E and F
a. All systems required for Seismic Design Categories C and D
b. All electrical equipment

[NOTE TO DESIGNER AND SPECIFIER: This specification assumes that the requirements for testing and inspection of post-installed anchors are covered elsewhere in the specifications or drawings. If not, specific test requirements should be added here.]

B. Special Seismic Certifications
1. Verify that the label, anchorage or mounting conforms to the certificate of compliance for designated seismic systems defined in Section 130541.1.2 and 1.3.

END OF SECTION 130541

B. RESPONSIBILITY MATRIX

This appendix contains responsibility matrix templates for the seismic protection of nonstructural components. The templates are to be used for assigning responsibility for design, construction, and inspection of nonstructural installations governed by ASCE/SEI 7-10. Three separate templates are provided for Seismic Design Categories B, C, and D/E/F, respectively. In addition, a Basic Form is provided for general use. The matrices are intended to be used in conjunction with the construction specification provided in Appendix A.

The matrices are provided as a Microsoft Excel file (.xls) on the CD-ROM and should be customized for use in projects.

.

	A	B	C	D	E	F	G	H	I	J
1		RESPONSIBILITY MATRIX								
2		FOR THE SEISMIC PROTECTION OF NONSTRUCTURAL COMPONENTS								
3		SEISMIC DESIGN CATEGORY B								
4										
5		NONSTRUCTURAL COMPONENTS								
6		General categories shown with sample entries (in blue); insert line items for project specific components	Is Seismic Design Required? (yes/exempt)	Component Importance Factor, Ip (See Note 1)	Party Responsible for Design of Seismic Details (See Note 2)	Party Responsible for Preparation of Seismic Shop Drawings (See Note 2)	Party Responsible for Preparation of Seismic Calculations (See Note 2)	Is Special Seismic Certification Required? (See Note 3)	Is seismic design being handled as a Deferred Approval?	Party Responsible for Site Inspection of Installed Component/System
7	ITEM	DESIGNATED SEISMIC SYSTEMS (See Note 1)	Exempt	Ip=1.5				No		
8	S.1	**Component required to function for life-safety purposes after an earthquake, including fire protection sprinkler systems and egress stairways. (per 13.1.3.1)**	**Exempt per 13.1.4.2**							
9										
10	S.2	**Component conveys, supports or contains toxic or explosive substances. (per**	**Exempt per 13.1.4.2**							
11										
12	S.3	**Component in or attached to Risk Category IV structure and is needed for continued operation of the facility or its failure could impair the continued**	**NA**							
13										
14	Note	**Systems in Seismic Design Category B (other exemptions may apply, see ASCE 7-10)**	**Exempt**							
15		Mechanical and electrical components in Seismic Design Category B are exempt from the requirements of Chapter 13 of ASCE 7.	Exempt per 13.1.4							
16										
17										
18	ITEM	STANDARD NONSTRUCTURAL COMPONENTS		Ip=1.0 (UON)						
19		ARCHITECTURAL COMPONENTS								
20	A.1	**Exterior Wall Components**	**Exempt**							
21										
22	A.2	**Interior Partitions**	**Exempt**							
23										
24	A.3	**Ceilings**	**Exempt**							

Figure B-1 Screenshot showing Responsibility Matrix for the Seismic Protection of nonstructural Components, Seismic Design Catergory B worksheet.

C. NONSTRUCTURAL INVENTORY FORM

The intent is that Appendices C, D and E be used together as tools for the facility survey. The first step is to review the map in Figure 3.2.1-1 and discussion in Section 1.3 to see if nonstructural hazard mitigation is a concern for the facility in question. If so, then Appendices C and D can be used in tandem to perform the survey. Risk ratings from Appendix E could be added to the inventory form during the field survey or added later in order to help prioritize the items in the list.

The questions in Appendix D are stated in such a way that the answer "No" or "Unknown" indicates that the component may be noncompliant and likely to pose a nonstructural earthquake hazard. All of the noncompliant components should be entered as individual line items on the facility inventory form in this Appendix. As shown below, the form provides columns for the following information:

- Priority: This can be added at the end after the priorities have been established.
- Nonstructural Item: Name or description of nonstructural component.
- Location: Information such as building, floor, or room number.
- Quantity: Number of items, lineal feet, or square feet.
- Risk Rating for Life Safety (LS), Property Loss (PL) and Functional Loss (FL) from Appendix E.
- Notes: Space for comments regarding the current condition, presence or absence of anchorage details, proximity to other hazardous items, issues with secondary damage such as leaks or hazardous materials release, and whether the component in question is important for functionality of the facility. This might also include a photo number if photos of each item are taken to assist with the survey.

The inventory form provided here has been adapted from the spreadsheet provided by the U.S. Bureau of Reclamation on their website under the heading "Online Orders/Free Tools," http://www.usbr.gov/ssle/seismicsafety/onlineorders.html. The website contains two types of downloadable survey forms: one in spreadsheet format (Microsoft Excel) and one in database format (Microsoft Access). Both of these forms have built-in sorting algorithms so that components with high risk in any category can be shifted to the top of the list. These sorting criteria may be adjusted to suit individual needs. Survey forms can be customized to include cost data, which may be useful for prioritization and planning. Proprietary forms are also available for purchase from specialty vendors.

PRIORITIZED INVENTORY										Rank by LS	Rank by Highest Rank
ID	Description	Location	Quantity	Units	LS	PL	LF	Detail Type	Notes	Rank by PL	
					"H", "M", or "L"			NE, PR, ER		Rank by LF	
1	Bookcase in the south east corner	Room 13	2	each	H	M	M	NE	The two wooden bookcases are unanchored an could tip over during an earthquake blocking egress. Relocate the bookcases away from the doorway or anchor them to the supporting floor or adjacent wall.		
6	Computer monitor	04-N3	1	each	H	H	L	NE	Equipment stored less than four feet above the floor, like this computer monitor, is not a significant life safety hazard. However consideration should be made to securing these types of equipment to the desk top or adjacent wall.		
82	Bookcase	02-12	3	each	H	M	M	NE	Tall shelving or bookcases that have width to height ratios greater than four should be attached to the supporting floor or adjacent wall.		
182	Unreinforced Masonry parapet	South Elevation	50	LF	H	H	L	ER			
13	File cabinets	04-W4	3	each	M	M	M	NE	These flat files are three individual units stacked on top of each other. Without lateral restraints, they can easily slide off each other.		
16	Hot water heater	04-W7	1	each	M	H	L	PR	Gas hot water heaters should be anchored to the floor or adjacent wall to prevent tipping and damage to water and gas lines.		
65	Vending machine	02-15	1	each	M	M	L	NE			
83	Suspended ceiling	02-12	150	SF	M	M	M	PR	The suspended ceiling tiles are supported vertically to the roof structure. There are no lateral tie wires to compensate for lateral loads due to seismicity.		
85	Natural gas supply line	02 North Elevation	200	each	M	M	M	ER	Each gas line that enters the building should have an automatic shutoff valve to prevent escaping gas from feeding a potential fire.		
138	Credenza	04-N4	1	each	M	M	L	NE	The credenza should be anchored to the desk top or adjacent wall to prevent a potential falling hazard.		
63	Computer cabinet	02-14a	1	each	L	H	M	NE	Computer hub should be anchored to the floor or adjacent wall to limit potential damage.		
86	Communication hub	04-W8	1	each	L	L	L	NE	The communication equipment should be stored inside of protective cabinets to prevent potential damage from falling debris.		
178	Desktop computer with monitor	04-E110	2	each	L	M	L	NE	Computers could be placed on the floor to limit potential damage to stored data or the computer's electrical components. The monitor should also be anchored to the desk.		

Figure C-1 Sample inventory checklist for a facility located in an area with Moderate seismic risk. The sorting algorithm of the spreadsheet makes this a useful tool for prioritization. The electronic file is free to download from the U.S. Department of the Interior Bureau of Reclamation's website, http://www.usbr.gov/ssle/seismicsafety/onlineorders.html.

D. CHECKLIST OF NONSTRUCTURAL SEISMIC HAZARDS

This checklist is intended to be used in surveying buildings to assess whether the nonstructural elements (architectural, MEP, FF&E, or contents) pose a danger to the building occupants or are likely to cause financial loss or interruption following an earthquake.

This checklist of nonstructural hazards is intended for use in areas where seismic hazards are a significant concern. Review the discussion in Section 1.3 for the applicability of these nonstructural guidelines and the sidebar in Section 5.3.1 for rules regarding exemptions from the nonstructural provisions in ASCE/SEI 7-10 *Minimal Design Loads for Buildings and Other Structures* (ASCE, 2010) that apply to new construction.

The form includes eight columns marked as follows:

ITEM NO.: ID number to indicate the type of component (architectural, MEP, FF&E or contents) and the subgroup. These numbers are based on the section or subsection in this text and as shown in the tables in Chapter 6.

COMPONENT NAME(S): Name or description of item.

PRINCIPAL CONCERNS: List of problems often associated with this type of item such as falling hazard, water or fuel leakage, broken glass. These concerns should be taken into account when answering the checklist questions. For example, the primary concern for adhered veneer is that it may pose a falling hazard. If a facility has adhered veneer, but only at the base of the building below 6 ft, then this might be checked “Compliance,” if the purpose of the survey is to identify life safety hazards or might be rated “Noncompliance,” if the survey is also intended to help control property damage and limit losses.

EXAMPLE: Example number. All examples, which contain photos and detailed drawings when applicable, can be found in Chapter 6.

COMPLIANCE (C): The questions in this form have been stated in such a way that an affirmative answer indicates that the item is not likely to pose a nonstructural hazard.

NONCOMPLIANCE (NC): The questions in this checklist are stated in such a way that the answer "No" or “Unknown” indicates that the component may be noncompliant and likely to pose a nonstructural earthquake hazard. All of the noncompliant components should be entered as individual line items on the facility inventory form in Appendix A. Comments should

be entered in the survey form noting the location, condition, presence or absence of anchorage details, proximity to other hazardous items, issues with secondary damage such as leaks or hazardous materials release, and whether the component in question is important for functionality of the facility.

NOT APPLICABLE (N/A): This column should be checked if none of the listed items are present and has been included, so that it is clear that the item was not missed or overlooked when performing the survey.

CHECKLIST QUESTIONS: Questions are all "Yes-No" questions, which are answered by checking the appropriate box from among the previous three columns.

6.3	Architectural Components						
Item No.	**Component Name**	**Principal Concerns**	**Example**	**C**	**NC**	**NA**	**Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)**
6.3.1	**Exterior Wall Components**						*[Exterior falling hazards are a primary concern, especially items situated above 10 feet and items that may fall over exits, walkways, or sidewalks.]*
	Adhered veneer	Falling hazard	6.3.1.1				Is the adhered veneer adequately attached to the structure? [This includes relatively thin sections of tile, masonry, stone, terra cotta, ceramic tile, glass mosaic units, stucco, or similar materials attached to a structural wall or framework by means of an adhesive].
							Based on visual observations and/or tapping, is the veneer free of cracked or loose sections that may fall during an earthquake?
	Anchored veneer	Falling hazard	6.3.1.2				Is the anchored veneer adequately attached to the structure? [This includes thicker masonry, stone, or stone slab units that are attached to the structure by mechanical anchors].
							Is the masonry or other veneer supported by shelf angles or other elements at each floor?
							Is the masonry or other veneer connected to a structural back-up wall at adequate spacing?
							Has the veneer been adequately maintained? Are the anchors in good condition, free of significant corrosion, and inspected regularly?
	Prefabricated panels	Falling hazard, damage to panels and connections, broken glass	6.3.1.3				Were the panels and connections designed by an architect or engineer to accommodate the expected seismic distortion of the surrounding structure?
							Are prefabricated cladding panels detailed to allow relative movement between the panel and the structure?
							Are prefabricated panels supported for vertical loads with at least two connections per panel?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are prefabricated panels supported for out-of-plane loads with at least four connections per panel?
							Have the panels been adequately maintained? Are the panel connections in good condition, free of significant corrosion, and inspected regularly?
							Are there adequate separations between panels so they will not come into contact with each other during an earthquake?
	Glazing exterior wall system	Falling hazard, broken glass	6.3.1.4				Is it known that the glazing was designed by an architect or engineer to accommodate the expected seismic distortion of the surrounding structure?
							Do large window panes and storefront windows have safety glass? [All exterior glazing should be laminated, annealed or laminated heat-strengthened safety glass or other glazing system that will remain in the frame when the glass is cracked. This is particularly important for glazing located over 10 feet above an exterior walking surface].
	Glass blocks	Falling hazard, broken glass	6.3.1.5				Are partial-height glass block walls laterally braced to the structure?
							Is the glass block reinforced with panel anchors and panel reinforcing wire?
	Overhead glazing or skylights	Falling hazard, broken glass	6.3.1.6				Are transoms (glass panes over doors) made of safety glass?
							Are skylights made of safety glass or covered with shatter-resistant film?
							Are large panes made of safety glass or is it known whether the glazing assembly was designed by an architect or engineer to accommodate the expected seismic distortion of the surrounding structure?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
6.3.2	**Partitions**						
	Heavy	Falling hazard; collapse or spalling with debris in exitways; large cracks often mistaken for structural damage	6.3.2.1				Are block wall partitions reinforced? [This would include concrete masonry unit (CMU), brick, and hollow clay tile partitions. Most brick and hollow clay tile walls in pre-1933 buildings in California are unreinforced; unreinforced masonry partitions may still be found in current construction in other parts of the country.]
							Are unreinforced masonry walls braced at regular intervals? [In zones of low and moderate seismicity, are partitions braced at 10 foot intervals or less? In zones of high seismicity, are partitions braced at 6 foot intervals or less?]
							Are full-height CMU partitions detailed to allow sliding at the top?
	Light	Cracking of plaster or gypsum board; costly to patch and paint	6.3.2.2				Are partial-height stud wall partitions braced to the structure above the ceiling line?
							Are full-height stud wall partitions detailed to allow sliding at the top?
							If partitions function as lateral support for tall shelving or other nonstructural components, are these partitions adequately anchored or braced to the structure above the ceiling line?
	Glazed	Broken glass	6.3.2.3				Are interior glazed or glass block partitions laterally braced to the structure?
6.3.3	**Interior Veneers**						
	Stone and tile	Falling hazard, debris in exitways	6.3.3.1				Is the adhered veneer adequately attached to the structure?
							Is the anchored veneer adequately attached to the structure?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
6.3.4	**Ceilings, Soffits**						
	Suspended acoustic lay-in tile ceiling	Dropped acoustical tiles, perimeter damage, separation of runners and cross runners; falling hazard if grid and lights come down	6.3.4.1				Does the suspended ceiling have adequate diagonal bracing wires and compression struts to support seismic loads from the ceiling grid plus all lay-in items that do not have independent lateral supports?
							If the ceiling supports lay-in lighting or diffusers, do the lay-in items all have independent vertical supports consisting of wires located at least at two diagonally opposite corners?
							Do lay-in fixtures weighing over 50 pounds additionally have independent lateral bracing wires at all four corners?
							If located in a high seismic zone, is the suspended ceiling supported by a heavy duty ceiling grid with adequate capacity and does the grid include supplemental hanger wires at light fixtures or other mechanical items?
	Directly applied to structure	Falling hazard	6.3.4.2				Are decorative ceiling panels and/or latticework securely attached, particularly beneath exterior eves over exits?
							Are decorative finishes and/or latticework on beam soffits or beneath exterior eves securely attached, particularly over exits?
							For plaster ceilings or stucco soffits, is the wire mesh or wood lath securely attached to the structural framing above?
							Is the plaster or stucco in good condition and not deteriorated by water damage or corrosion?
	Suspended heavy ceilings	Falling hazard	6.3.4.3				If the suspended gypsum board ceiling extends over more than one level, does the suspended ceiling system have adequate diagonal bracing?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Is the suspended wire mesh or wood lath securely attached to the structural framing above?
							Is the plaster ceiling in good condition and not deteriorated by water damage?
6.3.5	**Parapets, Appendages, Roof Tiles**						
	Unreinforced masonry parapet	Falling hazard	6.3.5.1				Are unreinforced masonry parapets adequately braced? [If there is a local parapet ordinance, is it known if the bracing complies with the local ordinance?]
	Parapets, cornices, appendages	Falling hazard					Are parapets and cornices reinforced and adequately braced?
							Do other decorative elements and appendages have positive anchorage to the building?
							Are hanging appendages braced or secured with a safety cable?
6.3.6	**Canopies, Marquees, Signs**						
	Canopy, Marquees, Signs	Falling hazard	6.3.6.1				Are cantilevered elements braced to the structure with steel shapes, not chains, to provide restraint and prevent bouncing?
							Are exterior signs or billboards adequately braced and anchored?
							Are interior signs securely attached with positive connections?
	Flagpoles	Falling hazard					Are flagpoles securely attached to the structure?
6.3.7	**Chimneys and Stacks**						
	Unreinforced masonry chimney	Falling hazard	6.3.7.1				Is the brick chimney restrained with braces to the roof near the top of the chimney?
							Is the brick chimney anchored near the roof line?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Stacks	Falling hazard					Are stacks anchored to the supports or foundation by means of anchor bolts of adequate length and double nuts?
6.3.8	**Stairways**						
	Stairways		6.3.8.1				Do steel stairs in multistory buildings have sliding supports at one end that can accommodate the anticipated interstory displacements?
							Have any unreinforced masonry partitions, piping, or lighting in stairwells been removed, strengthened, encapsulated or braced, especially if the stairway is used as a primary exit route?
6.3.9	**Freestanding Walls or Fences**						
	Freestanding Walls or Fences	Falling hazard if over 4' tall	6.3.9.1				Were freestanding walls or fences designed by an architect/engineer to resist lateral forces?
							Are CMU walls adequately reinforced with vertical bars set in grout-filled cells and horizontal bars embedded in the mortar joints?
							Were CMU walls or fences built with adequate foundations to prevent them from tipping over in an earthquake?

6.4	Mechanical, Electrical and Plumbing Components						
Item No.	**Component Name**	**Principal Concerns**	**Example**	**C**	**NC**	**NA**	**Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)**
6.4.1	**Mechanical Equipment**						
	Boilers, furnaces, pumps and chillers (HVAC wet-side equipment)	Sliding, overturning, broken gas/fuel or exhaust lines, leaking fluids, loss of function	6.4.1.1				Are the boilers, pumps, chillers and similar wet-side HVAC equipment securely anchored to the floor or wall with adequately sized bolts?
							Do HVAC wet-side equipment items that are mounted on vibration isolators have adequate lateral restraint provided by snubbers, bumpers, or restrained vibration isolators?
							Are housekeeping pads under boilers and similar equipment anchored to the floor slab?
							Does the gas line have a flexible connection to the water heater or boiler that is able to accommodate movement?
							Are furnaces, and furnace or boiler bases, constructed without using unreinforced masonry?
	General manufacturing and process machinery	Falling hazards, hazardous material leaks or spills, loss of function	6.4.1.2				Is manufacturing and process machinery and related equipment, cranes, tanks, piping, chutes, and conveyors all adequately restrained and anchored, particularly items that may fall and injure workers, result in hazardous materials release, or create hazardous electrical conditions?
							Have all life safety hazards been addressed by bracing or anchoring clear falling hazards and other hazardous items?
							If immediate occupancy or operations is a project objective, has a design professional familiar with nonstructural anchorage of manufacturing and process machinery been engaged to perform a detailed survey of the plant?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	HVAC equipment with vibration isolation	Fall off isolators, overturning, broken gas/fuel or exhaust lines, leaking fluids, loss of function	6.4.1.3				Do HVAC dry-side equipment items such as air compressors, fans, blowers and filters that are mounted on vibration isolators have adequate lateral restraint provided by snubbers, bumpers, or restrained vibration isolators?
							If large equipment is mounted on a concrete housekeeping pad, is the pad adequately anchored into the structural slab?
							Do roof-mounted HVAC units that are mounted on vibration isolators have adequate lateral restraint provided by snubbers, bumpers, or restrained vibration isolators?
							For roof-mounted units, are the curbs supporting the vibration isolators securely attached to the structural roof framing?
	HVAC equipment without vibration isolation	Sliding, overturning, broken gas/fuel or exhaust lines, leaking fluids, loss of function	6.4.1.4				Is equipment (e.g. gas-fired boiler, commercial water heater, chiller, etc.) securely mounted to the floor, wall, or roof with adequately sized bolts?
							If large equipment is mounted on a concrete housekeeping pad, is the pad adequately anchored into the structural slab?
							Does the gas or fuel line have a flexible connection that is able to accommodate movement?
							For roof-mounted units, are the curbs supporting the vibration isolators securely attached to the structural roof framing?
							Are wall- or window-mounted window air conditioning units securely mounted to the wall or shelf?
	HVAC equipment	Falling or swinging	6.4.1.5				Is suspended equipment braced or anchored independently from the ductwork?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	suspended in-line with ductwork	hazard, separate from ductwork, loss of function					Does the equipment have flexible connections to gas, fuel, or electrical lines?
	Suspended equipment	Gas leak, falling hazard	6.4.1.6				Are the suspended room heaters, especially gas-fired ones, laterally supported?
							Are gas-fired heaters fitted with flexible gas connections?
6.4.2	**Storage Tanks and Water Heaters**						
	Structurally supported tanks and vessels	Tank or vessel rupture, pipe break	6.4.2.1				Is the tank securely attached to the supports?
							Are the tank supports braced in both directions?
							Are the tank supports attached with anchor bolts to concrete walls or foundation pad?
							Is the foundation large enough to keep the tank from sliding or tipping over?
							Is the wall strong enough to support the tank?
	Flat bottom tanks and vessels	Tank or vessel rupture, pipe break	6.4.2.2				Is the tank securely anchored to a concrete slab or foundation?
							Is the foundation large enough to keep the tank from sliding or tipping over?
	Compressed gas cylinders	Gas leak	6.4.2.3				Are all gas cylinders tightly secured with a chain near the top and bottom or otherwise restrained from movement in each direction?
							Are the chains or restraints securely anchored to a wall or counter with screws or bolts rather than clamps?
							If the gas cylinders are attached to piping, are the restraints adequate to prevent damage at the piping connections?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Water heaters	Gas leak, water leak, loss of function	6.4.2.4				Are the water heaters securely anchored to the floor or wall?
							Do the gas lines or electrical conduit and water lines have flexible connections to the water heater that are able to accommodate movement?
							Does the water heater meet the limitations for use of prescriptive restraints? Is the capacity less than 100 gallons and is there a structural wall within 12 inches?
							Does the wall have adequate strength to restrain the water heater?
6.4.3	**Pressure Piping**						
	Suspended pressure piping	Breaks, leaks, loss of function	6.4.3.1				Are the pipes laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
							Are the pipes free of asbestos insulation that could be damaged by movement in an earthquake?
							Are the pipes free of asbestos that would need to be abated before any retrofit work?
	In-line valves and pumps	Loss of function, leaks	6.4.3.2				Are the distribution pumps anchored, or are they mounted on vibration isolation springs with additional seismic lateral restraints?
							Are suspended valves and pumps adequately braced and anchored to structural elements?
	Flexible connections, expansion joints, seismic separations	Breaks, leaks, loss of function	6.4.3.3				Are flexible connections provided where piping connects to rigidly mounted equipment?
							Are flexible connections provided where pipes cross expansion joints or seismic separations between buildings?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are pipe penetrations through structural walls or framing members large enough to allow for some seismic movement?
	Pipe Risers	Breaks, leaks, loss of function	6.4.3.4				Are risers (vertical runs of piping) laterally restrained at each floor level or roughly at 20 foot intervals?
							For risers subject to thermal expansion and contraction, have the seismic supports been designed to allow ample thermal movement?
	Floor-mounted pipe supports	Breaks, leaks, loss of function	6.4.3.5				Are the pipes laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
	Roof-mounted pipe supports	Breaks, leaks, loss of function	6.4.3.6				Are the pipes laterally restrained at reasonable intervals in each direction and do the restraints appear adequate for the roof level? [Accelerations at the roof level are typically higher than at lower levels of a building.]
							Are the curbs and restraints securely attached to the structure and protected from weathering and corrosion?
	Wall-mounted pipe supports	Breaks, leaks, loss of function	6.4.3.7				Are the pipes laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
	Pipe penetrations	Breaks, leaks, loss of function	6.4.3.8				Are pipe penetrations through structural walls or framing members large enough to allow for some seismic movement or are the pipes restrained to prevent impact with the structural element?
6.4.4	**Fire Protection Piping**						
	Suspended fire protection	Damage to sprinkler	6.4.4.1				Are the fire sprinkler piping components laterally restrained in each direction?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	piping	heads, leaks, loss of function					Is the ceiling restrained so the ceilings won't break the sprinkler heads?
6.4.5	**Fluid Piping, not Fire Protection**						
	Hazardous materials	Breaks, leaks, hazardous materials release	6.4.5.1				Is the hazardous material piping laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
							Where required, does the hazardous material piping have double walls, secondary containment, leak detection systems or monitoring and are these systems designed for seismic loading?
							Do the pipes have flexible connections that are able to accommodate relative movement at locations where they are attached to rigidly mounted equipment or where they cross seismic separations?
							Does piping containing fuel or other hazardous materials have a seismic shut-off valve or excess flow valve?
							If the shut-off for the line is manual, is a wrench stored within easy reach?
	Nonhazardous materials	Breaks, leaks, loss of function	6.4.5.2				Is the piping laterally restrained at reasonable intervals in each direction?
							Are the restraints securely attached to the structure?
							Do the pipes have flexible connections that are able to accommodate relative movement at locations where they are attached to rigidly mounted equipment or where they cross seismic separations?
6.4.6	**Ductwork**						

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Suspended ductwork	Collapse, separation, leaking, fumes	6.4.6.1				Are the rectangular distribution ducts larger than 6 sq ft in cross sectional area laterally supported in each direction?
							Are circular ducts larger than 28 inches diameter laterally supported in each direction?
							Are the supports and hangers securely attached to the structure?
							Are the distribution ducts able to accommodate movement at locations where they cross separations between buildings?
	Air diffusers	Drop out of ceiling grid	6.4.6.2				Are the air distribution grills or diffusers anchored to adequately supported sheet-metal ducts or to the ceiling grid or wall?
							Do the diffusers have positive restraint, independent of the ceiling grid, such as at least two vertical hanger wires per diffuser?
6.4.7	**Electrical and Communications Equipment**						*Caution: Only qualified personnel should open access panels on electrical equipment.*
	Control panels, motor control centers, switchgear, etc.	Sliding or overturning, broken or damaged conduit or electrical bus	6.4.7.1				Are the control panels, motor control centers, switchgear and similar items all properly anchored to the floor or laterally supported by a structural wall?
							Do the walls used to support these electrical cabinets have adequate strength to restrain these items?
	Emergency generator	Failed vibration isolation mounts; broken fuel, signal, power and exhaust lines; loss of function	6.4.7.2				Is the emergency generator adequately secured, especially if mounted on motor vibration isolation springs?
							Is the concrete housekeeping pad adequately anchored to the structural slab?
							Is the diesel fuel tank adequately braced and anchored? (Refer to additional questions for structurally supported tanks and vessels).

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are the fuel lines, cooling water lines, and exhaust flues for the emergency generator attached with flexible connections that are able to accommodate relative movement at junctions to spring-mounted equipment, at building entry and exit points, and at expansion joints within the building?
							Have all the components of the emergency power generating system and the electrical distribution system been checked as part of this survey?
	Transformers	Sliding, oil leakage, bushing failure, loss of function	6.4.7.3				Are transformers properly anchored to the floor or wall?
	Batteries and battery rack	Batteries fall, rack tips; loss of emergency power	6.4.7.4				Are the batteries securely attached to the battery rack?
							Is the battery rack cross-braced in both directions?
							Does the battery rack have anchor bolts secured to a concrete foundation pad?
							Is the foundation large enough to keep the battery rack from sliding or tipping?
	Photovoltaic power systems	Falling hazard for roof mounted panels	6.4.7.5				Are the solar panels securely anchored to the roof?
							Is the piping laterally restrained?
	Communica-tions equipment	Sliding, overturning, or toppling leading to loss of function	6.4.7.6				Is the microwave communications equipment (antennae, receiver, transmitter, etc.) securely supported and/or anchored?
							Are the components of the public address system and phone system secured?
6.4.8	**Electrical and Communications Distribution Equipment**						

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Electrical raceways, conduit, cable trays	Electrical hazards, loss of function	6.4.8.1				Are the raceways, bus ducts, and cable trays all laterally braced, including both transverse and longitudinal braces at reasonable spacing?
							Are electrical cables or conduit able to distort at the connections with the equipment or where they cross seismic joints between buildings?
	Distribution panels	Electrical hazards, loss of function	6.4.8.2				Are the electrical distribution panels securely anchored to the floor or wall?
6.4.9	**Light Fixtures**						
	Recessed	Falling hazards	6.4.9.1				Are recessed lights securely attached to the ceiling grid to resist seismic shaking and is the ceiling grid adequately braced?
							Do the lay-in fluorescent light fixtures have positive support, independent of the ceiling grid, such as at least two diagonally opposite hanger wires per light fixture?
							Do lay-in fixtures weighing more than 50 pounds have independent lateral support?
							Are lens covers attached or supplied with safety devices?
	Surface-mounted	Falling hazards	6.4.9.2				Are spot lights or track lights securely attached to resist seismic shaking?
							Are exterior light fixtures properly supported or securely attached to the structure?
							Are emergency lights and exit lights mounted to protect them from falling off the wall or off shelf supports?
	Pendant light fixtures	Falling hazard, light fixture or	6.4.9.3				Do chandeliers or other hanging fixtures have safety cables to prevent them from impacting each other or a window?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
		unrestrained bulbs					Are lens covers attached or supplied with safety devices?
							Do pendant or stem light fixtures have safety cables so they will not fall if the fixture sways and breaks the stem connection, or are they braced to prevent swaying?
	Heavy light-fixtures	Falling hazards	6.4.9.4				Are heavy light fixtures, such as operating room lights, adequately braced and anchored to the structure independent of the ceiling system?
6.4.10	**Elevators and escalators**						*Caution: The moving parts or components of these systems need to be evaluated by qualified personnel. Inappropriate seismic restraints may compromise the safe operation of these systems.*
	Hydraulic elevator	Loss of function	6.4.10.1				Are the components of the hydraulic system properly anchored?
	Traction elevator	Loss of function, counter-weights out of guide rails, cables out of sheaves, dislodged equipment	6.4.10.2				Are the cables installed in such a way that they are protected against misalignment during an earthquake?
							Is the elevator cab properly attached to the guide rails?
							Are the counterweights properly attached to the guide rails?
							Are the guide rails securely attached to the building?
							Are the motor and motor control cabinets properly anchored?
							Is the elevator equipped with a seismic switch?
	Escalators	Loss of function	6.4.10.3				Is the escalator control equipment securely anchored?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Is it known if the escalator was designed by an engineer to accommodate relative movement between floors during an earthquake?
							Is the control equipment for the moving walkway properly anchored?
6.4.11	**Conveyors, material handling**						
	Conveyors	Loss of function, falling hazard if elevated, contents fall	6.4.11.1				Are supports for the conveyors properly anchored to the floor or wall?
							Is the conveyor control equipment properly anchored?

6.5	Furniture, Fixtures & Equipment and Contents						
Item No.	**Component Name**	**Principal Concerns**	**Example**	**C**	**NC**	**NA**	**Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)**
6.5.1	**Storage racks**						
	Light duty shelving	Contents fall, shelves damaged	6.5.1.1				Are tall shelving units securely anchored to the floor or walls?
							If walls are used for lateral support, has the capacity of the walls been checked for adequacy to restrain the shelving?
							Are heavily loaded shelving units supported in both directions?
							For shelving units significantly taller than wide, are large anchor bolts used to anchor each leg to a concrete slab?
							Are breakable items secured to the shelves, or are they stored in stable units (e.g., are they shelved in the original packing boxes, or are small items shrink-wrapped together)?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Industrial storage racks	Contents fall, racks damaged	6.5.1.2				Are industrial storage racks braced and anchored to a concrete floor slab or concrete walls?
							If walls are used for lateral support, has the capacity of the walls been checked for adequacy to restrain the shelving?
							Has the capacity of the concrete floor slab been checked for adequacy to resist uplift of the storage racks?
							Are the racks equipped with dampers, base isolation, or other specialized seismic restraint systems?
6.5.2	**Bookcases, Shelving**						
	Bookshelves	Contents fall, shelving damaged	6.5.2.1				Are bookshelves 5' or taller properly anchored with brackets to a solid wall or studs, or anchored to the floor, particularly if they are located next to a bed or desk or where they could block an exit?
							Does the wall or partition used to anchor the book shelves have adequate strength to support seismic loading from the shelving?
							Are bookshelves fitted with edge restraints or elastic cords to keep books from falling?
							Are large and heavy books located on the lowest shelves?
	Library and other shelving	Contents fall, shelving damaged	6.5.2.2				Is it known if the lateral supports for the library stacks and shelving have been designed by an architect or engineer?
							Are library shelving and stacks properly braced and anchored to the floor and walls, including bracing to the floor above if shelving is tall and slender that tie the shelving units together?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							If all shelving units are not independently braced or anchored, are adjacent units fastened together with bolts or other mechanical fasteners?
							Do walls or partitions used to anchor library stacks have adequate strength for the imposed lateral loads?
							Are bookshelves fitted with edge restraints or elastic cords to keep books from falling?
							Are large and heavy books located on the lowest shelves?
							Are rare or fragile books given extra protection to prevent falling and water damage?
6.5.3	**Computer and Communications Equipment**						
	Computer access floors and equipment	Collapse, separation between modules, loss of function	6.5.3.1				Are the support pedestals for computer access floors anchored to the floor and braced with diagonal steel members, or is it verified that the vertical pedestals are a seismically qualified model, installed in accordance with the manufacturer's recommendations?
							Do cable openings in the access floor have edge guards to prevent equipment legs from sliding into the openings
							Are computers, tape racks, and associated equipment that are about twice as tall as wide, anchored, tethered, and/or laterally supported?
							Does heavy computer equipment have supports which are braced and anchored to the structural floor slab independently of the computer access floors?
							Is computer cabling long enough to accommodate lateral movement within the building?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Computer and communication racks	Lost data or damaged equipment may cause downtime	6.5.3.2				Is computer information vital to operations backed up and stored off-site?
							Is critical computer and communications equipment securely anchored to the rack?
							Are computer and communication racks securely anchored to the floor or wall?
							Is sensitive computer or communications equipment located out of range of fire sprinkler heads or joints in the sprinkler pipes where they are less prone to water damage if the sprinkler lines break?
	Desktop computers and accessories	Falling hazard, lost data or damaged equipment may cause downtime	6.5.3.3				Are computers and monitors anchored to desktops?
							Are desktop or countertop computers and printers mounted with positive restraint, resting on high-friction rubber pads, or located far enough from the edges of desks and tables to prevent them from sliding and falling in an earthquake?
	Televisions and video monitors, wall-mounted	Falling hazard	6.5.3.4				Are wall- or overhead-mounted television sets, video monitors, surveillance cameras or sound system speakers securely braced and anchored to the wall or ceiling or equipped with safety cables?
6.5.4	**Hazardous materials storage**						
	Hazardous materials storage	Hazardous material release, mixing of incompatible substances	6.5.4.1				Are chemical supplies secured with shelf lips several inches high, or are they stored in "egg crate" containers in drawers, so that the containers will not overturn or fall and spill?
							Are chemicals stored in accordance with manufacturers' recommendations?
							Are incompatible chemicals stored at an appropriate distance from one another so that they will not mix if the containers are broken?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are the chemicals in each cabinet catalogued properly and marked clearly?
							Are Material Safety Data Sheets (MSDSs) stored in a location separate from the chemicals?
							Are cabinets for hazardous materials securely attached to the floor or to a sturdy wall?
							Has asbestos insulation been removed, or has it been encapsulated to reduce the possibility of damage in an earthquake?
							Is the facility free of asbestos that would need to be abated before any retrofit work?
6.5.5	**Miscellaneous FF&E**						
	File cabinets	Cabinets fall, may block exits, contents spill	6.5.5.1				Do the file cabinet drawers or doors latch securely?
							Are tall file cabinets anchored with wall brackets to a solid wall or studs, anchored to the floor, or bolted to one or more adjacent cabinets to form a more stable configuration, i.e., a larger "footprint"?
							Are unanchored cabinets located so that they will not fall or slide and block a door or exit?
	Demountable partitions	Collapse, block exit path	6.5.5.2				Are demountable partitions attached to each other and arranged in a stable layout with many perpendicular wall segments?
							Are partial-height partitions anchored to the floor?
							If tall shelving or cabinets are located next to the partitions, can these items be moved or independently anchored to the floor or structure?
	Miscellaneous furniture and fixtures	Falling hazard	6.5.5.3				Are tall items located near beds or desks securely anchored to a wall with adequate capacity?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are large kitchen and laundry equipment all securely anchored to the floor, wall, or countertop with adequate capacity?
							Are vending machines tethered a column or wall to prevent tipping and sliding?
							Are unanchored furnishings located where they cannot slide or overturn to block corridors or doors?
							Are heavy wall pictures and other wall hangings well anchored to the studs or structural framing?
							Are heavy hanging plants secured to prevent falling or impact with windows?
							Are personal or storage lockers and vending machines anchored and laterally supported, or are they clear of exits?
6.5.6	**Miscellaneous Contents**						
	Shelf-mounted items	Contents fall, items broken or mixed	6.5.6.1				Are valuable or fragile items protected against tipping or falling off shelving?
							Are the drawers and cabinet doors latched securely, e.g., with special latches or baby-proof hardware that will not fly open in an earthquake?
							Are rare or valuable items (rare books, museum collections, medical records) given extra protection against falling and water damage?
							Are heavy potted plants on file cabinets or tall shelves restrained to prevent falling?
	Desktop, countertop items		6.5.6.2				Is radio equipment restrained to keep it from sliding off shelving or tabletops?
							Is important equipment restrained to keep it from sliding off shelving or tabletops?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are fax machines restrained or placed far enough from the edge that they will not slide and fall off?
							Is the public address system restrained to prevent the equipment from sliding and falling off the shelving?
	Fragile artwork	Loss of rare or expensive art objects, falling hazards	6.5.6.3				Are heavy sculptures anchored to prevent overturning during an earthquake?
							Are heavy wall-mounted paintings, mirrors, or other wall hangings well anchored to structural studs or framing?
							Do hanging sculptures or mobiles have a safety cable to prevent them from swinging excessively, impacting windows or other artwork, or falling?
							Are fragile items restrained by mono-filament lines, hook and loop material, Plexiglas display cases, or some other seismic safety device?
	Fire extinguisher and cabinet		6.5.6.4				Are the fire extinguisher cabinets and/or hose cabinets securely mounted?

	Emergency Systems						
Item No.	**Component Name**	**Principal Concerns**	**Example**	**C**	**NC**	**NA**	**Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)**
	Emergency Egress						*Emergency system components were not covered in the body of the document but are an important consideration for providing earthquake safety.*
	Emergency Egress	Exit doors jammed, corridors blocked, no emergency lighting, falling hazards	6.6.1.1				If primary exit doors are heavy metal fire doors that might jam if the building racks during an earthquake, is there a crowbar or sledgehammer located near the exit to facilitate emergency exiting?
							Do automatic doors with optical or floor sensors and mechanized roll-up doors have a manual override in case of a power outage after an earthquake?
							Are the building utilities and architectural finishes along egress routes (piping, ducts, ceilings, lights, partitions, etc.) braced or anchored adequately to prevent falling obstructions and to keep the egress routes clear after an earthquake?
							Are the furniture and contents along egress routes (desks, supply cabinets, shelving, etc.) braced or anchored adequately to prevent falling obstructions and keep the egress routes clear after an earthquake?
							Are unanchored furniture and contents along egress routes kept far enough from the exits so they will not fall or slide and obstruct the doors?
							Have any unreinforced masonry walls in stairwells, corridors, and elevator enclosures been removed, strengthened, or encapsulated to prevent collapse during an earthquake?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
							Are parapets, canopies, veneers, cornices and any other ornamentation above building exits braced and anchored to prevent collapse?
							Are emergency lights and exit lights securely mounted to protect them from falling off walls or shelf supports during an earthquake?
							Are transoms, skylights, corridor glazing or glazing above exits made of safety glass or covered with shatter-resistant film?
							If the building has elevators, does the elevator have a seismic switch?
	Emergency Power Generation and Distribution System	Loss of function					Is the emergency generator adequately secured, especially if mounted on motor vibration isolation springs?
							Is the concrete housekeeping pad adequately anchored to the structural slab?
							Is the diesel fuel tank adequately braced and anchored?
							Are the batteries and battery racks adequately braced and anchored?
							Are the fuel lines, cooling water lines, and exhaust flues for the emergency generator attached with flexible connections that are able to accommodate relative movement at junctions to spring-mounted equipment, at building entry and exit points, and at expansion joints within the building?
							Have the transformer, MCC, switchgear and bus ducts been checked?
							Have all the components of the emergency power generating system and the electrical distribution system been checked as part of this survey?

Item No.	Component Name	Principal Concerns	Example	C	NC	NA	Checklist Questions (Yes=Compliance; No or Unknown=Noncompliance; NA=Not Applicable)
	Fire Detection and Protection System	Loss of function					Are fire and smoke detectors properly mounted?
							Is the control equipment for the fire alarm system and automatic fire doors securely anchored?
							Are the fire extinguisher cabinets and/or hose cabinets securely mounted?
							Are the fire extinguishers secured with quick-release straps?
							Are the fire sprinkler piping components laterally restrained in each direction?
							Is the ceiling restrained so the ceilings won't break the sprinkler heads?
							Are the distribution lines able to accommodate movement where they cross between buildings?
							Is the fire water pump anchored, or is it mounted on vibration isolation springs with additional seismic restraints?
							Is the emergency water tank or reservoir securely attached to its supports?
							Are the tank supports anchored to the floor and braced in both directions?
							Are the supports or braces properly anchored to the foundation?
							Are the smoke control fans properly supported and/or anchored?
							Are the fan control centers securely anchored?
	Emergency Supply Cabinet	Supplies inaccessible in emergency					Is the cabinet properly braced and anchored to the floor and/or walls?

E. Nonstructural Seismic Risk Ratings

The risk ratings that appear in this Appendix are provided as an aid to establishing priorities. Nonstructural components are organized by component type, and estimates of the potential risk posed by the component are given for different ground shaking intensities. Each component is rated for High (H), Moderate (M) or Low (L) potential risk to Life Safety, Property Loss, and Functional Loss. The seismic risk ratings are based on the following definitions and assumptions:

SHAKING INTENSITY: For a particular geographic location in the United States, the shaking intensity may be estimated by using the seismic map in Figure 3.2.1-1 that shows the areas that are likely to experience minimal, low, moderate, or high ground shaking during future probable maximum considered earthquake events that may affect the areas. The shaking intensity estimates based on the map in Figure 3.2.1-1 should be adequate for items situated at or near the ground in simple, nonessential facilities. For other situations, it may be advisable to choose the next higher shaking intensity or to seek the advice of professional consultants. Note that for areas with light shaking, a full blown upgrade of nonstructural components may not be warranted, unless an owner is particularly risk averse; the current code would not require many of the protective measures recommended herein, even for new construction.

LIFE SAFETY (LS) RISK: Risk of death or direct injury requiring hospitalization.. This does not include the overall impact on life safety systems in a building, such as loss of emergency power in a hospital or loss of fire detection or suppression capability. These disruptions of service are covered under Functional Loss below.

PROPERTY LOSS (PL) RISK: Risk of incurring a repair or replacement cost because of damage to the item. This property loss, as used here, includes the cost of fixing a broken pipe but not the indirect cost of water leakage damage, and includes the cost of repairing a computer but not the loss of business revenue computer downtime might cause. These indirect effects cannot be estimated here on a generic basis.

FUNCTIONAL LOSS (FL) RISK: Risk that the item will not function because it has been damaged. This includes some consideration of the impact of this loss of function of the component on the operation of an ordinary occupancy building. Not included are off-site functional impacts, such as the loss of function of a piece of equipment because of a city-wide

power outage. Outages of power, water, and other utility company or agency services are real problems to consider but are outside the scope of the item-by-item ratings here.

TYPE OF DETAIL: For components where an illustrated example is provided in Chapter 6, the detail type is indicated as Non-engineered (NE), Prescriptive (PR), or Engineering Required (ER). The example number (e.g. 6.3.1.1 for adhered veneer) is shown at the left.

ASSUMPTION 1: The risk ratings are based on the assumption that the item has been installed without seismic bracing, seismic anchorage, seismic restraint, or allowance for differential movements. In areas of the U.S. where seismic building code provisions have only recently been enforced, this assumption will be generally true. In areas of the western U.S. where seismic codes have been enforced for some time, this assumption may not always be true. Particularly in buildings constructed in the western states since the mid-1970s, some nonstructural items may be anchored or braced, but the assumption of unanchored and unbraced items will still be true for many items on these lists.

ASSUMPTION 2: The item is assumed to be located at or near the ground level, or in a low-rise building. The most common case of a relatively stiff low-rise building with structural walls is presumed in the ratings here. Items such as full-height partitions and glazing are more likely to be damaged in flexible buildings that experience large lateral deformations. Damage to items sensitive to imposed deformation will be greater in buildings or portions of buildings that are more flexible, such as mid- and high-rise buildings; flexible frame buildings without significant structural walls; "soft stories" of buildings with structural walls in most stories but with a story, typically the ground story, that is much less laterally stiff because of the absence of walls; and the "soft wall" sides of bearing wall buildings where there is little or no solid wall area, such as the face of a typical commercial storefront building.

ASSUMPTION 3: For building occupancy, an ordinary occupancy category is assumed. Thus, in the case of essential or specialized facilities, some nonstructural components would be rated differently. For example, in this appendix the risk ratings are given for shelving in an ordinary occupancy building, but the same shelving would be rated quite differently with regard to Life Safety risk in a lab, Property Loss risk in a museum, or risk of Functional Loss in a communications center.

For most of the nonstructural components listed below, the risk ratings for those components would be reduced significantly if the components were installed or retrofitted in accordance with recommendations of Chapter 6 or were installed within a seismically isolated building.

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.3	**Architectural Components**					
6.3.1	**Exterior Wall Components[1]**					
6.3.1.1	Adhered veneer	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.3.1.2	Anchored veneer	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.3.1.3	Prefabricated panels	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	M	
6.3.1.4	Glazed exterior wall system	Low	L	L	L	ER
		Mod	M	M	L	
		High	H	M	M	
6.3.1.5	Glass blocks	Low	L	L	L	ER
		Mod	M	M	L	
		High	H	H	M	
N/A	Overhead glazing or skylights	Low	L	L	L	
		Mod	H	M	L	
		High	H	M	M	
6.3.2	**Partitions[2]**					
6.3.2.1	Heavy (CMU, brick, hollow clay tile)	Low	L	L	L	ER
		Mod	H	H	H	
		High	H	H	H	
6.3.2.2	Light (partial- or full-height stud wall partitions)	Low	L	L	L	ER
		Mod	M	M	M	
		High	M	H	H	
6.3.2.3	Glazed	Low	L	L	L	ER
		Mod	M	M	L	
		High	M	H	M	
6.3.3	**Interior Veneers[2]**					
6.3.3.1	Stone and tile	Low	L	L	L	ER
		Mod	H	H	M	
		High	H	H	M	
6.3.4	**Ceilings**					
6.3.4.1	Suspended acoustic lay-in tile ceiling	Low	L	L	L	PR
		Mod	L	M	M	
		High	M	H	H	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.3.4.2	Directly applied to structure	Low	L	L	L	NE
		Mod	M	M	M	
		High	M	H	H	
N/A	Soffits (stucco, gypsum board, plaster)	Low	L	L	L	
		Mod	M	M	M	
		High	H	H	H	
6.3.4.3	Suspended heavy ceilings	Low	L	L	L	PR
		Mod	M	M	M	
		High	H	H	H	
6.3.5	**Parapets, Appendages, Roof Tiles**					
6.3.5.1	Unreinforced masonry parapet	Low	M	M	L	ER
		Mod	H	H	L	
		High	H	H	L	
N/A	Parapets, cornices, decoration	Low	M	M	L	
		Mod	H	H	L	
		High	H	H	L	
N/A	Hanging appendages	Low	L	L	L	
		Mod	H	H	L	
		High	H	H	M	
N/A	Clay roof tiles[1]	Low	L	L	L	
		Mod	L	M	L	
		High	M	H	M	
6.3.6	**Canopies, Marquees, Signs**					
6.3.6.1	Canopies, Marquees, Signs	Low	L	L	L	ER
		Mod	H	H	L	
		High	H	H	M	
N/A	Heavy signs or exterior billboards	Low	L	L	L	
		Mod	H	H	L	
		High	H	H	L	
N/A	Flagpoles	Low	L	L	L	
		Mod	L	L	L	
		High	M	L	L	
6.3.7	**Chimneys and Stacks**					
6.3.7.1	Unreinforced masonry chimney	Low	L	L	L	ER
		Mod	M	M	L	
		High	H	M	M	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
N/A	Stacks, small	Low	L	L	L	
		Mod	M	M	L	
		High	H	M	M	
6.3.8	**Stairways**					
6.3.8.1	Stairways	Low	L	L	L	
		Mod	H	M	M	ER
		High	H	M	H	
6.3.9	**Freestanding Walls or Fences**					
6.3.9.1	Freestanding Walls or Fences	Low	L	L	L	
		Mod	L	L	L	PR
		High	M	H	M	
6.4	**Mechanical, Electrical, & Plumbing Components**					
6.4.1	**Mechanical Equipment**					
6.4.1.1	Boilers, furnaces, pumps and chillers (HVAC wet side)	Low	L	L	L	
		Mod	L	L	L	ER
		High	M	M	H	
N/A	Boilers and furnaces (rigid mount)	Low	L	L	L	
		Mod	L	L	L	
		High	M	M	M	
N/A	Chillers	Low	L	L	L	
		Mod	L	L	L	
		High	L	M	H	
N/A	Heat pumps or heat exchangers	Low	L	L	L	
		Mod	L	L	L	
		High	L	M	M	
6.4.1.2	General manufacturing and process machinery	Low	L	L	L	
		Mod	M	M	M	ER
		High	M	H	H	
6.4.1.3	HVAC equipment with vibration isolation	Low	L	L	L	
		Mod	L	M	L	ER
		High	L	M	M	
N/A	Fans, blowers, filters	Low	L	L	L	
		Mod	L	M	L	
		High	L	M	M	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
N/A	Air compressors	Low	L	L	L	
		Mod	L	M	L	
		High	L	M	M	
N/A	Roof mounted HVAC units	Low	L	M	L	
		Mod	L	M	L	
		High	M	H	M	
N/A	Roof mounted equipment, vents or flues	Low	L	L	L	
		Mod	L	M	L	
		High	M	M	M	
6.4.1.4	HVAC equipment without vibration isolation (rigid mount)	Low	L	L	L	ER
		Mod	L	L	L	
		High	L	M	M	
N/A	Wall-mounted room air conditioning units	Low	L	L	L	
		Mod	M	M	L	
		High	M	M	L	
6.4.1.5	HVAC equipment suspended in-line with ductwork	Low	L	L	L	ER
		Mod	L	M	L	
		High	L	M	M	
6.4.1.6	Suspended equipment	Low	L	L	L	ER
		Mod	H	H	L	
		High	H	H	L	
6.4.2	**Storage Tanks and Water Heaters**					
6.4.2.1	Structurally supported tanks and vessels	Low	L	L	L	ER
		Mod	M	H	M	
		High	M	H	M	
N/A	Diesel fuel tank	Low	L	L	L	
		Mod	H	H	L	
		High	H	H	M	
N/A	Propane tank	Low	L	L	L	
		Mod	H	H	M	
		High	H	H	M	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.4.2.2	Flat bottom tanks and vessels	Low	L	L	L	ER
		Mod	M	H	M	
		High	M	H	M	
6.4.2.3	Compressed gas cylinders (oxygen, CO_2, ammonia, etc.)	Low	L	L	L	NE
		Mod	M	M	L	
		High	H	M	M	
6.4.2.4	Gas water heaters	Low	L	L	L	PR
		Mod	M	H	L	
		High	H	H	L	
6.4.3	**Pressure Piping**					
6.4.3.1	Suspended pressure piping	Low	L	L	L	ER
		Mod	M	M	M	
		High	M	H	M	
6.4.3.2	In-line valves and pumps	Low	L	L	L	ER
		Mod	M	M	M	
		High	M	M	M	
6.4.3.3	Flexible connections, expansion joints and seismic separations	Low	L	L	L	ER
		Mod	M	M	M	
		High	M	M	M	
6.4.3.4	Pipe Risers	Low	L	L	L	ER
		Mod	L	M	M	
		High	M	M	M	
6.4.3.5	Floor-mounted supports	Low	L	L	L	ER
		Mod	L	M	M	
		High	M	M	M	
6.4.3.6	Roof-mounted supports	Low	L	L	L	ER
		Mod	L	M	M	
		High	M	M	M	
6.4.3.7	Wall-mounted supports	Low	L	L	L	ER
		Mod	M	M	M	
		High	M	M	M	
6.4.4	**Fire Protection Piping**					
6.4.4.1	Suspended fire protection piping	Low	L	M	M	ER
		Mod	L	H	H	
		High	M	H	H	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.4.5	**Fluid Piping, not Fire Protection**					
6.4.5.1	Hazardous materials	Low	L	L	L	ER
		Mod	H	H	H	
		High	H	H	H	
N/A	Fuel line	Low	L	L	L	
		Mod	H	H	L	
		High	H	H	M	
6.4.5.2	Nonhazardous materials	Low	L	L	L	ER
		Mod	M	M	M	
		High	M	M	M	
6.4.6	**Ductwork**					
6.4.6.1	Suspended Ductwork	Low	L	L	L	ER
		Mod	L	L	L	
		High	M	M	L	
6.4.6.2	Air diffuser	Low	L	L	L	NE, ER
		Mod	M	M	L	
		High	M	HM	L	
6.4.7	**Electrical and Communications Equipment**					
6.4.7.1	Control panels, motor control centers and switchgear	Low	L	L	L	ER
		Mod	L	L	L	
		High	M	M	M	
6.4.7.2	Emergency generator	Low	L	L	M	ER
		Mod	L	M	H	
		High	L	H	H	
6.4.7.3	Transformers	Low	L	L	L	ER
		Mod	L	L	L	
		High	M	M	M	
6.4.7.4	Batteries and battery rack	Low	L	L	L	ER
		Mod	L	H	M	
		High	L	H	H	
6.4.7.5	Photovoltaic power systems (Solar panels)	Low	L	L	L	ER
		Mod	L	L	L	
		High	M	M	L	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.4.7.6	Communication antennae	Low	L	L	L	ER
		Mod	L	M	L	
		High	M	H	M	
6.4.8	**Electrical and Communications Distribution Equipment**					
6.4.8.1	Electrical raceways, conduit, and cable trays	Low	L	L	L	ER
		Mod	L	M	M	
		High	M	M	M	
6.4.8.2	Distribution panels	Low	L	L	L	ER
		Mod	L	L	L	
		High	M	M	M	
6.4.9	**Light Fixtures**					
6.4.9.1	Recessed	Low	L	L	L	PR
		Mod	H	L	L	
		High	H	M	M	
6.4.9.2	Surface-mounted lighting	Low	L	L	L	PR
		Mod	H	L	L	
		High	H	M	M	
6.4.9.3	Pendant light fixtures	Low	L	L	L	NE
		Mod	H	L	L	
		High	H	M	M	
6.4.9.4	Heavy light fixtures	Low	L	L	L	NE
		Mod	H	L	L	
		High	H	M	M	
N/A	Exterior lighting	Low	L	L	L	
		Mod	M	L	L	
		High	M	M	M	
6.4.10	**Elevators and Escalators**					
6.4.10.1	Hydraulic Elevator (cab and elevator equipment)	Low	L	L	L	ER
		Mod	L	M	M	
		High	M	M	M	
6.4.10.2	Traction Elevator (elevator cab and shaft doors)	Low	L	L	L	ER
		Mod	L	M	M	
		High	M	M	H	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
N/A	Cables, counterweights and guide rails (for cable-traction system)	Low	L	L	L	
		Mod	H	M	M	
		High	H	M	M	
N/A	Elevator motor and motor control cabinets	Low	L	L	L	
		Mod	L	M	M	
		High	L	H	M	
6.4.10.3	Escalator	Low	L	L	L	
		Mod	M	M	M	ER
		High	H	H	H	
6.4.11	**Conveyors**					
6.4.11.1	Conveyors	Low	L	L	L	
		Mod	L	M	M	ER
		High	M	M	M	
6.5	**Furniture, Fixtures, & Equipment**					
6.5.1	**Storage racks**					
6.5.1.1	Light duty shelving	Low	L	L	L	
		Mod	H	M	M	NE, ER
		High	H	M	M	
6.5.1.2	Industrial storage racks	Low	L	L	L	
		Mod	H	M	M	ER
		High	H	H	M	
6.5.2	**Bookcases, Shelving**					
6.5.2.1	Bookshelves	Low	L	L	L	
		Mod	H	M	M	NE
		High	H	M	M	
6.5.2.2	Library and other helving	Low	L	L	L	
		Mod	H	M	M	ER
		High	H	M	M	
6.5.3	**Computer & Communications Equipment**					
6.5.3.1	Computer access floors	Low	L	L	L	
		Mod	L	L	M	ER
		High	M	H	H	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
N/A	Large computer equipment	Low	L	L	L	
		Mod	L	M	M	
		High	M	H	M	
N/A	Computer networks, data storage	Low	L	L	L	
		Mod	L	M	H	
		High	L	H	H	
N/A	Computer cabling	Low	L	L	L	
		Mod	L	L	L	
		High	L	L	L	
6.5.3.2	Computer and communication racks	Low	L	L	L	NE
		Mod	L	H	M	
		High	M	H	M	
6.5.3.3	Desktop computers and accessories	Low	L	L	L	NE
		Mod	L	H	M	
		High	L	H	M	
6.5.3.4	Television and video monitors, cameras, wall-mounted	Low	L	L	L	NE
		Mod	H	H	L	
		High	H	H	L	
N/A	Suspended speakers in conference room or auditorium	Low	L	L	L	
		Mod	M	M	L	
		High	H	H	L	
6.5.4	**Hazardous materials storage**					
6.5.4.1	Hazardous materials storage, cabinet and contents	Low	L	L	L	NE
		Mod	H	M	H	
		High	H	M	H	
N/A	Chemical, laboratory, medical supplies	Low	L	L	L	
		Mod	H	M	L	
		High	H	M	M	
N/A	Asbestos	Low	L	M	M	
		Mod	L	H	H	
		High	L	H	H	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
6.5.5	**Miscellaneous FF&E**					
6.5.5.1	File cabinets, tall vertical or lateral files	Low	L	L	L	NE
		Mod	M	M	M	
		High	H	M	M	
6.5.5.2	Demountable partitions	Low	L	L	L	NE
		Mod	L	L	L	
		High	M	M	M	
6.5.5.3	Miscellaneous furniture under 4' tall	Low	L	L	L	NE
		Mod	L	L	L	
		High	L	L	L	
N/A	Large kitchen or laundry equipment	Low	L	L	L	
		Mod	M	M	L	
		High	M	H	M	
N/A	Lockers, vending machines	Low	L	L	L	
		Mod	H	M	L	
		High	H	M	L	
N/A	Freestanding wood stove (wood, pellet, or gas-fired)	Low	L	L	L	
		Mod	M	M	M	
		High	H	H	H	
6.5.6	**Miscellaneous Contents**					
6.5.6.1	Shelf-mounted items	Low	L	L	L	NE
		Mod	M	M	L	
		High	H	M	M	
N/A	Especially valuable or fragile merchandise	Low	L	M	L	
		Mod	L	H	L	
		High	L	H	L	

Example No.	Example Name	Shaking Intensity	Life Safety (LS)	Property Loss (PL)	Functional Loss (FL)	Type of Detail
N/A	Potted plants or indoor landscaping resting on shelves above the floor	Low	L	L	L	
		Mod	L	L	L	
		High	M	L	L	
6.5.6.2	Desktop, countertop items	Low	L	L	L	
		Mod	L	M	L	NE
		High	L	H	M	
6.5.6.3	Fragile artwork	Low	L	L	L	
		Mod	L	H	L	NE
		High	L	H	L	
N/A	Tall sculptures (over 5 ft)	Low	L	L	L	
		Mod	M	M	L	
		High	H	H	L	
6.5.6.4	Fire extinguisher and cabinet	Low	L	L	L	
		Mod	M	H	L	NE
		High	M	H	L	

Footnotes:

1. Ratings for exterior components assume an entrance or walkway is located near the exterior wall. At locations where there is limited access, the life safety risk would be low.
2. Ratings assume component is located in a corridor or along the path of egress.

F. POST-EARTHQUAKE DATA COLLECTION FORMS

Two post-earthquake data collection forms were developed for two nonstructural components: (1) suspended acoustical tile ceilings and (2) metal stud partitions. Collection of these data is essential to advancing the protection of nonstructural components. These forms are intended to serve as a starting point for data collection subject to revision and refinement as they are used in the field. Other similar forms can be developed for other systems and components when resources become available.

The forms are provided as Microsoft word files on the CD-ROM and should be customized for use in projects.

FEMA E-74 – Detailed Post-Earthquake Condition Assessment: Suspended Acoustical Tile Ceiling

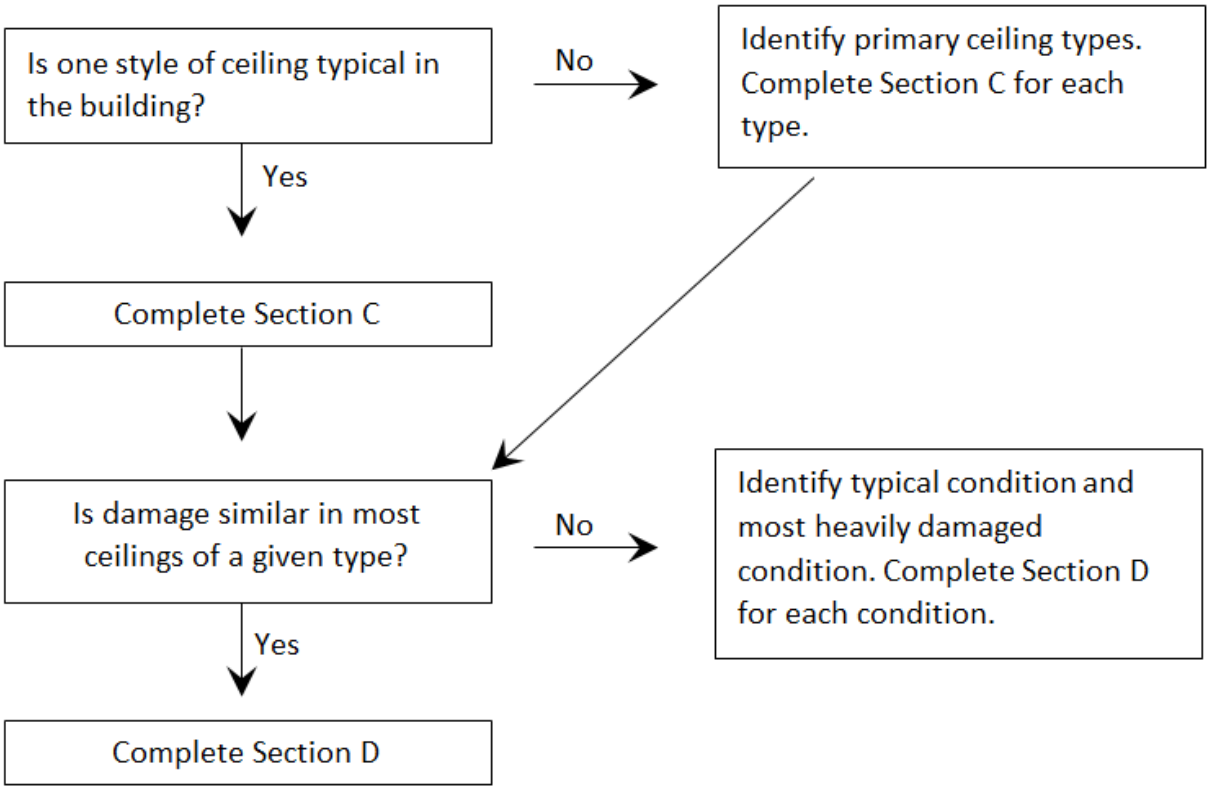
INSTRUCTIONS TO USERS:

The purpose of a detailed investigation is to collect data that can be used to quantitatively evaluate the performance of suspended acoustic tile ceilings in earthquakes.
The following procedure is recommended for a comprehensive ceiling investigation in one building:

Step 1: Observe building or review drawings to describe basic construction characteristics. Complete Section A.

Step 2: Walk through building. Assess overall building condition and general condition of ceilings. Assess whether ceilings in some floors are more heavily damaged than others. Complete Section B.

Step 3: Complete Sections C and D, as required, to describe ceiling construction and conditions in one building. The flowchart below is intended to provide guidance on determining how many ceilings to examine in detail. Consideration should be given to the scope and nature of damage, and any unique factors that may have caused damage.



For example:

- If the ceilings in one story appear to be more heavily damaged than in other floors, but construction is similar throughout the building, Section C should be completed to describe the typical construction and two Section D forms should be completed as follows: one for the typical ceiling in the heavily damaged floor and one for the typical floor.
- If construction or conditions vary throughout the building, complete Section C and D forms should be prepared to describe predominant ceiling types and typical damage. Additional Sections C and D forms should be completed to capture unique features.

FEMA E-74 – Detailed Post-Earthquake Condition Assessment: Suspended Acoustical Tile Ceiling

SECTION A: Building Description

Inspection

Inspector ID:_____

Affiliation: _____

Inspection Date and Time: _____

Building Description

Building name: _____

Address: _____

_____

Building contact/phone: _____

No. of stories above ground: _____ below ground: _

Approx. footprint area (square feet): _____

Typical Floor Construction

☐ Concrete slab

☐ Metal deck and concrete fill

☐ Plywood ☐ with topping slab ☐ without topping slab

☐ Other: _____

Building Lateral Force Resisting System

☐ Concrete or Masonry Shear Wall

☐ Plywood Shear Wall

☐ Concrete Moment Frame ☐ Steel Braced Frame

☐ Steel Moment Frame ☐Base Isolated

☐ Other: _____

Primary Occupancy

☐Retail ☐Government ☐Residential

☐Offices ☐Historic ☐Public Assembly

☐Industrial ☐School ☐Emergency Services

☐Other:_____

SECTION B: Damage Descriptions

Building Posting, if known:
☐ Inspected
☐ Restricted Use
☐ Unsafe
☐ Comments: _____

Structural Damage:
☐ Minor/None: _____
☐ Moderate: _____
☐ Severe: _____

Ground Movement:
☐ None Observed
☐ Observed:_____

General Ceiling Damage:
☐ None
☐ Minor (less than 1% of tiles dislodged, no damage to the grid)
☐ Moderate (upto 1/3 of tiles dislodged, minor repairable damage to grid)
☐ Severe (severe damage to tiles and grid requiring reconstruction of ceiling)

Floor by Floor:
☐ Ceilings in all floors appear to be in about the same condition.
☐ Ceilings in some floors are more heavily damaged than in others.
List floors with most damage: _____

SECTION C: Ceiling Definition (Use separate assessment form for each ceiling area investigated)

Floor: _____

Location in building (sketch plan – see page 7)

Ceiling Area (within full height walls, braced soffits or other terminations) L x W: _____' x _____'

Tile: Type: ☐ Acoustic Tile 2'x2' ☐ Acoustic Tile 2'x4' ☐ Other:_____

Grid: Type: ☐ Heavy Duty ☐ Medium Duty ☐ Other:_____
Spacing of Main Tees: ☐ 4' ☐ Other:_____
Spacing of Cross Tees: ☐ 2' ☐ Other:_____
Splices: ☐ Capable of Resisting 180# in Tension and Compression ☐ Other:_____

Hangers:
Gauge: ☐ 12 Gauge ☐ Other:_____
Spacing: ☐ 4' each way ☐ Other:_____
Connection to Structure:
☐ Powder Actuated Fastener ☐ Expansion Anchor ☐Wire Loop
☐Screw ☐Nail ☐Other: _____
Connection Hardware:
☐Sheet Metal Angle ☐Integral wire/fastener assembly ☐ Other: _____
No. of Turns each end:
☐ 3 turns in 3" ☐ 3 turns in 1 ½" ☐ Other: _____
Plumbness: ☐Plumb to within one in six ☐ Other: _____

Bracing (if present):
Type: ☐ Rigid Diagonal Braces ☐ Splayed Wires ☐ None
If rigid:
Type: ☐ Strut ☐ Stud ☐ Other: _____
If wire:
Wire Size: ☐ 12 gauge ☐ Other:_____
Spacing: ☐ Every 144 sf ☐ Every 96 sf ☐ Other:_____
Spacing from Wall:
☐ 6' maximum ☐ Other:_____
Connection to Structure:
☐ Powder Actuated Fastener ☐ Expansion Anchor ☐Screw ☐Nail ☐Other: _____
No. of Turns each end: ☐ 4 turns in 1 ½" ☐ Other: _____
Compression Post: ☐ Yes ☐ No
If yes:
Type of Compression Post: ☐ Strut ☐EMT ☐ CRC ☐ Other: _____
Independent ceiling wire at Compression Post: ☐ Yes ☐ No

FEMA E-74 – Detailed Post-Earthquake Condition Assessment: Suspended Acoustical Tile Ceiling

Boundaries:

Perimeter Support Angles

☐2" horizontal leg, vertical leg screwed to studs

☐7/8" horizontal leg, vertical leg screwed to studs; proprietary clip connecting each tee

☐7/8" horizontal leg, vertical leg screwed to stud

☐Other: _____

Perimeter Restraint:

☐ Ceiling installed with main runner and/or cross runner positively connected to two adjacent walls and with 3/4" gap between main runner/cross runner ends and walls at opposite walls

☐ "Fixed" sides have ceiling grid screwed to perimeter support angle

☐ "Fixed" sides have proprietary clip connecting tee to perimeter support angle

☐ Other: _____

Spreaders:

☐ Stabilizer bars, cross tees or other means to prevent spreading are provided within 8" of each wall

☐ Stabilizer bars or similar are not provided

☐Other: _____

Perimeter Support:

☐ Terminal end of each cross runner and main runner are independently supported within 8" of wall

☐ Other: _____

Sprinkler Installation:

☐ 2" Oversized hole at sprinkler head penetrations

☐ No oversized hole at sprinkler head penetration

☐ Flexible Sprinkler Hose, 1"diameter hole

☐ Sprinkler lines are braced

☐ Sprinkler lines are not braced

☐ Sprinklers have end of line restraint

☐ Sprinklers do not have end of line restraint

☐ Other: _____

Lights:

Type: ☐ Rigid Diagonal Braces ☐ Splayed Wires ☐ None

If rigid:

Recessed:

Size: ☐ 1'x1' ☐ 2'x2' ☐ 2'x4' ☐ can ☐ Other:_____

Support: ☐ 2 independent wires at diagonally opposite corners

☐ With positive connection to grid

Describe:_____

☐ 1 independent wire

☐ No independent wire

☐ Other:_____

Lights (continued):

If Surface Mounted:

Size: ☐ 1'x1' ☐ 2'x2' ☐ 2'x4' ☐ Other:_____

Support: ☐ Bolted through to hardware connected to grid

☐ Other:_____

If Pendant:

Size: ☐ _____

Support: ☐ #9 wire to structure

☐ Other_____

Other Items Supported by Ceiling:

☐ Diffusers

☐ Speakers

☐ Projector

☐Other: _____

Partitions:

☐ Partitions at boundaries of ceiling extend to the structure above or are independently braced to the structure above

☐ Partitions at boundaries of ceiling are not independently braced against out-of-plane forces

Other:

Any building seismic separations in ceiling area? ☐ Yes ☐ No

If yes, describe: _____

Perimeter Support Angles:

☐ No visible damage

At Free Edge:

☐ Main/cross main tee dislodged from angle; approximate percentage_____

At Fixed Edge:

☐ Pullout of screw connection angle to stud

☐ Visible bending of angle

☐ Failure of rivet or screw connecting tee to angle

Lights:

☐ No visible damage

☐ Light dislodged from grid, but still suspended from independent wires; approximate percentage_____

☐ Light fully dislodged and fallen to floor; approximate percentage_____

FEMA E-74 – Detailed Post-Earthquake Condition Assessment: Suspended Acoustical Tile Ceiling

SECTION D: Condition Assessment

General damage assessment for ceiling area under investigation: ☐ None ☐ Severe ☐ Insignificant ☐ Moderate

Tile:
- ☐ < 1% tiles dislodged
- ☐ 2 – 10% tiles dislodged
- ☐ 11-33% tiles dislodged
- ☐ > 34% tiles dislodged

Grid:
- ☐ No visible damage requiring repair
- ☐ Perimeter tees dislodged at ceiling boundaries; approximate percentage:_____
- ☐ Damage to Grid Requiring Repair; describe: _____
- ☐ Grid Dislodged; approximate percentage:_____

Hangers:
- ☐ No visible damage to hangers
- ☐ Hanger connection to structure failed or visibly damaged; approximate percentage:_____
- ☐ Wire ties untied or visibly loosened; approximate percentage:_____

Bracing:
- ☐ No visible damage to braces
- ☐ Connection of diagonal wires/braces to structure failed or visibly damaged; approximate percentage: _____
- ☐ Bracing wire ties untied or visibly loosened; approximate percentage:_____

Perimeter Support Angles:
- ☐ No visible damage

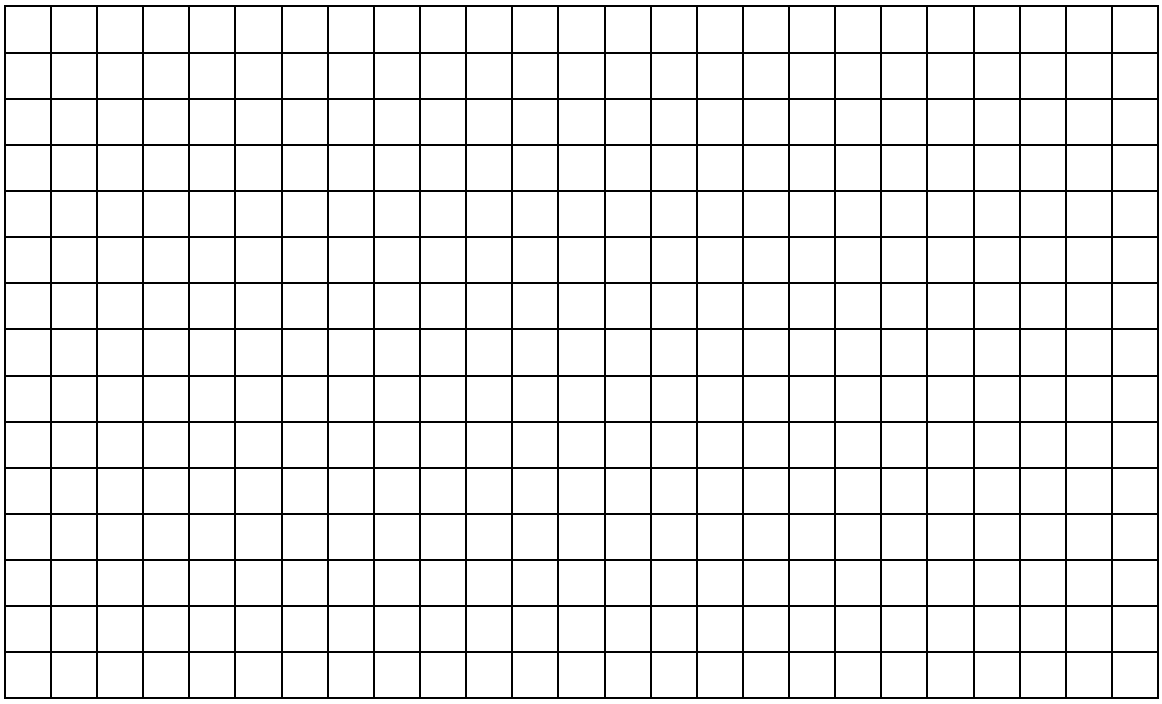
At Free Edge:
- ☐ Main/cross main tee dislodged from angle; approximate percentage:_____

At Fixed Edge:
- ☐ Pullout of screw connection angle to stud
- ☐ Visible bending of angle
- ☐ Failure of rivet or screw connecting tee to angle

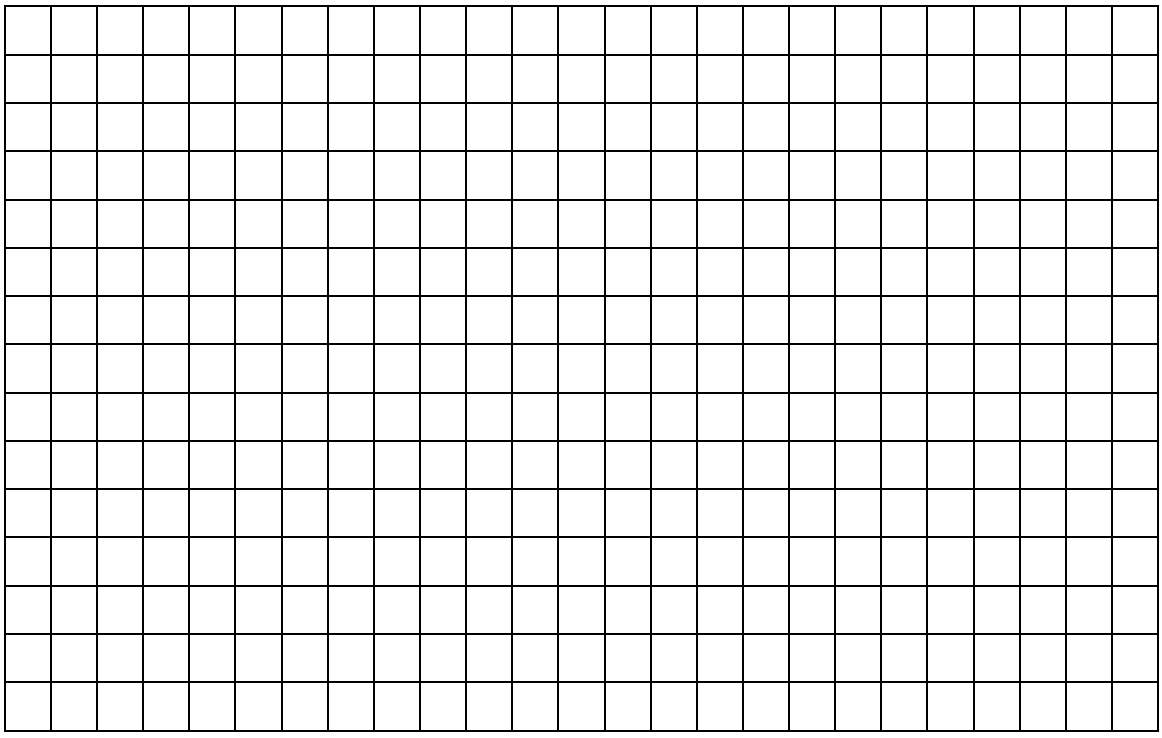
Lights:
- ☐ No visible damage
- ☐ Light dislodged from grid, but still suspended from independent wires; approximate percentage:_____
- ☐ Light fully dislodged and fallen to floor; approximate percentage:_____

SECTION E: Sketches and Photographs

1. Building Footprint



2. Plan of Ceiling Area under Investigation (indicate wall locations, and show ceiling boundary conditions (fixed and free))



3. Photographs

The following photographs are provided as an attachment to this section

☐ Overall view ☐ Above ceiling damage ☐ Cross tee splices

FEMA E-74 – Detailed Post-Earthquake Condition Assessment: Metal Stud Partitions

INSTRUCTIONS TO USERS:

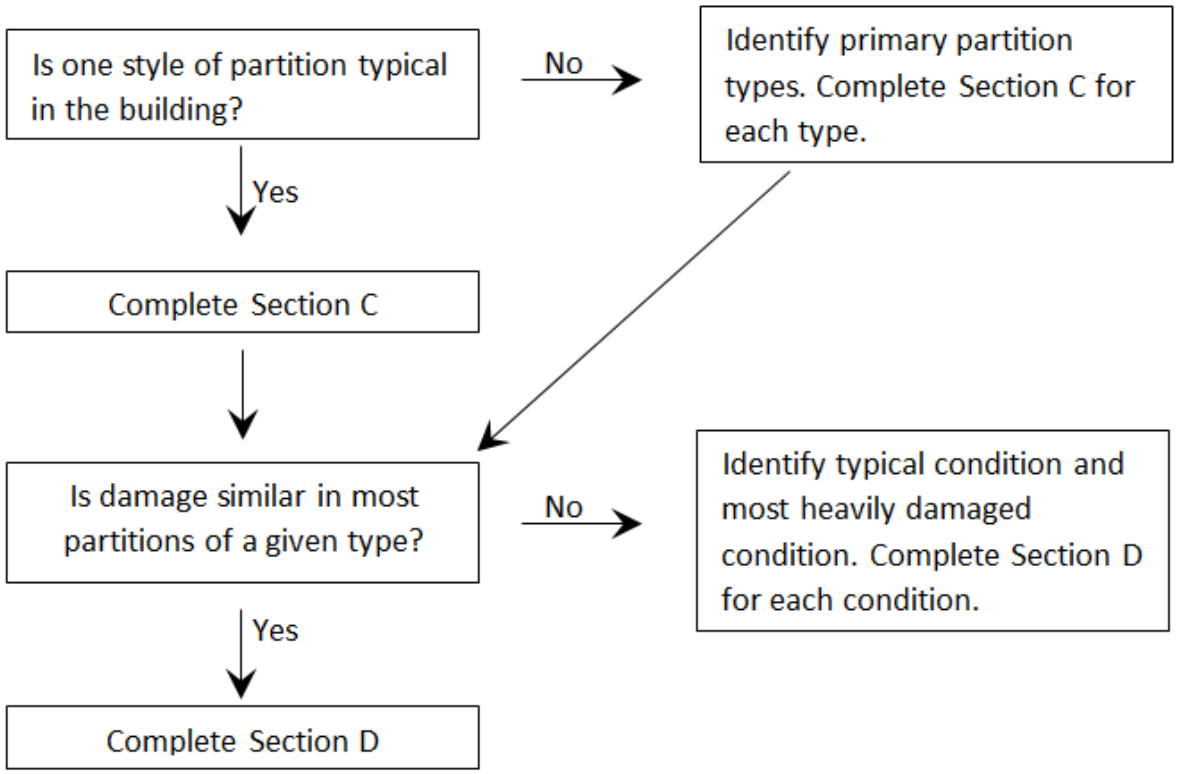
The purpose of a detailed investigation is to collect data that can be used to quantitatively evaluate the performance of partitions in earthquakes.

The following procedure is recommended for a comprehensive partition investigation in one building:

Step 1: Observe building or review drawings to describe basic construction characteristics. Complete Section A.

Step 2: Walk through building. Assess overall building condition and general condition of partitions. Assess whether walls in one direction are more heavily damaged than others. Assess whether walls in some floors are more heavily damaged than others. Complete Section B.

Step 3: Complete Sections C and D, as required, to describe partition construction and conditions in one building. The flowchart below is intended to provide guidance on determining how many partitions to examine in detail. Consideration should be given to the scope and nature of damage, and any unique factors that may have caused damage.



For example:

- If the walls in one story appear to be more heavily damaged than in other floors, but construction is similar throughout the building, Section C should be completed to describe the typical construction and two Section D forms should be completed as follows: one for the typical partition in the heavily damaged floor and one for the typical floor.
- If the walls in one direction are more heavily damaged than another on a given floor, one Section C and two Section D forms should be completed as follows: one for a typical wall in each direction.
- If construction or conditions vary throughout the building appropriate number of Section C and D forms should be prepared to describe predominant partition types and typical damage. Additional Section C and D forms should be completed to capture unique features.

FEMA E-74 – Detailed Post-Earthquake Condition Assessment: Metal Stud Partitions

SECTION A: Building Description

Inspection

Inspector ID/ Affiliation: _____

Inspection Date and Time: _____

Building Description

Building name: _____

Address: _____

_____

Building contact/phone: _____

Number of stories above ground: _____ below ground: _

Approx. footprint area (square feet): _____

For typical floor:

Approx. total length of partition in direction 1 (feet):____

Approx. total length of partition in direction 2 (feet):____

Primary Occupancy

☐Retail ☐Government ☐Residential
☐Offices ☐Historic ☐Public assembly
☐Industrial ☐School ☐Emergency services
☐Other:_____

Typical Floor Construction

☐ Concrete slab
☐ Metal deck and concrete fill
☐ Plywood ☐ with topping slab ☐ without topping slab
☐ Other: _____

At grade construction (if different from typical)

☐ Concrete slab
☐ Metal deck and concrete fill
☐ Plywood ☐ with topping slab ☐ without topping slab
☐ Other: _____

Roof Construction (if different from typical)

☐ Concrete slab
☐ Metal deck and concrete fill
☐ Untopped metal deck
☐ Plywood ☐ with topping slab ☐ without topping slab
☐ Other: _____

SECTION B: Damage Descriptions

Building posting if known:
- ☐ Inspected
- ☐ Restricted Use
- ☐ Unsafe

Comments: _____

Structural Damage:
- ☐ Minor/None: _____
- ☐ Moderate: _____
- ☐ Severe: _____

Ground Movement:
- ☐ None Observed
- ☐ Observed: _____

General Partition Damage:
- ☐ None
- ☐ Minor (minor cracking of wall finishes that can be repaired by patching and painting)
- ☐ Moderate (moderate damage to finishes requiring removal and replacement of some gypsum wallboard or plaster)
- ☐ Severe (severe damage to finishes and wall framing requiring reconstruction of the wall

Directionality:
- ☐ Walls in both directions appear to be in similar condition.
- ☐ Walls in one direction appear to be more heavily damaged than walls in perpendicular direction. Direction of heaviest damage:
  - ☐ N – S ☐ E – W ☐ Other_____

Floor by Floor:
- ☐ Walls in all floors appear to be in about the same condition.
- ☐ Walls in some floors are more heavily damaged than in others.
  List floors with most damage: _____

SECTION C: Component Definition

Partition Wall:

Wall Type:
- ☐ Full height studs (studs are continuous from one floor to the next)
- ☐ Partial height studs (studs are continuous from floor to ceiling)
- ☐ Other _____

Stud Depth:
- ☐ 1 5/8" C stud
- ☐ 2 1/2" C stud
- ☐ 3 5/8" C stud
- ☐ 4" C stud
- ☐ 5 1/2" C stud
- ☐ 6" C stud
- ☐ 8" C stud
- ☐ 2 1/2" CH stud
- ☐ 4" CH stud

Stud Gage:
- ☐ 16 ga (0.057") (very difficult to bend flange)
- ☐ 18 ga (0.045")
- ☐ 20 ga (0.035") (can bend flange slightly)
- ☐ 22 ga (0.028")
- ☐ 25 ga (0.019") (very easy to bend flange)

Stud Spacing:
- ☐ 16"
- ☐ 24"
- ☐ Other _____

Stud Flange Width:
- ☐ 1 1/4"
- ☐ 1 3/8"
- ☐ 1 5/8"
- ☐ 2"
- ☐ 2 1/2"

Sheathing:
- ☐ 5/8" gypsum wallboard both sides, floor to floor
- ☐ 5/8" gypsum wallboard both sides, floor to ceiling
- ☐ 5/8" gypsum wallboard both one side, floor to floor
- ☐ 5/8" gypsum wallboard both one side, floor to ceiling
- ☐ 7/8" plaster both sides, floor to floor
- ☐ 7/8" plaster both sides, floor to ceiling
- ☐ Other _____

Bottom Track Fasteners (if visible):

Type:
- ☐ Powder actuated fasteners (shot pin)
- ☐ Expansion anchors
- ☐ Nails
- ☐ Screws
- ☐ Other _____

Size: _____

Spacing:
- ☐ 16"
- ☐ 24"
- ☐ Other _____

FEMA E-74 – Detailed Post-Earthquake Condition Assessment: Metal Stud Partitions

Top Track Fasteners (if visible):

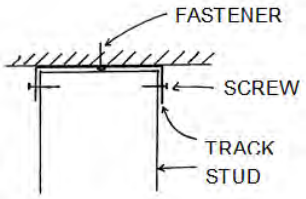
Type:
- ☐ Powder actuated fasteners (shot pin)
- ☐ Expansion anchors
- ☐ Nails
- ☐ Screws
- ☐ Other _____

Size: _____

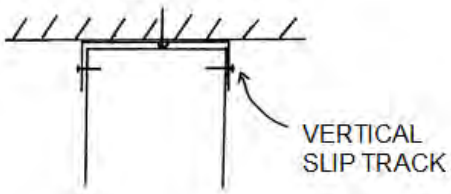
Spacing:
- ☐ 16”
- ☐ 24”
- ☐ Other _____

Top Track Detailing:

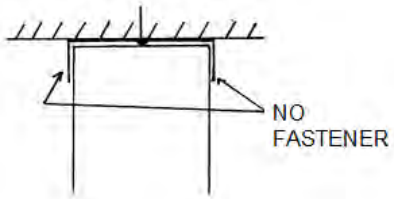
☐ No slip track



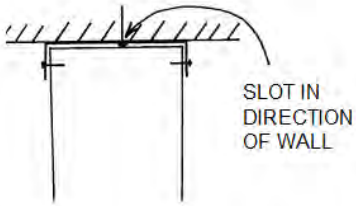
☐ No slip track for horizontal movements, vertical slotted holes



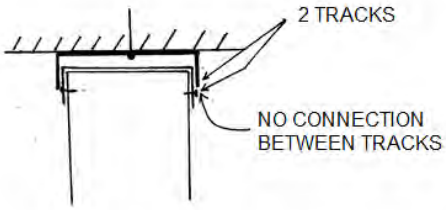
☐ Studs free to slide in track



☐ Track connected to structure with fasteners in slotted holes



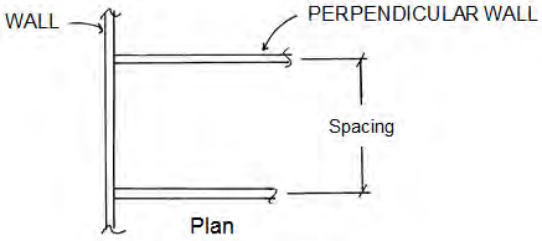
☐ Nested Track



☐ Other _____

Bracing (for partial height walls):

☐ None
☐ Top of wall is braced by gypsum wallboard or plaster ceiling
☐ Wall is braced by perpendicular walls
Spacing _____



☐ Top of wall is braced by diagonal braces
Spacing _____
Brace type _____
Anchorage at structure _____
☐ Wall is braced by full height studs at regular spacing
Spacing _____
Stud type/size _____
Top connection _____

Items Mounted on or Braced by Wall:

Wall supported items (i.e. items that are supported solely by the wall)
☐ Shelving; describe contents _____
☐ Upper Cabinets; describe contents _____
☐ Television/monitor
☐ Other _____

Floor supported items that are braced by the wall (i.e. items that have a positive connection to the wall but bear on the floor)
☐ Base Cabinets; describe contents _____
☐ Book Shelf; describe contents _____
☐ Storage Shelving; describe contents _____
☐ Equipment _____
☐ Other _____

Does wall contain glazing?
☐ No
☐ Yes, describe: _____
(glass type if known, size, number, etc.)

Does wall contain doors?
☐ No
☐ Yes, describe: _____
(size, number, etc.)

Does wall contain duct/pipe/conduit penetrations through wall finish?
☐ No
☐ Yes, describe: _____

SECTION D: Condition Assessment

Floor _____

Location in building (sketch – see page 9) _____

Story height (measure from top of finished floor to underside of floor above) _____

Length of wall (estimate total straight length of wall, including doors and windows) _____

Average length of wall between door openings_____

General Damage Assessment for Wall Under Investigation

- ☐ None
- ☐ Minor (minor cracking of wall finishes that can be repaired by patching and painting)
- ☐ Moderate (moderate damage to finishes requiring removal and replacement of some gypsum wallboard/plaster)
- ☐ Severe (severe damage to finishes and wall framing requiring reconstruction of the wall

Wall Finishes (check as many as apply)

- ☐ No visible damage
- ☐ Cracking distributed throughout wall
- ☐ Cracking concentrated at door and window openings
- ☐ Cracking concentrated at intersections with perpendicular walls
- ☐ Sheathing spalled or dislodged, describe: _____

  If sheathing is cracked,

  Crack width: _____ average

  _____ maximum

  Total length of cracks in 10' length x height of wall: _____ average

  _____ maximum
- ☐ Other, Describe: _____

Framing (check as many as apply)

- ☐ No visible damage to framing
- ☐ Studs are damaged, describe: _____
- ☐ Bottom track is damaged, describe: _____
- ☐ Top track is damaged, describe: _____
- ☐ Bracing is damaged, describe: _____
- ☐ Sheathing fasteners exposed, describe: _____
- ☐ Framing fasteners damaged, describe: _____
- ☐ Other, describe: _____

FEMA E-74 – Detailed Post-Earthquake Condition Assessment: Metal Stud Partitions

Wall Mounted Items:
- ☐ No visible damage
- ☐ Items damaged, describe: _____
- ☐ Items dislodged, describe: _____

Floor-Mounted Items Braced by Wall:
- ☐ No visible damage
- ☐ Damage at connection to wall, describe:_____
- ☐ Other, describe: _____

Glazing:
- ☐ No visible damage
- ☐ Glass has visibly shifted in frame but not fallen out or cracked
- ☐ Glass is cracked, describe: _____
- ☐ Glass is cracked and has partially or completely fallen out of frame
- ☐ Other, describe: _____

Doors:
- ☐ No visible damage
- ☐ Doors stick when opening
- ☐ Door inoperable
- ☐ Other, describe: _____

Penetrations:
- ☐ No visible damage
- ☐ Local crushing of wall finish at penetration
- ☐ Visible gap created between pipe/duct/conduit and finish
- ☐ Pipe/duct/conduit damaged at penetration
- ☐ Other, describe: _____

SECTION E: Sketches and Photographs

Building Footprint

Plan of walls under investigation

Photographs

The following photographs are provided as an attachment to this section

☐ Overall view

☐ Connections at top track, bottom track, brace connection

G. LIST OF RESOURCES RELATED TO NONSTRUCTURAL COMPONENTS

This appendix is a list of available resources related to nonstructural components, including codes and standards, testing protocols, guidance documents, nonproprietary details, photos, sample specifications, proprietary details, products, and research efforts. This list originates from Appendix B of the ATC-69 Report, *Reducing the Risks of Nonstructural Earthquake Damage, State-of-the-Art and Practice Report,* prepared by the Applied Technology Council for FEMA (ATC, 2008).

The information in this appendix is organized into the following tables:

Table G-1	Codes and Standards Related to Nonstructural Components	G-2
Table G-2	Guidance Documents Related to Nonstructural Components	G-10
Table G-3	Nonproprietary Details and Other Resources for Nonstructural Components	G-23
Table G-4	Proprietary Details and Products for the Protection of Nonstructural Components	G-32
Table G-5	Recent and Ongoing Research Related to Nonstructural Components	G-37

Table G-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
ACI 318-08	Building Code Requirements for Reinforced Concrete and Commentary	2008	Appendix D	Appendix on requirements for anchorage in concrete; published by the American Concrete Institute, Detroit, Michigan.
ACI 355.2-07	Qualification of Post-Installed Mechanical Anchors in Concrete	2007		Published by the American Concrete Institute, Detroit, Michigan.
ASCE/SEI 7-05	Minimum Design Loads for Buildings and Other Structures	2005	Chapter 13	Chapter specifying seismic design requirements for nonstructural components; published by the American Society of Civil Engineers, Reston, Virginia.
SEI/ASCE 31-03	Seismic Evaluation of Existing Buildings	2003	Sections 3.9, 4.2.7, 4.8, and Table 4-9	Successor document to FEMA 310 *Handbook for the Seismic Evaluation of Buildings – A Prestandard*. Relevant sections describe evaluation procedures for existing nonstructural components. Includes comprehensive checklists of potential nonstructural hazards. Published by the American Society of Civil Engineers, Reston, Virginia.
ASCE/SEI 41-06	Seismic Rehabilitation of Existing Buildings	2007	Chapter 11	Successor document to FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*. Relevant chapter describes design procedures for the rehabilitation of existing nonstructural components, and a table identifying nonstructural component types and their applicability to different performance objectives. Published by the American Society of Civil Engineers, Reston, Virginia.

Table G-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
ASCE/SEI 43-05	Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities	2005		Provides design criteria for structures, systems, and components in nuclear facilities, with the goal of ensuring that these facilities can withstand the effects of earthquake ground shaking at the desired level of performance. Published by the American Society of Civil Engineers, Reston, Virginia.
ASHRAE SPC 171P	Method of Test of Seismic Restraint Devices for HVAC&R Equipment	2006		Establishes methods of testing and documenting the working shear and tensile strength of seismic restraint devices that are integral with vibration isolators or resilient devices. Published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.
ASTM E580/ E580M-06	Standard Practice for Application of Ceiling Suspension Systems for Acoustical Tile and Lay-In Panels in Areas Requiring Seismic Restraint	2006		Standard for Zone 2; could also be used for Zones 3 and 4. Published by ASTM International, West Conshohocken, Pennsylvania.
Bulletin 2004-014-BU (Vancouver)	Seismic Restraint of Nonstructural Components	2004		Addresses suspended ceilings and non-load bearing partitions. Published by the City of Vancouver, British Columbia.

Table G-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
CSA S832-06 (Canada)	Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings	2006		Operational and functional components (OFCs) is a Canadian term for nonstructural components. The second edition of a document first published in 2001. Describes how to identify and evaluate hazards caused by nonstructural components, and provides strategies to mitigate damage. Intended to be applicable to most buildings types, either new or existing, and intended for building owners, inspectors, facility managers, engineers, architects and others whose focus is to provide safety, serviceability and durability of nonstructural components when subjected to earthquakes. Published by the Canadian Standard Association, Mississauga, Ontario.
E.030 (Peru)	National Construction Code, Technical Standard for Buildings, E.030 Earthquake-Resistant Design	2003		Design requirements for buildings in Peru. Drift provisions changed in 1997, and are now among the most stringent in the world. Drift must be computed without an R factor, and allowable drift is limited to .007h for reinforced concrete, and .01h for steel structures. Standard school construction must be confined concrete, and masonry infill must be isolated from the concrete frame. Schools built since 1997 meeting these criteria have suffered virtually no damage in recent large earthquakes in Peru. Published by El Servicio Nacional de Normalización, Capacitación e Investigación para la Industria de la Construcción (SENCICO), Lima, Perú.

Table G-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
EN 1998-1:2004(E) (Europe)	Eurocode 8: Design of Structures For Earthquake Resistance (English version, Final Draft)	2004	Part 1, Sections 4.3.5, 4.3.6	Includes general rules, seismic actions, and rules for buildings. Relevant sections cover design of nonstructural elements and additional measures for masonry infilled frames. Non-structural elements mentioned include parapets, gables, antennae, mechanical appendages and equipment, curtain walls, partitions, and railings. Nonstructural elements that might cause risks to persons, affect the main structure, or disrupt services of critical facilities must be verified to resist seismic design actions. Designs for nonstructural elements of great importance are based on realistic models of the structure and on appropriate response spectra derived from the response of the supporting structural elements. Lateral force calculations include consideration of period ratio, importance factor, and behavior factor. Published by the European Committee for Standardization (CEN).
IBC 2006	2006 International Building Code	2006		National model building code, latest edition; scheduled for adoption in most jurisdictions across the United States. Specifically references ASCE 7-05 for design of nonstructural components. Published by the International Code Council, Washington, D.C.
IBC 2003	2003 International Building Code	2003		National model building code; adopted in some areas of the United States. Published by the International Code Council, Washington, D.C.

Table G-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
ICC-ES AC-156	Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems.	2004		Published by the International Code Council Evaluation Service, Whittier, California.
NFPA 13	Standard for the Installation of Sprinkler Systems, 2007 Edition	2007		Published by the National Fire Protection Association, Quincy, Massachusetts.
NCh 433.Of96 (Chile)	Chilean Norm NCh 433.Of96, Earthquake Resistant Design of Buildings	1996		Chilean code for buildings. Includes the following drift criteria: (1) drift must be computed without an R factor; and (2) must be less than 0.002h for buildings with precast shear walls with dry joints; less than 0.003h for shear wall building with rigidly attached masonry infill; less than .0075h for unbraced frames with isolated infill; and less than .015h for other structures. Includes a scale factor Q/Q_{min} that allows a reduction of the computed drift for longer period structures where the design base shear Q is less than a minimum base shear Q_{min}. Stringent drift criteria (more stringent than U.S. codes) have resulted in an almost exclusive use of shear wall systems in buildings. As a result, drift-related nonstructural damage is significantly reduced. Published by the Instituto Nacional de Normalizacion (INN-Chile), Santiago, Chile.

Table G-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
NCh 2369.Of2003 (Chile)	Chilean Norm NCh2369, Earthquake Resistant Design of Industrial Structures and Facilities	2003		Chilean code for industrial buildings. Includes recommendations and design rules for mechanical equipment that could be applicable to other types of buildings. Currently only available in Spanish. Published by the Instituto Nacional de Normalizacion (INN-Chile), Santiago, Chile.
UBC 1961	Uniform Building Code, 1961 Edition	1961		First appearance of separate provisions for nonstructural components in the UBC; maximum lateral force of 0.2g in Zone 3.
UBC 1976	Uniform Building Code, 1976 Edition	1976		Nonstructural provisions updated in response to 1971 San Fernando Earthquake; maximum force increased to 0.3g in Zone 4.
UBC 1988	Uniform Building Code, 1988 Edition	1988		Update of nonstructural provisions to consider response of non-rigid items and items at grade; maximum force remained 0.3g in Zone 4 for rigid items.
UBC 1997	Uniform Building Code, 1997 Edition	1997		Nonstructural seismic requirements are a blend of requirements from the 1994 and 1997 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*.
USACE TI 809-04	Tri-Service Manual, Seismic Design for Buildings	1998	Chapter 10	Successor document to TM 5-809-10 and TM 5-809-10-1. Published by the US Army Corps of Engineers, Washington, D.C.

Table G-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
USACE TM 5-809-10	Tri-Service Manual, Seismic Design for Buildings	1996	Chapter 8, Appendix L	Provides a dynamic analysis procedure for design of nonstructural components that must remain functional after a major earthquake. Requires generation of floor response spectra and consideration of inter-story drift at the location of essential equipment. Appendix includes four design examples. Published by the US Army Corps of Engineers, Washington, D.C.
USACE TM 5-809-10-1	Tri-Service Manual, Seismic Design Guidelines for Essential Buildings	1986	Chapter 6	Provides methodology for design; defines essential nonstructural systems (Table 6-3); defines two levels of earthquake ground motion (EQ-I and EQ-II); requires equipment certification. Published by the US Army Corps of Engineers, Washington, D.C.
USACE TM-5-809-10-2	Tri-Service Manual, Seismic Design Guidelines for Upgrading Existing Buildings	1988	Chapter 9	Chapter focuses on improving performance of existing nonstructural installations. Includes a list of nonstructural systems with descriptions of potential damage and failure modes (Table 9-1). Published by the US Army Corps of Engineers, Washington, D.C.
VISCMA 102-07	Static Qualification Standards for Obtaining a VISCMA Compliant Seismic Component Rating	2007		Testing protocol for mechanical, electrical and plumbing equipment. Published by the Vibration Isolation and Seismic Control Manufacturers Association, Wayne, Pennsylvania.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
ASHRAE RP-812	A Practical Guide to Seismic Restraint	1999		Published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.
ASHRAE /SMACNA	Seismic Restraint Applications CD-ROM	2002		Provides technical information for design and installation of seismic restraints for HVAC equipment, piping, and ducts. Includes representative bracing details, layout examples, and tables. Consists of portions of the following documents: SMACNA's Seismic Restraint Manual: Guidelines for Mechanical Systems; ASHRAE's Handbook - HVAC Applications (2003); and ASHRAE's A Practical Guide to Seismic Restraint. Produced by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. and the Sheet Metal and Air Conditioning Contractors' National Association.
CISCA 1991	Recommendations for Direct-Hung Acoustical and Lay-in Panel Ceilings, Seismic Zones 0-2	1991		Industry standards for ceilings in low seismic zones. Published by Ceilings and Interior Systems Construction Association, Deerfield, Illinois.
CISCA 1990	Recommendations for Direct-Hung Acoustical and Lay-in Panel Ceilings, Seismic Zones 3-4	1990		Industry standards for ceilings in high seismic zones. Published by Ceilings and Interior Systems Construction Association, Deerfield, Illinois.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
DGS, DSA (California)	Guide and Checklist for Nonstructural Earthquake Hazards in California Schools			Identifies potential hazards associated with nonstructural components and provides recommendations to mitigate hazards. Includes typical details and a nonstructural earthquake hazards checklist. Published by the California State Department of General Services, Division of the State Architect, and the Governer's Office of Emergency Services, Sacramento, California.
DOISSP	Nonstructural Hazards Rehabilitation Guidelines; Vol. I; Guidelines Usage, Architectural, Mechanical, Electrical, Plumbing			Contains guidance gathered from various sources, both public and private sources. Includes both proprietary and non-proprietary details. Published by the Department of the Interior Bureau of Reclamation, Seismic Safety Program (DOISSP), Washington, D.C.
DOISSP	Nonstructural Hazards Rehabilitation Guidelines; Vol. II; Furnishings, Interior Equipment, Miscellaneous Components, Mobile Homes, Manufactured Homes, FEMA 273, FEMA 310, FEMA 178, & ASCE 31-			Contains guidance gathered from various sources, both public and private sources. Includes both proprietary and non-proprietary details. Published by the Department of the Interior Bureau of Reclamation, Seismic Safety Program (DOISSP), Washington, D.C.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
	xx Excerpts			
EERI 84-04	Nonstructural Issues of Seismic Design and Construction	1984		Results of workshop including invited papers on nonstructural issues. Published by the Earthquake Engineering Research Institute, Oakland, California.
FEMA	Instructor's Guide for Nonstructural Earthquake Mitigation for Hospitals and other Health Care facilities.	1988		Materials for course given by Emergency Management Institute, Emmitsburg, Maryland.
FEMA	Final Report, Nonstructural Earthquake Mitigation Guidance Manual.	2004		Based on FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, 2002. Includes flowcharts, step-by-step procedures and some details. Divides nonstructural components into four groups: contents, exterior building elements, interior building elements, and building utilities. Prepared by URS Group, Inc. for FEMA.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA Region X	Earthquake Hazard Mitigation Handbook for Public Facilities	2002		Available at http://www.conservationtech.com/FEMA-WEB/FEMA-subweb-EQ/index.htm
FEMA 74	Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide. Third Edition	1994		Successor document to previous editions of FEMA 74, first published in 1985.
FEMA 74-FM	Earthquake Hazard Mitigation for Nonstructural Elements, Field Manual	2005		Includes three types of details: Non-Engineered, Prescriptive, and Engineered. Contains more details than FEMA 74, along with a field data sheet based on the FEMA 74 checklist.
FEMA 150	Seismic Considerations: Health Care Facilities	1990		Published by the Federal Emergency Management Agency, Washington, D.C.
FEMA 172	NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings	1992	Chapters 5, 6	Relevant chapters include details for electrical cabinets, chimneys, parapets, masonry partitions, raised access floors, and mechanical equipment.
FEMA 178	NEHRP Handbook for the Seismic Evaluation of Existing	1992	Section 10.5	Predecessor document to FEMA 310.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
	Buildings			
FEMA 232	Homebuilders' Guide to Earthquake-Resistant Design and Construction	2006		Includes details based on the 1994 edition of FEMA 74.
FEMA 273	NEHRP Guidelines for the Seismic Rehabilitation of Buildings	1997		Predecessor document to FEMA 356.
FEMA 310	Handbook for the Seismic Evaluation of Buildings - A Prestandard	1998	Sections 3.9, 4.2.7, 4.8, and Table 4-9	Predecessor document to SEI/ASCE 31-03. Relevant sections describe evaluation procedures for existing nonstructural components. Includes comprehensive checklists of potential nonstructural hazards.
FEMA 356	Prestandard and Commentary for the Seismic Rehabilitation of Buildings	2000	Chapter 11	Successor document to FEMA 273/274, and predecessor to ASCE/SEI 31-03. Relevant chapter describes design procedures for the rehabilitation of existing nonstructural components, and a table identifying nonstructural component types and their applicability to different performance objectives.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA 389	Communicating with Owners and Managers of New Buildings on Earthquake Risk: A Primer for Design Professionals	2004		
FEMA 395	Incremental Seismic Rehabilitation of School Buildings (K-12): Providing Protection to People and Buildings	2003		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-21) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to school occupancies.
FEMA 396	Incremental Seismic Rehabilitation of Hospital Buildings: Providing Protection to People and Buildings	2003		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-23) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to hospital occupancies.
FEMA 397	Incremental Seismic Rehabilitation of Office Buildings: Providing Protection to People and Buildings	2003		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-24) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to office occupancies.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA 398	Incremental Seismic Rehabilitation of Multifamily Apartment Buildings: Providing Protection to People and Buildings	2004		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-22) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to multifamily apartment occupancies.
FEMA 399	Incremental Seismic Rehabilitation of Retail Buildings: Providing Protection to People and Buildings	2004		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-22) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to retail occupancies.
FEMA 400	Incremental Seismic Rehabilitation of Hotel and Motel Buildings	2005		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-23) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to hotel and motel occupancies.
FEMA 412	Installing Seismic Restraints for Mechanical Equipment	2002		Includes numerous elaborate details and many recommendations for seismic restraint of mechanical equipment.
FEMA 413	Installing Seismic Restraints for Electrical Equipment	2004		Includes numerous elaborate details and many recommendations for seismic restraint of electrical equipment.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA 414	Installing Seismic Restraints for Duct and Pipe	2004		Includes numerous elaborate details and many recommendations for seismic restraint of duct and piping components.
FEMA 424	Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds	2004		Includes pictures of nonstructural damage (pages 4-17 through 4-19, 4-23, 4-24, 4-30, 4-31); a list of types of nonstructural components (page 4-59); graphics for ceilings, shelves, and walls (pages 4-60 and 4-61).
FEMA 433	Using HAZUS-MH for Risk Assessment: How-To Guide	2004		
FEMA 445	Next-Generation Performance-Based Seismic Design Guidelines: Program Plan for New and Existing Buildings	2006	Section 4.2	Describes how performance-based seismic design guidelines will be developed under the ATC-58 Project. Section 4.2 refers specifically to the development of nonstructural performance products.
FEMA 450	NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Part 1 and 2: Provisions and Commentary	2004	Chapters 6, 6A, and Commentary	Provides criteria for the design and construction of structures to resist earthquake ground motions. Relevant chapters include prescriptive requirements for the design of architectural, mechanical, electrical and piping components.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA 452	A How-To Guide to Mitigate Potential Terrorist Attacks Against Buildings	2005		
FEMA 454	Designing for Earthquakes: A Manual for Architects	2006	Section 6.6, Chapter 9	Discussion of code issues including nonstructural issues. Contains a collection of photos and generic details borrowed from various sources including: FEMA 74; details developed for the Lawrence Livermore National Lab; and the SMACNA Guidelines. Includes a discussion on the need for systems engineering, considering all parts of the building as a whole. Provides a checklist (Table 9-3) showing allocation of design responsibilities for nonstructural systems and components.
FEMA 460	Seismic Considerations for Steel Storage Racks Located in Areas Accessible to the Public	2005		Includes: a review of the performance of storage racks in past earthquakes; a history of the development of codes and standards used for storage rack design; current storage rack design practices; guidance on recommended performance goals and design requirements for storage racks; guidelines for implementation/responsibilities associated with the specification, procurement, and installation of pallet storage racks; suggested guidance for securing contents; recommendations for operations and use; suggested guidance for quality assurance programs; a discussion of current and past storage rack research and testing; suggestions for post-earthquake inspections; and proposed modifications to seismic

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
				design provisions and standards for racks.
FEMA 461	Interim Protocols for Determining Seismic Performance Characteristics of Structural and Nonstructural Components	2007		Provides an interim protocol for testing of building components to establish their performance capability in the form of fragility functions. Fragility functions are used to assess the seismic performance of individual components, systems incorporating these components, and buildings containing these systems and components that are subjected to earthquake shaking. Protocols are not intended for seismic performance qualification testing of nonstructural components required by the building code, although the loading protocols could be used for that purpose.
FEMA 577	Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and	2007		

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
	Buildings			
FEMA 582	Design Guide for Improving Commercial Buildings Safety in Earthquakes, Floods, and High Winds	Future		
John Wiley & Sons, Inc.	Earthquakes, an Architect's Guide to Nonstructural Seismic Hazards	1990		Target audience is architects. Written by H.J. Lagorio. Published by John Wiley & Sons, Inc., New York, New York.
OCIPEP (Canada)	Seismic Hazard Assessment and Mitigation for Buildings' Functional and Operational Components: A Canadian Perspective	2002		Contains figures and photos from various sources, including FEMA 74. Includes damage photos from 1999 Chi Chi, Taiwan Earthquake: damage to rooftop equipment (page 19); collapse of free-standing non-structural wall (page 20); and damage to sprinkler systems. Prepared by the Department of Civil Engineering, University of Ottowa, for the Office of Critical Infrastructure Protection and Emergency Preparedness (OCIPEP), Ontario, Canada.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
Oregon Emergency Management	Earthquake Preparedness and Mitigation Guidance for Oregon State Agency Offices and Warehouses	2004		Focuses on office and warehouse occupancies, with special attention to storage racks. Includes photos and guidance including shrink-wrap and netting to mitigate potential falling hazards. Provides some specific information on performance of furniture by specific vendors (Hayworth, Steelcase, and Artmet).
Pan American Health Organization	Principles of Disaster Mitigation in Health Facilities	2000	Chapter 3	Includes guidance on assessing and mitigating seismic vulnerabilities of nonstructural components. Published by the Pan American Health Organization, Regional Office of the World Health Organization, Washington, D.C.
Salt Lake City School District	Seismic Design Criteria of Nonstructural Systems For New School Facilities And Existing School Facilities	2001		Developed under a FEMA "Project Impact" Grant. Intended for use on new school design projects and seismic retrofit projects in the Salt Lake City School District. Establishes minimum design procedures, general detailing requirements, design approval procedures, and construction inspection procedures for nonstructural items. The design engineer or architect is responsible for development of project specific nonstructural details. Some requirements exceed the minimum standards given in the Uniform Building Code (UBC).
Seattle Public Schools	School Facilities Manual: Nonstructural Protection Guide. Safer Schools, Earthquake Hazards, Nonstructural. Second	2000		Includes detailed inventory form and details not included in FEMA 74.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
	Edition			
University of California, Berkeley	UC Berkeley: Q-Brace Quake Bracing Guidelines	2005		Guidelines developed for University of California, Berkeley campus facilities. Includes detailed solutions for contents identifying vendor supplied products or size of hardware to use.
USACERL TR-98/34	Seismic Mitigation for Equipment at Army Medical Centers	1998		Presents simple methods for reducing the seismic vulnerability of equipment at Army medical centers. Illustrations, observations, and recommendations are based on examples from Madigan Army Medical Center (MAMC). Concerns about particular well-anchored critical medical equipment are presented. Published by the U.S. Army Construction Engineering Research Laboratories.
USACE, Engineering and Support Center	Seismic Protection for Mechanical Equipment			Presentation on procedures to design seismic supports of equipment, piping, and ducts; includes force coefficients and methods to calculate forces. Also includes a list of references useful as guidelines for the design. Available from the U.S. Army Corps of Engineers at http://www.dtic.mil/ndia/2005triservice/track16/stut.pdf.

Table G-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
VISCMA	Understanding the 2000 IBC Code (Architectural Components and Equipment Restraint)	2005		Available on the Vibration Isolation and Seismic Control Manufacturers Association website at http://www.viscma.com/articles.htm
VISCMA	The Pitfalls of Combining Internal & External Equipment Isolation	2003		Explains problems associated with utilizing both internal and external isolation in equipment. Shows that performance is better if only external isolation is used. Available on the Vibration Isolation and Seismic Control Manufacturers Association website at http://www.viscma.com/articles.htm

Table G-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
ASHRAE /SMACNA	Non-proprietary Details	Seismic Restraint Applications CD-ROM	2002		Provides technical information for design and installation of seismic restraints for HVAC equipment, piping, and ducts. Includes representative bracing details, layout examples, and tables. Consists of portions of the following documents: SMACNA's Seismic Restraint Manual: Guidelines for Mechanical Systems; ASHRAE's Handbook - HVAC Applications (2003); and ASHRAE's A Practical Guide to Seismic Restraint. Produced by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. and the Sheet Metal and Air Conditioning Contractors' National Association.
ATC-38	Damage Inventory Form	ATC-38 Postearthquake Building Performance Assessment Form and Surveyor Instructions	2001		10-page form and instructions that provides standardized damage percentages and standardized codes for ceilings and partitions. Available with the ATC-38 Project report, or on the EERI website at http://www.eeri.org/
Dartmouth College	Sample Specification	Dartmouth College Design & Construction Guidelines, Section 15240 Seismic Restraint and Vibration Control	2004		Specification for the installation of equipment at Dartmouth College. Available at http://www.dartmouth.edu/~opdc/pdfs/15240.pdf

Table G-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
DGS, DSA (California)	Guide and Checklist	Guide and Checklist for Nonstructural Earthquake Hazards in California Schools	2003		Identifies potential hazards associated with nonstructural components and provides recommendations to mitigate hazards. Includes typical details and a nonstructural earthquake hazards checklist. Published by the California State Department of General Services, Division of the State Architect, and the Governer's Office of Emergency Services, Sacramento, California.
DOISSP	Non-proprietary Details	Nonstructural Hazards Rehabilitation Guidelines; Vol. I; Guidelines Usage, Architectural, Mechanical, Electrical, Plumbing	2003		Contains guidance gathered from various sources, both public and private sources. Includes both proprietary and non-proprietary details. Published by the Department of the Interior Bureau of Reclamation, Seismic Safety Program (DOISSP), Washington, D.C.
DOISSP	Non-proprietary Details	Nonstructural Hazards Rehabilitation Guidelines; Vol. II; Furnishings, Interior Equipment, Miscellaneous Components, Mobile Homes, Manufactured Homes, FEMA 273,	2003		Contains guidance gathered from various sources, both public and private sources. Includes both proprietary and non-proprietary details. Published by the Department of the Interior Bureau of Reclamation, Seismic Safety Program (DOISSP), Washington, D.C.

Table G-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
		FEMA 310, FEMA 178, & ASCE 31-xx Excerpts			
EERI	Damage Inventory Form	EERI Reconnaissance/ Clearinghouse Report Form - Architectural and Nonstructural Elements	2000		2-page form consisting of broad categories, several subcategories, and blank lines to report damage and gather damage statistics.
FEMA	Non-proprietary Details	Final Report, Nonstructural Earthquake Mitigation Guidance Manual	2004		Based on FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, 2002. Includes flowcharts, step-by-step procedures and some details. Divides nonstructural components into four groups: contents, exterior building elements, interior building elements, and building utilities. Prepared by URS Group, Inc. for FEMA.

Table G-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
FEMA Region X	Non-proprietary Details	Earthquake Hazard Mitigation Handbook for Public Facilities	2002		Available at http://www.conservationtech.com/FEMA-WEB/FEMA-subweb-EQ/index.htm
FEMA 74	Non-proprietary Details	Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide. Third Edition	1994		Successor document to previous editions of FEMA 74, first published in 1985.
FEMA 74 FM	Non-proprietary Details	FEMA 74 Field Manual	2005		Includes three types of details: Non-Engineered, Prescriptive, and Engineered. Contains more details than FEMA 74, along with a field data sheet based on the FEMA 74 checklist.
FEMA 172	Non-proprietary Details	NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings	1992	Chapters 5, 6	Relevant chapters include details for electrical cabinets, chimneys, parapets, masonry partitions, raised access floors, and mechanical equipment.
FEMA 412	Non-proprietary Details	Installing Seismic Restraints for Mechanical Equipment	2002		Includes numerous elaborate details and many recommendations for seismic restraint of mechanical equipment.

Table G-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
FEMA 413	Non-proprietary Details	Installing Seismic Restraints for Electrical Equipment	2004		Includes numerous elaborate details and many recommendations for seismic restraint of electrical equipment.
FEMA 414	Non-proprietary Details	Installing Seismic Restraints for Duct and Pipe	2004		Includes numerous elaborate details and many recommendations for seismic restraint of duct and piping components.
FEMA 424	Photos, Damage	Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds	2004		Includes pictures of nonstructural damage (pages 4-17 through 4-19, 4-23, 4-24, 4-30, 4-31); a list of types of nonstructural components (page 4-59); graphics for ceilings, shelves, and walls (pages 4-60 and 4-61).
FEMA 454	Non-proprietary Details	Designing for Earthquakes: A Manual for Architects	2006	Section 6.6, Chapter 9	Discussion of code issues including nonstructural issues. Contains a collection of photos and generic details borrowed from various sources including: FEMA 74; details developed for the Lawrence Livermore National Lab; and the SMACNA Guidelines. Includes a discussion on the need for systems engineering, considering all parts of the building as a whole. Provides a checklist (Table 9-3) showing allocation of design responsibilities for nonstructural systems and components.

Table G-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
Los Alamos National Laboratory	Sample Specification	Section 22 0548 Vibration and Seismic Controls for Plumbing, Piping, and Equipment	2006		Specification for the anchorage of equipment at Los Alamos National Lab. Available at http://engstandards.lanl.gov/conspec/pdf/22_0548R0.pdf
OCIPEP (Canada)	Photos, Damage	Seismic Hazard Assessment and Mitigation for Buildings' Functional and Operational Components: A Canadian Perspective	2002		Contains figures and photos from various sources, including FEMA 74. Includes damage photos from 1999 Chi Chi, Taiwan Earthquake: damage to rooftop equipment (page 19); collapse of free-standing non-structural wall (page 20); and damage to sprinkler systems. Prepared by the Department of Civil Engineering, University of Ottowa, for the Office of Critical Infrastructure Protection and Emergency Preparedness (OCIPEP), Ontario, Canada.
Oregon Emergency Management	Non-proprietary Details	Earthquake Preparedness and Mitigation Guidance for Oregon State Agency Offices and Warehouses	2004		Focuses on office and warehouse occupancies, with special attention to storage racks. Includes photos and guidance including shrink-wrap and netting to mitigate potential falling hazards. Provides some specific information on performance of furniture by specific vendors (Hayworth, Steelcase, and Artmet).

Table G-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
PEER 2003/05	Taxonomy and Nonstructural Damage Inventory Form	Response Assessment of Nonstructural Building Elements	2003		Proposes a taxonomy (classification) of nonstructural elements by functionality, modes of failure, acceleration-sensitive or drift-sensitive response parameter, and repercussions of damage. Provides damageability, cost, and loss data for 200 elements. Includes a Nonstructural Damage Inventory Form used following the Nisqually Earthquake.
PEER 2003/12	Non-proprietary Details	Implementation Manual for the Seismic Protection of Laboratory Contents: Format and Case Studies	2003		Presents case studies for University of California Berkeley campus labs. Suggests format for User's Manual that could be used to help occupants install do-it-yourself details for a particular facility.
PEER 2005/03	Taxonomy	A Taxonomy of Building Components for Performance-Based Earthquake Engineering	2005		Provides a detailed taxonomy (classification) of nonstructural components. Each component is assigned a unique identification number. The list differentiates between anchored and unanchored versions of the same item.
Sandia	Sample Specification	Special Specification Section 13085S - Seismic Protection			Sample specification for the anchorage of equipment at Sandia (16 pages). Includes lists of equipment, detailed requirements, specific instructions for some items, load limits, and member sizes.

Table G-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
Seattle Public Schools	Non-proprietary Details	School Facilities Manual: Nonstructural Protection Guide. Safer Schools, Earthquake Hazards, Nonstructural. Second Edition	2000		Includes detailed inventory form and details not included in FEMA 74.
Southern California Earthquake Center	Photos, Damage	Nonstructural Issues in Public Schools - "Stairs to Nowhere"	2000		Photos of damage in school facilities in Southern California. Available at http://www.scec.org/instanet/00news/images/mcgavin/sld001.htm
University of California, Berkeley	Non-proprietary Details	UC Berkeley: Q-Brace Quake Bracing Guidelines	2005		Guidelines developed for University of California, Berkeley campus facilities. Includes detailed solutions for contents identifying vendor supplied products or size of hardware to use.
USACERL TR-98/34	Photos, Mitigation	Seismic Mitigation for Equipment at Army Medical Centers	1998		Presents simple methods for reducing the seismic vulnerability of equipment at Army medical centers. Illustrations, observations, and recommendations are based on examples from Madigan Army Medical Center (MAMC). Concerns about particular well-anchored critical medical equipment are presented. Published by the U.S. Army Construction Engineering Research

Table G-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
					Laboratories.
VISCMA 101-07	Sample Specification	Seismic Restraint Specification Guidelines for Mechanical, Electrical And Plumbing Systems	2007		Sample specification for seismic restraint of mechanical, electrical and plumbing equipment. Published by the Vibration Isolation and Seismic Control Manufacturer's Association, Wayne, Pennsylvania.

Table G-4 Proprietary Details and Products for the Protection of Nonstructural Components (continued)

Product Source/Vendor	Product or Service Description	Comments
Chatsworth Seismic Protection Products	Chatsworth Seismic Protection Products	Variety of seismic protection products. Available at http://www.twacomm.com/catalog/dept_id_644.htm
Flexhead	Flexible fire protection	Proprietary flexible connection for sprinklers heads. Available at http://www.flexhead.com/
Hilti	Concrete anchors and hardware	Information on product selection, different installation systems, and load data. Available at www.hilti.com
International Seismic Application Technology	International Seismic Application Technology (ISAT) Applications and Design Manual	Focuses exclusively on mechanical, electrical, plumbing equipment and piping. Includes load tables and details showing use of products. Available at www.isatsb.com
International Seismic Application Technology	2003 IBC Specification - Seismic Restraint of Suspended Utilities	Sample specification available at www.isatsb.com
Kinetics Noise Control	Kinetics noise control seismic restraint capabilities	Brochure presents restraint systems that serve to limit the movement of equipment during a seismic event. Available at http://www.kineticsnoise.com/hvac/pdf/seismic%20restraint%20capabilities.pdf
Loos & Co	Proprietary details approved by	Includes collections of details, such as: Section 7, Sway Brace Components, Installation

Table G-4 Proprietary Details and Products for the Protection of Nonstructural Components (continued)

Product Source/Vendor	Product or Service Description	Comments
	OSHPD for use in California hospitals	Instructions and Details. Available at www.earthquakebrace.com
Mason Industries	Details, Handbook, and online resources	Available at http://www.mason-ind.com/html/about.htm or http://209.200.80.33/html/seismic_engineering_index.htm
Metraflex	Thermal and seismic expansion joints for pipe	Available at http://www.metraflex.com/seismic_met.php
Pacific Seismic Products	ASCE 25-97 listed seismic actuated valves for residential, commercial and industrial applications	Gas shut off valves and other seismic actuated devices. Available at http://www.psp4gasoff.com/aboutpsp.htm
Ridg-U-Rak	Isolation system for storage racks	Isolation test of storage racks, both with and without transverse isolation. Movie of test available on website. Available at http://www.ridgurak.com
Technotes Issue No. 21 RWDI Consulting Engineers and Scientists	Base isolation system for museum pieces or equipment	"Seismic Protection of Museum Artifacts using Base Isolation," Bujar Myslimaj, Ph.D., P.Eng., Senior Specialist, Scott Gamble B.Sc., P.Eng., Principal, Ray Sinclair, Ph.D., Principal. Available at http://go.rwdi.com/technotes/t21.pdf
Safety Central	Earthquake safety fasteners, furniture straps, and emergency preparedness	Available at www.safetycentral.com

Table G-4 Proprietary Details and Products for the Protection of Nonstructural Components (continued)

Product Source/Vendor	Product or Service Description	Comments
	supplies	
Secure Quick	Secure Quick Seismic Fastening System	Consists of steel cable, wall bracket, and cable fasteners for attaching furniture to wood stud walls. Also provided on website, "Why You Should Not Use Plastic Tabs Devices, Velcro, Hook and Loop, Nylon Straps or Metal Braces." Available at www.quakesecure.com
Secure-It	PC Security Hardware	Provides products to secure computer equipment. Intended as protection against theft, but security cables and hardware could also be adapted as seismic restraint for other desktop items. Available at http://www.secure-it.com/shop/index.php/cPath/21
Seismic Restraints NZ	Hardware and systems for contents: collectables, home, office, school, hospital, lab, and technology.	Available at www.seismicrestraints.co.nz
Seismic Solutions	Seismic restraint for ducts, pipes, cable trays, and equipment using cables	Services include structural design, labor and materials for installation. Available at http://www.seismicsolutionsinc.com/details.html
Simpson Strong-Tie	Provides load rated straps and ties	Includes link for DIY (Do-it-Yourself) projects that illustrate the use of various connectors and adhesives, which could help with some nonstructural installations. Available at

Table G-4 Proprietary Details and Products for the Protection of Nonstructural Components (continued)

Product Source/Vendor	Product or Service Description	Comments
		http://www.strongtie.com/products/categories/diy.html
Strand Earthquake Consultants	Engineering and products for nonstructural seismic mitigation	Distributors for GeoSIG, Pacific Seismic Products, Metraflex, and WorkSafe Technologies.
Taylor Devices, Inc.	Viscous dampers for equipment protection	Available at http://www.taylordevices.com/SeismicDampers.htm
The Preparedness Center	Earthquake safety fasteners, furniture straps, and emergency preparedness supplies	Available at www.preparedness.com
USG	"Seismic Ceiling Resource Center"	Includes a series of technical notes and guidelines related to ceilings, ceiling tracks, and shadow moldings. Available at www.usg.com and www.seismicceilings.com
Viking	Flexible connections for sprinkler heads	Available at http://www.vikingcorp.com/databook/sprinklers/spk_accessories/070605.pdf

Table G-4 Proprietary Details and Products for the Protection of Nonstructural Components (continued)

Product Source/Vendor	Product or Service Description	Comments
WorkSafe Technologies	System for base-isolation of equipment	IsoBase™ Seismic Isolation Platform, available at http://www.worksafetech.com/
WorkSafe Technologies	Large variety of products for seismic protection of nonstructural components in offices, data centers, hospitals, laboratories, and warehouses.	Available at http://www.worksafetech.com/

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
8NCEE-002034	Enhancing the Resilience of Acute Care Facilities: An Overview of MCEER Research	Filiatrault, A., et al.	2006	Paper at 8th National Conference on Earthquake Engineering, San Francisco, California.
13WCEE-00295	Overturning Criteria for Non-Anchored Non-Symmetric Rigid Bodies	Boroschek, R.L., and Romo, D.	2004	Theoretical discussion of the effect of non-symmetric bodies subjected to overturning. Paper at 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada.
ATC-29	Proceedings of a Seminar on Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures		1992	Includes information on seismic design, performance, and research pertaining to nonstructural components. Funded by the National Center for Earthquake Engineering Research and the National Science Foundation.
ATC-29-1	Proceedings of a Seminar on Seismic Design, Retrofit, and Performance of Nonstructural Components		1998	Includes information on seismic design, performance, and research pertaining to nonstructural components. Funded by the National Center for Earthquake Engineering Research and the National Science Foundation.

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
ATC-29-2	Proceedings of Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities		2003	Focused principally on nonstructural components and systems in facilities with critical functions. Includes information on the state of the art, state of the practice, and efforts needed to improve both. Prepared in cooperation with the Multidisciplinary Center for Earthquake Engineering Research, and funded by the National Science Foundation.
ATC-38	Database on the Performance of Structures Near Strong-Motion Recordings: 1994 Northridge, California, Earthquake		2001	Effort to correlate structural and nonstructural damage with ground motion parameters recorded during the 1994 Northridge Earthquake. Report includes a CD-ROM with Access database, Excel files, text files, and collection of over 500 photos. Database includes some nonstructural damage data in the following categories: "cladding separation or damage," "partitions damage," "windows damage," "lights and ceilings damage," and "Building Contents Damage." Most photos do not show damage, but provide an overview of the building from street. Report also includes the ATC-38 Postearthquake Building Performance Assessment Form and Surveyor Instructions. Nonstructural categories include Exterior Cladding/Glazing; Partitions; Ceilings; Plumbing, Electrical, Lighting, HVAC; Fire Protection; Major Fixed Equipment, Elevators, Chimneys, and Unusual Contents.
ATC-58	Proceedings: Mini-Workshop/Invited Meeting on the Identification of		2005	ATC-58 Project workshop focusing on the selection of a nonstructural component taxonomy, and identifying nonstructural components that are significant to the estimation of casualty, direct economic, and downtime losses from earthquake damage.

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
	Nonstructural Components of Significance			
ATC-58	Guidelines for Seismic Performance Assessment of Buildings, ATC-58 35% Complete Draft		2007	Interim report on methodology for seismic performance assessment of new and existing buildings. Methodology will be applicable to most common building types designed and constructed in the United States within the past 50 years, and will estimate losses in terms of causalities, direct economic losses, and downtime as a result of earthquake damage. Loss estimation is based on fragility curves, which will be provided for both structural and nonstructural components.
FEMA 349	Action Plan for Performance Based Seismic Design		2000	Predecessor document to FEMA 445. Prepared by the Earthquake Engineering Research Institute for FEMA.
FEMA 445	Next-Generation Performance-Based Seismic Design Guidelines: Program Plan for New and Existing Buildings	2006	Section 4.2	Describes how performance-based seismic design guidelines will be developed under the ATC-58 Project. Section 4.2 refers specifically to the development of nonstructural performance products.

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
EERI	Learning from Earthquakes: a Survey of Surveys.	Porter, K.	2002	Taken from an EERI Invitational Workshop: An Action Plan to Develop Earthquake Damage and Loss Data Protocols, September 19-20, 2002, Doubletree Hotel, Pasadena, California.
MCEER	ASHRAE Consortium Investigates Performance of Roof-Top Air Handling Unit		Future	MCEER's ASHRAE Consortium is beginning Phase II studies involving shake table testing of a rigidly anchored and vibration isolated roof-top air handling unit. Testing will begin in March 2008 in the Structural Engineering and Earthquake Simulation Laboratory (SEESL) at the University at Buffalo. Studies will focus on developing a specialized numerical model capable of analyzing the seismic response of various types of HVAC equipment mounted on ASHRAE-type isolation/restraint systems.
MCEER	Seismic Vulnerability and Protection of Nonstructural Components	T.T. Soong and D. Lopez Garcia	2003	Addresses seismic vulnerability and protection strategies. Divides nonstructural items into 3 categories: Unrestrained Nonstructural Components; Restrained Nonstructural components; and Nonstructural Systems, which consist of systems of nonstructural components. Cites examples of fragility curves developed for each category. Contains discussion of both damping systems and isolation systems as protection strategies. Ends with recommendations for 6 tasks: (1) Develop a Catalog of Nonstructural Components, Systems and Contents; (2) Identify Nonstructural Performance Measures; (3) Identify Engineering Demand Parameters; (4) Develop Damage Database; (5) Establish Comprehensive Testing and Certification Protocols; and (6) Performance Evaluation Case Studies/Test bed Checks.

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
MCEER-99-0014	MCEER Nonstructural Damage Database	Kao, A., and Soong, T.T.	1999	Database of earthquake damage to nonstructural elements.
MCEER-05-0005	"Simulation of Strong Ground Motions for Seismic Fragility Evaluation of Nonstructural Components in Hospitals"	Wanitkorkul, A. and Filiatrault, A.	2005	Published by the Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, State University of New York.
MCEER-06-0001	Seismic Fragility of Suspended Ceiling Systems	Badillo-Almaraz, Whittaker, Reinhorn, Cimellaro	2006	Report on testing of Armstrong ceiling systems. Concludes that compression bars and retention clips help in the behavior of ceilings, and that undersized tiles are a detriment.
PEER 1998/05	Rocking Response and Overturning of Equipment Under Horizontal Pulse-Type Motions	N. Makris, Y. Roussos	1998	Published by the Pacific Earthquake Engineering Research Center, Berkeley, California.

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
PEER 1999/06	Rocking Response and Overturning of Anchored Equipment under Seismic Excitations	N. Makris, J. Zhang	1999	Results of shake table testing.
PEER 2001/14	Rocking Response of Equipment Anchored to a Base Foundation	N. Makris, C. Black	2001	Example of PEER research related to Lifelines. PEER has done series of tests funded by PG&E on electrical substation equipment including rigid bus connectors, flexible bus connectors, transformer bushings, and heavy substation equipment.
PEER 2002/01	Nonstructural Loss Estimation: The UC Berkeley Case Study	M. Comerio, J. Stallmeyer	2002	Case studies of loss estimation for five University of California Berkeley campus buildings. Includes a table (Table 10) showing costs assumed for many types of equipment, and photos of lab equipment.
PEER 2002/05	Guidelines, Specifications, and Seismic Performance Characterization of Nonstructural Building Components and Equipment	Filiatrault, A., Christopoulus, C, and Stearns, C.	2001	Contents include chapters on nonstructural earthquake damage. Nonstructural items are divided into 5 groups: contents; building service equipment; building utilization equipment; interior architectural elements; and exterior architectural elements. Overview of various design guidelines and inventory of previous analytical and experimental studies. Includes recommendations, and comprehensive list of references.

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
PEER 2003/05	Response Assessment of Nonstructural Building Elements	S. Taghavi, E. Miranda	2003	Proposes a taxonomy (classification) of nonstructural elements by functionality, modes of failure, acceleration-sensitive or drift-sensitive response parameter, and repercussions of damage. Provides damageability, cost, and loss data for 200 elements. Includes a Nonstructural Damage Inventory Form used following the Nisqually Earthquake.
PEER 2003/12	Implementation Manual for the Seismic Protection of Laboratory Contents: Format and Case Studies	W. Holmes, M. Comerio	2003	Presents case studies for University of California Berkeley campus labs. Suggests format for User's Manual that could be used to help occupants install do-it-yourself details for a particular facility.
PEER 2005/03	A Taxonomy of Building Components for Performance-Based Earthquake Engineering	Porter, Keith	2005	Provides a detailed taxonomy (classification) of nonstructural components. Each component is assigned a unique identification number. The list differentiates between anchored and unanchored versions of the same item.
PEER 2005/05	Performance Characterization of Bench- and Shelf-Mounted Equipment	S. Chaudhuri and T. Hutchinson|	2005	

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
PEER 2005/07	Experimental and Analytical Studies on the Seismic Response of Freestanding and Anchored Laboratory Equipment	D. Konstantinidis, N. Makris	2005	Shake table testing of equipment.
PEER 2005/12	PEER Test bed Study on a Laboratory Building: Exercising Seismic Performance Assessment	M. Comerio	2005	Test bed performance assessment of the UC Science Building linking performance of contents to operational failure. Shows the interdependence of building structure, systems, and contents in performance assessment, and highlights where further research is needed.
SUNY Buffalo	Nonstructural Components Simulator (NCS).		Future	Specialized equipment for testing nonstructural components. University at Buffalo's NEES (UB-NEES) facility is commissioning a dedicated Nonstructural Component Simulator (NCS). The NCS is a modular and versatile two-level platform for experimental performance evaluation of nonstructural components and equipment under realistic full scale floor motions. NCS can provide the dynamic stroke necessary to replicate full-scale displacements, velocities and accelerations at the upper levels of multi-story buildings during earthquake shaking. Both displacement sensitive and acceleration sensitive nonstructural components and equipment can be experimentally evaluated under full-scale floor motions to understand, quantify and control their seismic response.

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
SUNY Buffalo, CSEE-SEESL-2004-02	"Shake Table Testing of Frazier Industrial Storage Pallet Racks"	Filiatrault, A. and Wanitkorkul, A.	2004	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2005-01	"Seismic Qualification By Shake Table Testing of a Centrifugal Liquid Chiller according to AC-156 Testing Protocol"	Filiatrault, A. and Wanitkorkul, A.	2005	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2005-03	"Shake Table Testing of Ridg-U-Rak Rigid Based and Ridg-U-Rak Patent Pending Base Isolated Industrial Storage Racks"	Filiatrault, A., Wanitkorkul, A. and Seo, J-M.	2005	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2005-05	"Seismic Qualification of a Centrifugal Liquid Chiller by Shake Table Testing"	Filiatrault, A. and Wanitkorkul, A.	2005	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2006-	"Experimental Seismic Performance Evaluation of ASRAE-Type	Fathali, S. and Filiatrault, A.	2006	Published by the University at Buffalo, State University of New York, Buffalo, New York.

Table G-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
05	Isolation/Restraint Systems"			
SUNY Buffalo, CSEE-SEESL-2006-07	"Shake Table Testing of Ridg-U-Rak Rigid Based and Ridg-U-Rak Patent Pending Base Isolated Industrial Storage Racks: Production Unit Testing"	Filiatrault, A., and Wanitkorkul, A.	2006	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2006-19	"Shake Table Testing of Ridg-U-Rak Rigid Based and Ridg-U-Rak Patent Pending Base Isolated Industrial Storage Racks: Final Production Unit Testing"	Filiatrault, A., and Wanitkorkul, A.	2006	Published by the University at Buffalo, State University of New York, Buffalo, New York.
University of Chile	Controlled Overturning of Unanchored Rigid Bodies	Boroschek, R.L., and Iruretagoyena, A.		Review of test results for equipment on an inclined surface. Results show that an incline can force overturning to occur in a preferred direction. For example, a 3-degree angle will result in an 89% probability that blocks will overturn in that direction. Could be useful information for keeping contents on shelves.

H. Glossary

Air gap: For vibration isolated equipment, the air gap is the nominal clearance between the equipment support frame and the bumper restraint or snubber. Where the air gap exceeds 0.25", the seismic design force must be doubled ($2F_p$) per ASCE/SEI 7-10. The optimal size of this air gap is a subject of continuing study and laboratory testing.

Anchorage: Connection or attachment of a nonstructural component to the structure typically through the use of welding, bolts, screws, post-installed anchors or other mechanical fasteners that provide a positive connection. Based on the configuration and the deformability of the components used, the anchorage may behave as a rigid attachment or a flexible attachment.

Anchors in Concrete and Masonry: Anchors into concrete or masonry are required for the attachments of many nonstructural components. See ACI 318 Appendix D for requirements for anchors embedded in concrete. See TMS 402/ACI 503/ASCE 5 for anchors embedded in masonry. See also post-installed anchors and power actuated fasteners.

Appendage: An architectural component such as a canopy, marquee, ornamental balcony or statuary.

Base: The portion of a building embedded in or resting on the ground surface. Seismic forces are delivered to the base of a building. This term is also used to describe the interface of a freestanding nonstructural component with the floor or roof of a building where it is supported. Seismic forces from the floor or roof level of the building are delivered to the base of the nonstructural component.

Base Isolation: A method whereby a building superstructure is separated from its foundation using flexible bearings in order to reduce the earthquake forces. Special detailing is required to provide flexible connections for architectural components, building utilities, piping, etc. that cross the isolation plane into the building. This method can also be used to protect individual pieces of critical, sensitive, or expensive equipment, museum artifacts, etc.

Base Shear: The total design lateral force or shear at the base of a building structure or nonbuilding structure.

Bending: The curvature of structural or nonstructural components in response to certain types of applied loading. (For example, a beam bends or flexes in response to the weight it supports or to seismic loading).

Cantilever Elements: Elements supported only at the base such as parapets, chimneys, freestanding partitions, or freestanding exterior walls.

Component Importance Factor, I_p: A factor equal to 1.0 for standard installations or 1.5 used for the design of Designated Seismic Systems that are required for post-earthquake life safety or for the continued operations of essential facilities; defined in ASCE/SEI 7-10 Section 13.1.3. Note that this is not the same as the Importance Factor, I_c, assigned for the building structure as a whole.

Consequential Damage: Essential components, such as designated seismic systems, must be protected from damage which might result from the failure of adjacent or connected elements. Thus both the functional and physical interrelationships of essential or nonessential components with essential components must be considered in order to properly safeguard the essential components.

Construction Documents: The written, graphic, electronic, or pictorial documents describing the design, locations, physical characteristics of a project. These documents are typically required to communicate the design intent to contractors and installers and may also be required to demonstrate compliance with applicable building codes or meet specific requirements of the jurisdiction where a project is located.

Construction Observation: The visual observation by a licensed design professional to determine that the elements of the project are constructed in general conformance with the construction documents. The architect, mechanical engineer, structural engineer, etc. may each have an independent duty to perform construction observation. This type of observation is distinct from special inspection.

Damper: Mechanical devices used to dissipate energy and reduce seismic displacements. Dampers come in many shapes and sizes and may be viscous, viscoelastic, lead extrusion, friction, plate yielding, shape memory, or unbonded braces.

Deformability: The ease with which a component deforms under seismic loading. Per ASCE/SEI 7-10, different design parameters are used for high-, limited-, and low-deformability elements and attachments. For example, a high-deformability element is one whose ultimate deformation is not less than 3.5 times the limit deformation (see ASCE/SEI 7-10 for clarification of these terms).

Design Force: The earthquake forces used for design typically expressed as a percentage of the acceleration of gravity such as 0.3g or 1.0g. Minimum code specified design forces for

nonstructural components are found in ASCE/SEI 7-10 Chapter 13 or in the appropriate Building Code in effect where the Project is located.

Design Spectral Response Acceleration Parameters: S_{DS} and S_{D1} are two parameters used in ASCE/SEI 7-10 to characterize the intensity of the ground motion and determine the Seismic Design Category. S_{DS} refers to the 5% damped spectral response acceleration at short periods; S_{D1} refers to the spectral response acceleration at a period of 1 second.

Designated Seismic Systems: This term is applied to those architectural, electrical and mechanical systems or their components that require design in accordance with ASCE/SEI 7-10 Chapter 13 and for which the component importance factor, I_p, is greater than one. This includes systems required to function for life safety purposes after an earthquake including sprinkler systems and egress stairways; components used to convey, support or contain toxic, highly toxic, or explosive substances or hazardous materials; or components needed for continued operation of essential facilities.

Distortion: The change in the configuration of an object or building as it bends or twists out of shape in response to earthquake loading.

Drift: The horizontal displacement of a building resulting from the application of lateral forces, usually forces from earthquake or wind. See also interstory drift.

Earthquake Shaking: The vibratory movement of the earth's crust caused by seismic activity.

Egress, Emergency Egress: Path provided for safe exit from a building in case of emergency. Extra care may be warranted in designing restraints or anchorage for nonstructural components along emergency egress routes and may be required for essential facilities in some jurisdictions. Exit doors, partitions, ceilings, glazing, lighting and piping along the egress route may need special details; furniture and cabinets should be removed or anchored.

Egress Stairways: Stairways required for life-safety purposes in an emergency may be considered designated seismic systems and require special design treatment per ASCE/SEI 7-10 Chapter 13. This requirement may apply to partitions, infill, lighting, piping, etc. in the stairway as well as to the structural supports for stairs that are not part of the building structure.

Essential Facility: Occupancy Category IV facility such as hospital, emergency call center, fire station, emergency shelter as defined in ASCE/SEI 7-10.

Expansion Joint: A separation joint provided to allow for thermal expansion and contraction.

Flexible Connection: The anchorage of an object to a structural member or braced nonstructural component, usually using hardware such as springs, cables, or corrugated tubing, which is designed to allow the object to move relative to the structural member or braced nonstructural component without degradation of performance. Also used to describe connections of pipe or duct to fixed equipment that allows for relative movement; for example, flexible hose connections are advisable for all gas-fired equipment.

Flexible Nonstructural Component: Per ASCE/SEI 7-10, these are nonstructural components with a fundamental period greater than 0.6 seconds. The fundamental period of the nonstructural component (including its supports and attachment to the structure) may be computed per Section 13.6.2 of ASCE 7-10. The design parameters for nonstructural components may depend on whether an item is rigid or flexible.

FM Approved: Third-party certified by FM Approvals.

Foundation: That part of a structure which serves to transmit vertical and lateral forces from the superstructure of a building to the ground.

Frame: A type of structural system in which the loads are carried by a grid or framework of beams and columns, rather than by load-bearing walls. Special purpose frames built up from struts or steel shapes are used to support many types of nonstructural components such as piping, ducts, etc.

Friction Clip: A mechanical device that relies on friction to resist applied loads in one or more directions to anchor a nonstructural component. Friction is applied mechanically and is not due to the frictional resistance produced by the effects of gravity. For Seismic Design Categories D, E and F, friction clips may not be used to support sustained loads in addition to resisting seismic forces.

Hazardous Contents: A material that is highly toxic or potentially explosive and in sufficient quantity to pose a significant life-safety threat to the general public if an uncontrolled release were to occur. (See also IBC 2009 Chapter 4).

Importance Factor, I_c : Per ASCE/SEI 7-10 Section 11.5-1 and Table 1.5-2, the factor applies to the building structure. This factor is distinct from the Component Importance Factor, I_p.

Inertial Forces: Forces necessary to overcome the tendency for a body at rest to stay at rest or for a body in motion to stay in motion.

Inspection Body: Organization or individual accredited to ISO 17020 and regularly engaged in factory inspection services for seismic restraint of nonstructural components and equipment.

Intensity: See Shaking intensity.

Interstory Drift: The horizontal displacement that occurs over the height of one story of a building resulting from the application of lateral forces, usually forces from earthquake or wind. This is often expressed as an interstory ratio; the ratio of the displacement to the height of the story. Interstory drifts from the structural design of a building are often needed in design calculations for nonstructural components such as glazing, pipe risers or precast panels that are attached to more than one floor.

Lateral Force Resisting System: The elements of a structure that resist horizontal forces. These structural elements are typically frames, braces or shear walls.

Magnitude: A measure of earthquake size which describes the amount of energy released.

Mitigation: An action taken to reduce the consequences of a future earthquake. Other terms such as retrofit, rehabilitation or upgrade are also used to describe these actions.

Moment: The moment of a force about a given point, typically referred to as "the moment", is the turning effect, measured by the product of the force and its perpendicular distance from the point.

Nonbuilding Structures: These are self-supporting structures and other structures governed by the design provisions in ASCE/SEI 7-10 Chapter 15. There is some overlap between the definitions for large nonstructural components and nonbuilding structures; it is recommended to check both provisions to see which apply for large or industrial items. Storage racks, tanks, signs, and chimneys are examples of items that may be covered in either Chapter 13 or 15 depending upon the size and support conditions.

Nonstructural Component: Any architectural element; mechanical, electrical, plumbing (MEP) equipment or systems or part thereof; any furniture, fixtures, equipment (FF&E) or building contents. This term is used to describe any and all components within or without a building or nonbuilding structure which are not an explicit part of the structural system. The seismic design of nonstructural components is governed by provisions in ASCE/SEI 7-10 Chapter 13. Some large nonstructural components may qualify as nonbuilding structures (see ASCE/SEI 7-10 Chapter 15).

OSHPD Approved: Approved by the State of California, Office of Statewide Health Planning and Development.

Risk Category: A category used to determine structural and nonstructural design requirements in ASCE/SEI 7-10 Table 1.5-1 based on a building's occupancy. Occupancy Category I is used for the buildings and other structures with the lowest risk to human life such as agricultural facilities; Occupancy Category IV is used for essential facilities such as hospitals which may pose a substantial hazard to humans and to the community.

Partition: A nonstructural interior wall used to subdivide interior spaces. Partitions may span horizontally or vertically from support to support; support may be provided by the building structure or secondary framing members. Partitions may be full-height or partial-height, often stopping just above the ceiling level and are typically constructed of steel or wood studs and gypsum board, wood studs and plaster, brick, or concrete masonry unit infill. Glass block and glazed partitions are also in use.

Positive Connection: A means of anchorage between a nonstructural item and a structural member or braced nonstructural component that does not rely on friction to resist the anticipated earthquake forces. Positive connections are typically made using hardware such as bolts, steel angles, or cables rather than C-clamps or thumb screws. Nails, adhesives and toggle bolts typically do not have enough capacity to provide positive connections for the seismic anchorage of nonstructural items.

Post-installed Anchors: Post-installed anchors in concrete or masonry are those which are drilled and placed into existing construction. Post-installed anchors must be prequalified for seismic applications; for instance, post-installed anchors in concrete must be prequalified in accordance with ACI 355.2 or other approved qualification procedure.

Pounding: The impact of two structures during an earthquake. Pounding frequently occurs when the seismic gap between two adjacent wings of a building, or the gap between two neighboring buildings, is insufficient to accommodate the relative lateral movement of both buildings.

Power Actuated Fasteners: Use of power actuated fasteners to resist seismic loading may be restricted depending on the substrate (concrete, steel, masonry, etc.) and the Seismic Design Category. See ASCE/SEI 7-10 Section 13.4.5 for restrictions and exemptions.

Professional Engineer: A professional engineer is one who is legally qualified to practice in the jurisdiction where the Project is located, who is experienced in providing engineering services of the kind indicated, and is registered with the state where the project is located.

Restraint/Bracing: Bracing or anchorage used to limit movement under seismic forces. Cables or rigid elements (struts, pipes, angles, etc) used to resist forces by uniaxial tension or compression. The term "bracing" may also be used to describe design to resist lateral forces through the use of wall or frame elements.

Rigid Connection: The anchorage of an object to a structural member or braced nonstructural component, usually using hardware such as bolts or brackets, which is designed to prohibit the object to move relative to the structural member or braced nonstructural component.

Rigid Nonstructural Component: Per ASCE/SEI 7-10, these are nonstructural components with a fundamental period less than or equal to 0.6 seconds. The fundamental period of the nonstructural component (including its supports and attachment to the structure) may be computed per Section 13.6.2 of ASCE 7-10. The design parameters for nonstructural components may depend on whether an item is rigid or flexible.

Schematic Upgrade Detail: A drawing outlining the basic elements of an upgrade scheme, but lacking dimensions, element sizes, and other specific information necessary for construction. The terms upgrade, retrofit, rehabilitation, and mitigation are often used interchangeably.

Seismic: Of, relating to, or caused by an earthquake.

Seismic Deformations: Drifts, deflections and seismic relative displacements determined in accordance with the applicable seismic requirements of ASCE/SEI 7-10 or the Building Codes currently in effect where the Project is located.

Seismic Design Category: A classification assigned to a building structure based on its risk category or occupancy and the severity of the design earthquake ground motion. See ASCE/SEI 7-10 Table 1.5-1 for the Risk Category; see Section 11.4 for ground motion; see Section 11.6 for Seismic Design Category. Requirements for nonstructural components depend on the Seismic Design Category which ranges from A to F, from A for the lowest seismicity to F for the highest seismicity. Structures rated Seismic Design Category A are exempt from the nonstructural requirements in Chapter 13; structures rated Seismic Design Categories D, E and F have the most stringent requirements for nonstructural components.

Seismic Drift: The horizontal displacement of a building resulting from the application of lateral earthquake forces. See also interstory drift.

Seismic Force: The force that will act on a nonstructural component during an earthquake is the product of its mass and the seismic acceleration.

Seismic Gap or Seismic Joint: The distance between adjacent buildings, or two portions of the same building, which is designed to accommodate relative lateral displacements during an earthquake.

Seismic Risk: The chance of injury, damage, or loss resulting from earthquake activity.

Seismic Stop: A rigidly mounted bumper or snubber used to limit the range of lateral motion of spring-mounted mechanical equipment. See also air gap, snubber, and vibration isolation.

Seismic Upgrade: Improvement of the resistance of a structural or nonstructural component to provide a higher level of safety or resistance to earthquake forces. For nonstructural components, seismic upgrade schemes typically involve the addition of anchorage hardware or braces to attach the nonstructural item to the surrounding structure. In some instances, the nonstructural item may also require internal strengthening.

Separation Joint: The distance between adjacent buildings, or two portions of the same building, which is designed to accommodate relative displacements between the two structures. Seismic gaps and expansion joints are two types of separation joint.

Shaking Intensity: The amount of energy released by an earthquake as measured or experienced at a particular location. Intensity is subjectively measured by the effects of the earthquake on people and structures.

Shear Wall: A wall designed to resist lateral forces parallel to the wall.

Snubber: A device, such as a mechanical or hydraulic shock absorber, used to absorb the energy of sudden impulses or shocks in machinery or structures. Snubbers are often used to brace pipe runs where thermal expansion and contraction is an important consideration. Snubbers are also required for many equipment items mounted on vibration isolators in order to limit the seismic movement. See also vibration isolation and air gap.

Special Inspection: The observation of work by a Special Inspector or Inspection Body to determine compliance with the approved construction documents and the standards of the authority having jurisdiction over the project. Continuous special inspection requires full-time observation by a special inspector who is present in the area where work in being performed. Periodic special inspection may be part-time or intermittent observation by a special inspector

who is present in the area where the work has been or is being performed. Requirements for continuous or periodic special inspection are typically specified by the jurisdiction.

Special Inspector: An International Accreditation Service (IAS) accredited International Building Code (IBC) special inspection agency or qualified professional engineer who demonstrates competence, to the satisfaction of the building official, for inspection of the designated seismic systems. The owner or the registered design professional in responsible charge acting as the owner's agent shall employ one or more special inspectors to provide periodic inspections during installation of designated seismic systems.

Supports: Those members, assemblies of members or manufactured elements including braces, frames, legs, shear lugs, snubbers, hangers, saddles, struts, and associated fasteners that transmit loads between nonstructural components and their attachments to the structure. Some supports may carry only gravity loads (the weight of the item), such as vertical hangers. Some supports may resist both gravity loads and seismic loads; some may resist only seismic loads.

UL Listed: Approved by the Underwriters Laboratories.

Upgrade Detail: A drawing presenting the necessary elements of an upgrade scheme, including dimensions, element sizes, and other specific information in sufficient detail so that the drawing can be used for construction.

Veneer: An architectural facing or ornamentation of brick, tile, concrete, stone or similar materials attached to a backing substrate. Veneer may be adhered to the substrate or anchored using mechanical anchors.

Vertical Force Resisting System: The elements of a structure that resist the gravity loads or self-weight.

Vibration Isolation: Mechanical equipment is often placed on specially designed springs to prevent the transmission of mechanical vibrations into the building. Components mounted on vibration isolators also require bumper restraints or snubbers in each horizontal direction to resist seismic loading. The nominal clearance between the snubbers and equipment may affect the seismic design forces; see also snubbers and air gap.

I. References

ACI, 2008, *Building Code Requirements and Specification for Masonry Structures and Related Commentary*, TMS 402-08/ACI 530-08/ASCE 5-08, reported by the Masonry Standards Joint Committee (MSJC), consisting of TMS Committees 402 and 602, ACI Committees 530 and 530.1, and ASCE Committees 5 and 6, published by the American Concrete Institute.

ACI, 2011, Building Code Requirements and Specification for Masonry Structures and Related Commentar*ies,* TMS 402-11/ACI 530-11/ASCE 5-11, reported by the Masonry Standards Joint Committee (MSJC), consisting of TMS Committees 402 and 602, ACI Committees 530 and 530.1, and ASCE Committees 5 and 6, published by the American Concrete Institute.

Adham, S. A., Brent B., 1985, "The Borah Peak, Idaho Earthquake of October 28, 1983 – Buildings and Schools," *Earthquake Spectra*, Vol. 2, No.1.

AFPA/ANSI, 2005, *National Design Specifications for Wood Construction,* NDS 2005*,* American Forest and Paper Association, Washington, D.C.

ANSI, 2004, *Safety Glazing Materials Used in Buildings – Safety Performance Specifications and Methods of Test,* ANSI Z97.1-2004*,* American National Standards Institute, New York, New York.

ANSI/ASHRAE, 2008, *Method of Test of Seismic Restraint Devices for HVAC&R Equipment,* Standard 171-2008, American Society of Heating, Refrigerating and Air-Conditioning Engineers Atlanta, Georgia.

ANSI/NISO, 1994, *Single-Tier Steel Bracket Library Shelving*, Z39.73 – 1994, National Information Standards Organization, Baltimore, Maryland.

ANSI/RMI, 2008, *Specification for the Design, Testing, and Utilization of Industrial Steel Storage Racks*, ANSI/RMI MH 16.1, Rack Manufacturers Institute, Material Handling Institute of America, Charlotte, North Carolina.

ASCE, 2002, *Seismic Evaluation of Existing Buildings,* ASCE/SEI 31-03, American Society of Civil Engineers, Reston, Virginia.

ASCE, 2006, *Minimum Design Loads for Buildings and Other Structures,* ASCE/SEI 7-05, American Society of Civil Engineers, Reston, Virginia.

ASCE, 2007, *Seismic Rehabilitation of Existing Buildings,* ASCE/SEI 41-06, American Society of Civil Engineers, Reston, Virginia.

ASCE, 2010, *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10, American Society of Civil Engineers, Reston, Virginia.

ASHRAE, 2012, *A Practical Guide to Seismic Restraint*, 2nd Edition, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

ASHRAE/SMACNA, 2002, *ASHRAE/SMACNA Seismic Restraint Applications CD-ROM*, prepared by the American Society of Heating, Refrigerating and Air-Conditioning Engineers and Sheet Metal and Air Conditioning Contractors' National Association, Atlanta, Georgia.

ASME, 2007a,*Safety Code for Elevators and Escalators*, A17.1/CSO B44, American Society of Mechanical Engineers, New York, New York.

ASME, 2007b, *Performance-Based Safety Code for Elevators and Escalators*, A17.7/B44.7, American Society of Mechanical Engineers, New York, New York.

ASME, 2008, *Process Piping*, B31.3, American Society of Mechanical Engineers, New York, New York.

ASTM C635/C635M-07, *Standard Specification for the Manufacture, Performance, and Testing of Metal Suspension Systems for Acoustical Tile and Lay-in Panel Ceilings*, ASTM International, West Conshohocken, Pennsylvania.

ASTM C636/C636M-06, *Standard Practice for Installation of Metal Ceiling Suspension Systems for Acoustical Tile and Lay-In Panels*, ASTM International, West Conshohocken, Pennsylvania.

ASTM C754-11, *Standard Specification for Installation of Steel Framing Members to Receive Screw-Attached Gypsum Panel Products,* ASTM International, West Conshohocken, Pennsylvania.

ASTM E580, 2010, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions*, ASTM International, West Conshohocken, Pennsylvania.

ATC, 2008, *Reducing the Risks of Nonstructural Earthquake Damage, State-of-the-Art and Practice Report,* ATC-69 Report, prepared by the Applied Technology Council for the Federal Emergency Management Agency in cooperation with the National Earthquake Hazard Reduction Program, Redwood City, California.

BSSC, 2004, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures – 2003 Edition,* FEMA 450 Report, prepared by the Building Seismic Safety Council for the Federal Emergency Management Agency, Washington, D.C.

California Department of General Services, Division of the State Architect, 1999, *Clay Brick Masonry High Lift Grouting Method*, Interpretation of Regulations Document, IR 21-3, Sacramento, California.

California Department of General Services, Division of the State Architect, 2005a, *Metal Suspension Systems for Lay-in Panel Ceilings*, revised 07-21-05, Interpretation of Regulations Document, IR 25-2, Sacramento, California.

California Department of General Services, Division of the State Architect, 2005b, *Drywall Ceiling Suspension Conventional Construction – One Layer*, revised 07-21-05, Interpretation of Regulations Document, IR 25-3, Sacramento, California.

California Department of General Services, Division of the State Architect, 2005c, *Guidelines for Earthquake Bracing of Residential Water Heaters,* prepared by the Division of the State Architect, Sacramento, California.

California Department of General Services, Division of the State Architect, 2007a, *Masonry Walls – Non Structural*, Interpretation of Regulations Document, IR 21-1, Sacramento, California.

California Department of General Services, Division of the State Architect, 2007b, *Masonry: Concrete Masonry Unit Standards*, revised 11-01-07, Interpretation of Regulations Document, IR 21-4, Sacramento, California.

California Department of General Services, Division of the State Architect, 2009a, *Pendant Mounted Light Fixtures,* Interpretation of Regulations Document, IR 16-9, Sacramento, California.

California Department of General Services, Division of the State Architect, 2009b, *Concrete Masonry High Light Grouting Method*, revised 12-17-09, Interpretation of Regulations Document, IR 21-2, Sacramento, California.

California Department of General Services, Division of the State Architect, 2009c, *Metal Suspension System for Lay-in Panel Ceilings*, Interpretation of Regulations Document, IR 25-5, Sacramento, California.

California Department of General Services, Division of the State Architect, 2010a, *Solar Photovoltaic and Thermal Systems and Acceptance Requirements*, revised 06-25-10, Interpretation of Regulations Document, IR 16-8, Sacramento, California.

California Department of General Services, Division of the State Architect, 2010b, *Plan Submittal Requirements: Automatic Fire Sprinkler Systems (AFSS)*, Policy Document, Policy 10-01, Sacramento, California.

Charleson, A., 2007, *Architectural Design for Earthquake*, Second Edition, New Zealand Society for Earthquake Engineering.

CISCA, 2004, *Guidelines for Seismic Restraint for Direct-hung Suspended Ceiling Assemblies (zones 3-4)*, Ceilings and Interior Systems Construction Association, St. Charles, Illinois.

CISN, 2009, *Shakemaps*, California Integrated Seismic Network.

City of Seattle, 2004, *Alteration and Repair of Unreinforced Masonry Chimneys*, prepared by the Department of Planning and Development, Seattle, Washington.

Ding, D. and Arnold, C., coordinators, 1990, "Architecture, building contents, and building Systems," Chapter 9 in *Earthquake Spectra*, Supplement to Volume 6, pp. 339-377.

Dobb, Linda, librarian, San Francisco State University, personal communication, San Francisco, California.

Dorge, V., Jones, S., 1999, *Building an Emergency Plan, A Guide for Museums and Other Cultural Institutions*, Getty Conservation Institute, Los Angeles, California.

FCC, 1997, *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields*, OET Bulleting 65 Edition 97-01, authored by the Standards Development Branch, Allocations and Standards Division, Office of Engineering Technology, Federal Communications Commission, Washington D.C.

FEMA, 1981, *An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake: Findings and Actions Taken*, Federal Emergency Management Agency, Washington, D.C.

FEMA 74, 1994, *Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide, Third Edition,* prepared by Wiss, Janey, Elstner Associates, Inc. for the Federal Emergency Management Agency, Washington, D.C.

FEMA 232, 2006, *Homebuilders' Guide to Earthquake-Resistant Design and Construction*, Federal Emergency Management Agency, Washington, D.C.

FEMA 395, 2003, *Incremental Seismic Rehabilitation of School Buildings (K-12): Providing Protection to People and Buildings*, Federal Emergency Management Agency, Washington, D.C.

FEMA 396, 2003, *Incremental Seismic Rehabilitation of Hospital Buildings: Providing Protection to People and Buildings*, Federal Emergency Management Agency, Washington, D.C.

FEMA 397, 2003, *Incremental Seismic Rehabilitation of Office Buildings: Providing Protection to People and Buildings*, Federal Emergency Management Agency, Washington, D.C.

FEMA 398, 2004, *Incremental Seismic Rehabilitation of Multifamily Apartment Buildings: Providing Protection to People and Buildings*, Federal Emergency Management Agency, Washington, D.C.

FEMA 399, 2004, *Incremental Seismic Rehabilitation of Retail Buildings: Providing Protection to People and Buildings*, Federal Emergency Management Agency, Washington, D.C.

FEMA 400, 2004, *Incremental Seismic Rehabilitation of Hotel and Motel Buildings: Providing Protection to People and Buildings*, Federal Emergency Management Agency, Washington, D.C.

FEMA 412, 2002, *Installing Seismic Restraints for Mechanical Equipment*, prepared by the Vibration Isolation and Seismic Control Manufacturers Association for the Federal Emergency Management Agency, Washington, D.C.

FEMA 413, 2004, *Installing Seismic Restraints for Electrical Equipment*, prepared by the Vibration Isolation and Seismic Control Manufacturers Association for the Federal Emergency Management Agency, Washington, D.C.

FEMA 414, 2004, *Installing Seismic Restraints for Duct and Pipe*, prepared by the Vibration Isolation and Seismic Control Manufacturers Association for the Federal Emergency Management Agency, Washington, D.C.

FEMA 460, 2005, *Seismic Considerations for Steel Storage Racks Located in Areas Accessible to the Public*, Federal Emergency Management Agency, Washington, D.C.

FEMA 461, 2007, *Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components,* prepared by the Applied Technology Council for the Federal Emergency Management Agency, Washington, D.C.

Gatscher, J.A., McGavin, G.L., Caldwell, P.J., 2012, *Earthquake Protection of Building Equipment and Systems, Bridging the Implementation Gap*, ASCE, Reston, Virginia

Goodno, B.J., Gould, N.C., Caldwell, P.J. and Gould, P.L.,2011, "Effects of the January 2010 Hatian Earthquake on Selected Electrical Equipment," *Earthquake Spectra*, Volume 27, No. S1, pp. 1-26

Hart, G.C, 1994, *Performance of Glass Block during the Northridge Earthquake,* prepared for Pittsburgh Corning Corporation, Technical/General Information Letter No: TD-249, Pittsburgh, Pennsylvania.

Huttenbach, R.A., 1980, *Policy on Seismic Hazard Reduction. Santa Barbara, California*, Office of the Chancellor, University of California, Santa Barbara.

ICBO, 1994, *Uniform Building Code*, International Conference of Building Officials, Whittier, California.

ICC, 2000, 2003, 2006, 2009, 2012, *International Building Code*, International Code Council, Washington, D.C.

ICC-ES, 2004, *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems*, AC 156, International Code Council Evaluation Service, Whittier, California.

ICC-ES, 2006, *Acceptance Criteria for Attachment Devices for Recessed Lighting Fixtures (Luminaries) in Suspended Ceiling Systems*, AC 184, International Code Council Evaluation Service, Whittier, California.

Staff of the Los Angeles Times. 1994," 4:31, Images of the 1994 Los Angeles Earthquake. Los Angeles, California," Los Angeles Times, Los Angeles, California.

NEBS, 2006, *NEBS Requirements: Physical Protection,* GR-63, Network Equipment Building Systems.

NFPA, 2006, *Building Construction and Safety Code*, NFPA 5000, National Fire Protection Association, Quincy, Massachusetts.

NFPA, 2007a, *Standard for Installation of Sprinkler Systems, 2007 Edition,* NFPA 13, National Fire Protection Association, Quincy, Massachusetts.

NFPA, 2007b, *Standard System for the Identification of Hazards of Materials for Emergency Response*, NFPA 704, National Fire Protection Association, Quincy, Massachusetts.

NFPA, 2009, *Standard for Electrical Safety in the Workplace*, NFPA 70E, National Fire Protection Association, Quincy, Massachusetts.

NFPA, 2010, *Standard for Installation of Sprinkler Systems, 2010 Edition,* NFPA 13, National Fire Protection Association, Quincy, Massachusetts.

NGDC, 2009, *Natural Hazards Slide Sets*, National Geophysical Data Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

PCI, 2011, *Behavior of Architectural Precast Panels in Response to Drift*, DN-21,

Podany, J., 2006, "Advances in the protection of museum collections from earthquake damage," *Papers from a Symposium Held at the J. Paul Getty Museum at the Villa on May 3-4, 2006,* J. Paul Getty Museum, Los Angeles, California.

Reitherman, R. And Sabol, T., coordinators, 1995, "Nonstructural damage," Chapter 11 in *Earthquake Spectra*, Supplement C to Volume 11, Northridge Earthquake Reconnaissance Report.

Richter, C.F., 1957, *Elementary Seismology*, W.H. Freeman Co, San Francisco, California.

Salt Lake City School District, 2001, *Seismic Design Criteria of Nonstructural Systems for New School Facilities and Existing School Facilities.*

SMACNA, 2009, *Seismic Restraint Manual: Guidelines for Mechanical Systems*, 3rd Edition, Sheet Metal and Air Conditioning Contractors' National Association, Washington, D.C.

Steinbrugge, K.V. and Schader, E.E., 1973, "Earthquake damage and related statistics In San Fernando, California, Earthquake of February 9, 1971," edited by Leonard Murphy. Volume 1A, pp. 709-710 and 713. National Oceanic and Atmospheric Administration, Washington D.C.

Steinmetz, W.H., 1979, "How a campus handles an earthquake disaster," presented at the 26th National Conference on Campus Safety, University of Michigan, Ann Arbor, Michigan.

Taly, N., 1988, "The Whittier Narrows, California Earthquake of October 1, 1987–Performance of buildings at California State University, Los Angeles," *Earthquake Spectra,* Volume 4, No. 2.

Whittaker, A.S. and Soong, T.T., 2003, "A overview of nonstructural component research at three U.S. earthquake engineering research centers," in *Proceedings of Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities,* Applied Technology Council, ATC-29-2, pp. 271-280, Redwood City, California.

Wong, K.M., 1993, *High Seismic Economic Risk Buildings: Research Report to the National Science Foundation*, Vickerman, Zachary, Miller, Oakland, California.

J. PROJECT PARTICIPANTS

APPLIED TECHNOLOGY COUNCIL – TASK ORDER MANAGEMENT

Christopher Rojahn (Project Executive Director)
Applied Technology Council
201 Redwood Shores Parkway, Suite 240
Redwood City, CA 94065

William T. Holmes (Project Technical Monitor)
Rutherford & Chekene
55 Second Street, Suite 600
San Francisco, CA 94105

Jon A. Heintz (Project Quality Control Monitor)
Applied Technology Council
201 Redwood Shores Parkway, Suite 240
Redwood City, CA 94065

FEMA PROJECT OFFICERS

Cathleen M. Carlisle
Dept. of Homeland Security – FEMA
500 C Street SW
Washington, DC 20008

Michael Mahoney
Dept. of Homeland Security – FEMA
500 C Street SW
Washington, DC 20008

PROJECT MANAGERS

Thomas R. McLane
Applied Technology Council
2111 Wilson Blvd., Suite 700
Arlington, VA 22201

Ayse Hortacsu
Applied Technology Council
201 Redwood Shores Parkway, Suite 240
Redwood City, CA 94065

PROJECT MANAGEMENT COMMITTEE

Maryann Phipps, Lead Technical Consultant
Estructure
8331 Kent Court
El Cerrito, CA 94530

Robert Bachman
Consulting Structural Engineer
25152 La Estrada Drive
Laguna Niguel, CA 92677

James Carlson
Omaha Public Power District
Fort Calhoun Station
13801 Buffalo Road
Springfield, NE 68059

Eduardo A. Fierro
BFP Engineers, Inc.
1803 Oxford Street, Suite 2
Berkeley, CA 94709

John G. Gillengerten
5155 Holly Drive
Shingle Springs, CA 95862

William T. Holmes
Rutherford & Chekene
55 Second Street, Suite 600
San Francisco, CA 94105

Richard Kirchner
Hawley Peterson & Snyder Architects
444 Castro Street, Suite 1000
Mountain View, CA 94041

Eduardo Miranda
Dept. of Civil and Environmental Engineering
Stanford University
Yang and Yamazaki Building, Rm. 281
Stanford, CA 94305

Cynthia L. Perry
BFP Engineers, Inc.
1803 Oxford Street, Suite 2
Berkeley, CA 94709

Jon A. Heintz (ex-officio)

PROJECT REVIEW PANEL

Tim P. Brown
Bureau of Reclamation
Denver Federal Center
6th and Kipling, Building #67
Denver, CO 80225

Mary C. Comerio
University of California, Berkeley
Department of Architecture
382D Wurster Hall
Berkeley, CA 94720-1800

David Conover
International Code Council (ICC)
500 New Jersey Ave. NW, Suite 600
Washington, DC 20001

Doug Fitts
Fitts HVAC Consulting, LLC
P. O. Box 16847
St. Louis, MO 63105

Michael J. Griffin
CCS Group, Inc.
1415 Elbridge Payne Road, Suite 265
Chesterfield, MO 63017

*ATC Board Contact

John R. Henry
International Code Council, Inc.
P.O. Box 968
Knights Landing, CA 95645

Steven Kuan*
Office of Housing and Construction Standards
P.O. Box 9844
Stn Prov Govt, 5th Floor, 609 Broughton Street
Victoria, BC V8W 9T2 Canada

Robert K. Reitherman
Consortium of Universities for Research in Earthquake Engineering (CUREE)
1301 South 46th St., Building 420
Richmond, CA 94804

Jeffrey R. Soulages
Strategic Facilities Technology Design (SFTD)
Intel Corporation
2501 NW 229th Street MS: RA1-220
Hillsboro, OR 97124

William T. Holmes (ex-officio)
Christopher Rojahn (ex-officio)

ADDITIONAL REVIEWERS

Dawn Anderson
As It Stands
2059 Camden Ave. Suite 229
San Jose, CA 95124

Jon Gregg
ISAT Seismic Bracing
42550 Albrae St.
Fremont, CA 94538

Eric Peabody
The Design Partnership
1412 Van Ness Avenue
San Francisco, CA 94109

Philip J. Caldwell
Schneider Electric
1990 Sandifer Blvd.
Seneca, SC 29682

ADDITIONAL CONTRIBUTOR

Scott Hiner
Creative Marketing Resources
447 Sheridan Circle
Livermore, CA 94551-1775