

Reducing the Risks of Nonstructural Earthquake Damage



A PRACTICAL GUIDE

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Reducing the Risks of Nonstructural Earthquake Damage

A Practical Guide

Third Edition

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PREFACE

The first edition of this guide was prepared under contract to the Southern California Earthquake Preparedness Project (SCEPP), a joint state-federal effort. It was prepared by Scientific Service, Inc., a firm specializing in engineering and emergency planning consulting related to natural and man-made hazards. It was written and researched by Robert Reitherman with the assistance of Dr. T. C. Zsutty; they provided architectural and structural engineering expertise, respectively, in the field of nonstructural earthquake damage.

The second edition was published in 1985 by the Bay Area Regional Earthquake Preparedness Project, now part of the California Office of Emergency Services, Earthquake Program. Revisions were based on the suggestions of users and a peer review committee consisting of Christopher Arnold, president, Building Systems Development, Inc.; Richard Eisner, director of BAREPP; Eric Elsesser, vice president, Forell/Elsesser; William Holmes, structural engineer, Rutherford & Chekene; John Meehan, chief, structural safety, Office of the State Architect; and Gilbert Najera, Southern California Earthquake Preparedness Project.

The revisions made in the second edition of the guide consisted primarily of modifying graphics, updating construction cost estimates, and identifying the need for engineering and architectural assistance in designing and carrying out the guide's recommendations.

This third edition was prepared by Wiss, Janney, Elstner Associates, Inc., for the Federal Emergency Management Agency (FEMA) under the National Earthquake Technical Assistance Contract (EMW-92-C-3852). The objective of

this revision is to incorporate lessons learned from earthquakes that have occurred since the second edition was published, provide additional details, distinguish between do-it-yourself details and those for which there is additional engineering required, update the cost estimates presented, and incorporate new techniques and trends in earthquake engineering. The format of the document has been substantially revised. Review comments and suggestions were provided by the advisory panel, which was composed of Christopher Arnold, Richard Eisner, William Holmes, and Robert Reitherman.

Individual photo credits are provided, both for photos carried over from previous editions and for those new to the third edition. Some new anchorage or bracing details have been adapted from other publications that are listed in the References (References 16 to 21).

Disclaimer FEMA and Wiss, Janney, Elstner Associates have attempted to produce reliable and practical information in this publication, but neither they nor any consultants involved in preparing or reviewing material contained in this guide can guarantee that its application will safeguard people or property in case of an earthquake. The state of the art of earthquake engineering is not sufficiently developed to perfectly predict the performance of nonstructural elements or to guarantee adequate earthquake protection if these or other guidelines are followed. Professional expertise is recommended to increase the probability that intended levels of earthquake protection will be achieved. Liability for any losses that may occur in an earthquake or as a result of using this guidance is specifically disclaimed.

1 HOW TO USE THIS GUIDE

PURPOSE

This guide was developed to fulfill several different objectives and address a wide audience with varying needs. The primary intent is to explain the sources of nonstructural earthquake damage in simple terms and to provide information on effective methods of reducing the potential risks. The recommendations contained in this guide are intended to reduce the potential hazards but cannot completely eliminate them.

INTENDED AUDIENCE

This guide is intended primarily for use by a lay audience: building owners, facilities managers, maintenance personnel, store or office managers, corporate/agency department heads, business proprietors, homeowners, etc. Some readers may be small-business owners with a small number of potential problems that could be addressed in a few days' time by having a handyman install some of the generic details presented in this guide. Other readers may be responsible for hundreds of facilities and may need a survey methodology to help them understand the magnitude of their potential problems.

The purpose of this section is to help readers identify those portions of the guide that may be applicable to their particular situation and interests. The prospective audience can be subdivided into the four general categories described below. Each description contains a list of the chapters that may be the most useful for that group of readers. The chapter contents are also described below.

General Interest The lay reader who wants an illustrated overview of the subject of nonstructural earthquake damage.

Suggested reading for the general interest reader: Chapters 1 and 2 and the nonstructural examples in Chapter 4.

Do-It-Yourself The reader who wants a general overview of the subject, help in identifying potential hazards, and specific guidance with suggested upgrade details that the reader can implement him- or herself.

Suggested reading for the do-it-yourself reader: Chapters 1, 2, 3, and 4. Chapter 4 contains some generic details and installation guidelines.

Facilities/Planning Personnel Facilities or planning personnel who need an overview of the subject as well as a survey methodology applicable to an organizational setting. This guide contains forms and checklists that can be used to survey a facility to identify potential hazards, estimate seismic vulnerability and potential earthquake losses and repair costs, and estimate the costs in implementing hazard reduction methods. The guide differentiates between methods that can be readily implemented by a handyman and those that require professional assistance. The guide also contains a discussion of various implementation strategies and general guidance on earthquake preparedness and emergency planning.

Suggested reading for facilities/planning personnel: Chapters 1-7 and survey forms and checklists (Appendixes A, B, and C).

Architect/Engineer The A/E who has little or no knowledge of nonstructural earthquake damage and needs an introduction to the subject and a list of sources that will provide more detailed technical information.

Suggested reading for architect/engineer unfamiliar with the subject matter: Chapters 1-7, survey forms and checklists (Appendixes A, B, and C), and annotated bibliography.

The categories and suggested reading above are intended to be helpful, not restrictive. Readers are encouraged to use this guide and/or adapt the forms and checklists herein in any way that is helpful to their particular circumstances. Self-diagnosis and self-implementation by the nonengineer may be adequate in many instances, and an attempt has been made to provide enough detail to allow for complete implementation of some of the simpler protective measures. *However, there are limits to the self-help approach, as explicitly stated below.*

LIMITATIONS

If this were a guide that explained how a person could administer his or her own physical exam, diagnose any health problems, and prescribe and carry out the appropriate treatment, certain obvious questions would arise: How far along

that path can an untrained person proceed before requiring the services of a physician? Wouldn't the layperson get into trouble trying to practice self-help medical care?

When in doubt, consult a civil or structural engineer.

There are similar limitations and caveats that must be made explicit in this guide's attempt to instruct laypersons in self-help earthquake engineering. In addition to the individual notes found later, which point out specific areas where expertise is required, the general disclaimer should be made here that the use of earthquake engineering expertise is often desirable to improve the reliability of identifying and reducing earthquake risks. When in doubt about a health problem, consult a doctor. When in doubt about the "seismic health" of a facility, consult a civil or structural engineer, or an architect. On the other hand, many self-help techniques are commonly recommended by doctors, such as taking one's temperature, treating minor colds with commonsense measures rather than costly trips to the doctor, managing one's diet with only occasional professional advice, and so on. Similarly, this guide attempts to provide advice for self-help earthquake protection measures and presumes that the advice will be applied wisely and that expert assistance will be obtained where necessary.

CHAPTER CONTENTS

The material in this book is organized as follows.

Chapter 1 — How to Use This Guide
Information to help readers with different interests find the relevant portions of this guide.

Chapter 2 — Overview General discussion

of the problems associated with nonstructural earthquake damage.

Chapter 3 — Survey and Assessment

Procedures Guidelines on how to survey the nonstructural items in a facility and assess the vulnerability of these items to earthquake damage. The appendixes contain inventory forms and detailed checklists with information designed to help identify vulnerable items.

Chapter 4 — Nonstructural Examples: Earthquake Damage and Upgrade

Details Examples for selected nonstructural items. Each example typically includes a photograph showing earthquake damage to an unanchored or inadequately anchored item and suggested upgrade details that can be used to reduce the seismic vulnerability of such items. Some of the simpler details in this chapter are marked *Do-It-Yourself* and can be installed by a handyman following the installation guidelines contained in the text. The details marked *Engineering Required* are schematic only, and design professionals should be retained to evaluate these systems and develop appropriate upgrade details. The design of upgrade details to protect against earthquake damage to these items is complicated and requires specialized professional expertise.

Chapter 5 — Developing an Earthquake Protection Program

A discussion of various implementation strategies: whether to use existing staff or outside consultants; whether to embark on an ambitious upgrade program or combine the upgrades with ongoing maintenance or remodeling; how to evaluate the success of a program.

Chapter 6 — Emergency Planning Guidelines

A discussion of emergency

response planning, that is, how to include potential damage to nonstructural components in an emergency plan. Have emergency exits been designated that do not have glass, veneer, or heavy canopies that are vulnerable to damage? Who is responsible for shutting off the water and gas if the pipes break, and is that person--and an alternate--available 24 hours a day? Does the organization provide training for employees on what to do in an earthquake?

Chapter 7 — Facilities Development Guidelines

For essential facilities and/or large organizations. In these cases, it may be appropriate to develop formal construction guidelines or specifications for the installation of nonstructural components. Such guidelines might include a statement of the desired performance for particular equipment, requirements for inspection during construction, or specification of a particular design code or force level to be used in the design of equipment anchorage.

Glossary Earthquake engineering terms used in this guide.

References References cited in the text.

Annotated Bibliography Additional references that may be useful to architects, engineers, or others seeking more detailed information about this topic.

Appendix A — Nonstructural Inventory Form

Appendix B — Checklist of Nonstructural Earthquake Hazards

Appendix C — Nonstructural Risk Ratings

2 OVERVIEW

The primary focus of this guide is to help the reader understand which nonstructural items are most vulnerable in an earthquake and most likely to cause personal injury, costly property damage, or loss of function if they are damaged. In addition, this guide contains recommendations on how to implement cost-effective measures that can help to reduce the potential hazards.

DEFINITIONS

At the outset, two terms frequently used in the earthquake engineering field should be defined.

Structural The structural portions of a building are those that resist gravity, earthquake, wind, and other types of loads. These are called structural components and include columns (posts, pillars); beams (girders, joists); braces; floor or roof sheathing, slabs, or decking; load-bearing walls (i.e., walls designed to support the building weight and/or provide lateral resistance); and foundations (mat, spread footings, piles). For buildings planned by design professionals, the structure is typically designed and analyzed in detail by a structural engineer.

Nonstructural The nonstructural portions of a building include every part of the building and all its contents with the exception of the structure--in other words, everything except the columns, floors, beams, etc. Common nonstructural components include ceilings; windows; office equipment; computers; inventory stored on shelves; file cabinets; heating, ventilating, and air conditioning (HVAC) equipment; electrical equipment; furnishings; lights; etc. Typically, nonstructural items are not analyzed by engineers and may be specified by architects, mechanical engineers

(who design HVAC systems and plumbing for larger buildings), electrical engineers, or interior designers; or they may be purchased without the involvement of any design professional by owners or tenants after construction of a building. Figure 1 identifies the structural and nonstructural components of a typical building. Note that most of the structural components of a typical building are concealed from view by nonstructural materials.

SIGNIFICANCE OF NONSTRUCTURAL DAMAGE

Why is nonstructural earthquake damage of concern? What are the direct effects of damage to nonstructural items? What are the secondary effects or potential consequences of damage?

The following discussion covers three types of risk associated with earthquake damage to nonstructural components: life safety, property loss, and interruption or loss of essential functions. Damage to a particular nonstructural item may have 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 consequence of the failure of the item.

LS

Life Safety The first type of risk is that people could be injured or killed by damaged or falling nonstructural components. Even seemingly innocuous items can be lethal if they fall on an unsuspecting victim. If a 25-pound fluorescent 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. Examples of potentially hazardous nonstructural damage that

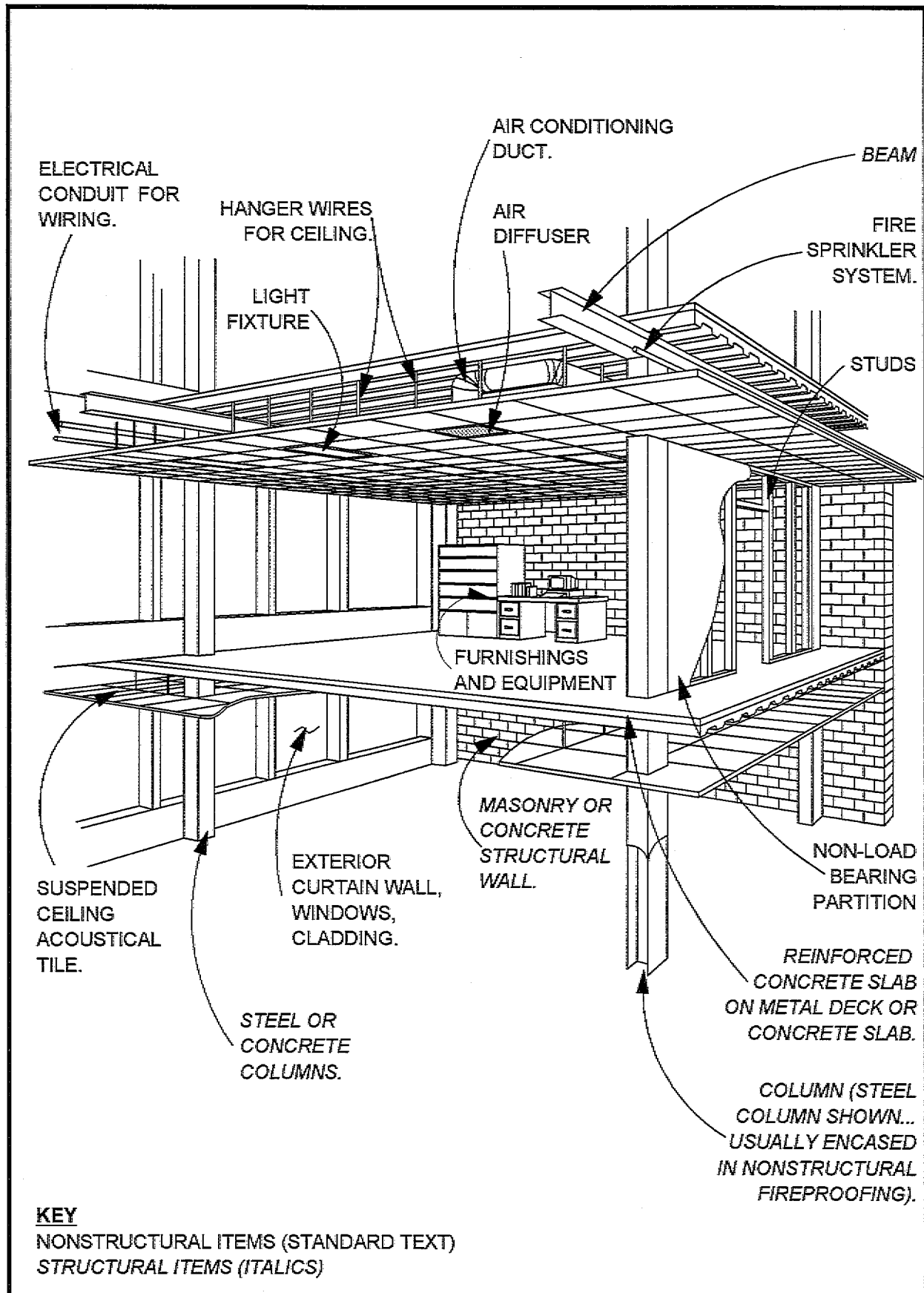


Figure 1 - Nonstructural and Structural Components of a Typical Building



Failure of office partitions, ceilings, and light fixtures
Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Shard of broken nontempered glass that fell several stories from a multistory building
Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.

Figure 2 - Examples of Hazardous Nonstructural Damage

has occurred during past earthquakes include broken glass, overturned tall and heavy cabinets or shelves, falling ceilings or overhead light fixtures, ruptured gas lines or other piping containing hazardous materials, damaged friable asbestos materials, falling pieces of decorative brickwork or precast concrete panels, and collapsed masonry walls or fences. (Figures 2 and 3).

Several specific examples will help to illustrate the point.

- More than 170 campuses in the Los Angeles Unified School District suffered damage--most of it nonstructural--during the 1994 Northridge earthquake. At Reseda High School, the ceiling in a classroom collapsed and covered the school desks with debris. The acoustic ceiling panels fell in relatively large pieces, approximately 3 feet or 4 feet square, accompanied by pieces of the metal ceiling runners and full-length sections of strip fluorescent light fixtures. Because the earthquake occurred at 4:31 a.m., when the building was unoccupied, none of the students were injured [1].

- A survey of elevator damage following the 1989 Loma Prieta earthquake revealed 98 instances where counterweights came out of the guide rails and 6 instances where the counterweight impacted the elevator cab, including one case where the counterweight came through the roof of the cab. Fortunately, no injuries were reported [2].

- One hospital patient on a life-support system died during the 1994 Northridge earthquake because of failure of the hospital's electrical supply [3].

- 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

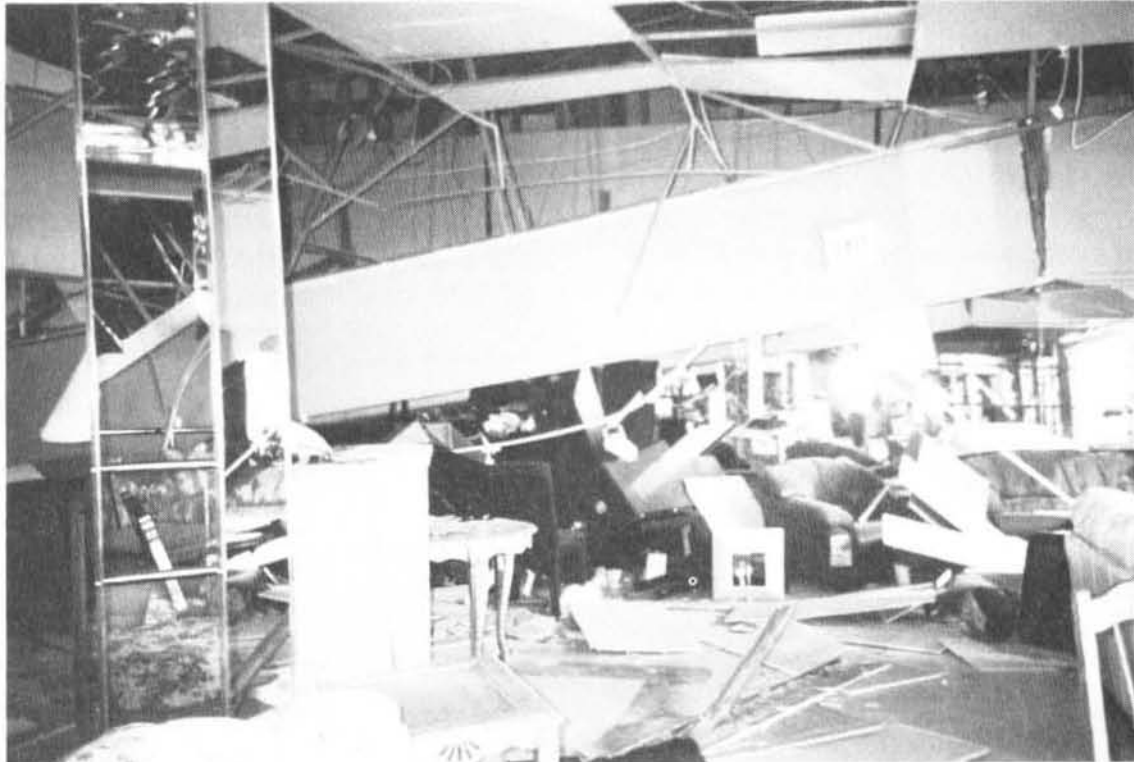
through the gypsum wallboard partitions between rooms in order to get out of the building, a process that took as long as several hours. It was fortunate that the earthquake did not cause a fire in the building, and no serious injuries were reported.

PL

Property Loss

For most commercial buildings, the foundation and superstructure account for approximately 20-25% of the original construction cost, while the mechanical, electrical, and architectural elements account for the remaining 75-80%. Contents belonging to the building occupants, such as movable partitions, furniture, files, and office or medical equipment, represent a significant additional expense. Damage to the nonstructural elements and contents of a building can be costly, since these components account for the vast majority of building costs. Immediate property losses attributable to contents alone are often estimated to be one third of the total earthquake losses [4].

Property losses may be the result of direct damage to a nonstructural item or of consequential damage. As used here, the term property loss refers only to immediate, direct damage. If water pipes or fire sprinkler lines break, the overall property losses will include the cost to repair the piping plus the cost to repair water damage to the facility. If the gas line to a water heater ruptures and causes a fire, clearly the property loss will be much greater than the cost of a new pipe fitting. On the other hand, if many file cabinets overturn and all the contents end up on the floor, the direct damage to the cabinets and documents will probably be negligible (unless they are also affected by water damage), but employees may spend many hours or days refiling the documents. If a reserve water tank is situated on the roof of a building, the consequences of damage may be more severe than they would be if it were in the



Failure of suspended ceiling and light fixtures in furniture store
Earthquake Damage: 1994, Northridge, California
Photo Credit: William McKeivitt



Failure of heavy stucco soffit at building entrance
Earthquake Damage: 1994, Northridge, California
Photo Credit: Robert Reitherman

Figure 3 - Examples of Hazardous Nonstructural Damage

basement or outside the building in the parking lot.

A few individual cases may help illustrate the potential for property loss. (See Figure 4).

- A survey of 25 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 high-rise buildings, which were far enough away from the earthquake fault to experience only mild shaking, showed that none had major structural damage but 43 suffered damage to drywall or plaster partitions, 18 suffered damaged elevators, 15 had broken windows, and 8 incurred damage to air conditioning systems [5].

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 cover the cleanup and repair costs. The next examples, which are more dramatic, involve library and museum facilities whose function is to store and maintain valuable contents, where the nonstructural losses are easy to identify.

- Following 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 [6, 7].

- A survey of eight museums in the San Francisco Bay Area following the 1989 Loma Prieta earthquake indicated that approximately 150 out of more than 500,000 items had suffered some type of damage, resulting in

losses on the order of \$10 million. At the Asian Art Museum in San Francisco, with a collection estimated to have a market value of \$3 billion, damage to 26 items resulted in a total loss of \$3 million, or roughly 1%. All eight of these facilities had implemented some form of seismic mitigation before the earthquake, and these measures prevented more serious losses [2, 8].

LF

Loss of Function In addition to the 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 normally accomplished in a facility. After the serious life safety threats have been dealt with, the potential for postearthquake downtime or reduced productivity is often the most important risk.

Many external factors may affect postearthquake operations, including power and water outages, damage to transportation structures, civil disorder, police lines, curfews, etc. These effects are outside the control of building owners and tenants and hence outside the scope of this discussion.

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

- 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 over a dozen of these facilities, water leaks occurred when fire sprinkler, chilled-water, or other pipelines broke. Hospital personnel were apparently unavailable or unable to shut off the water, and

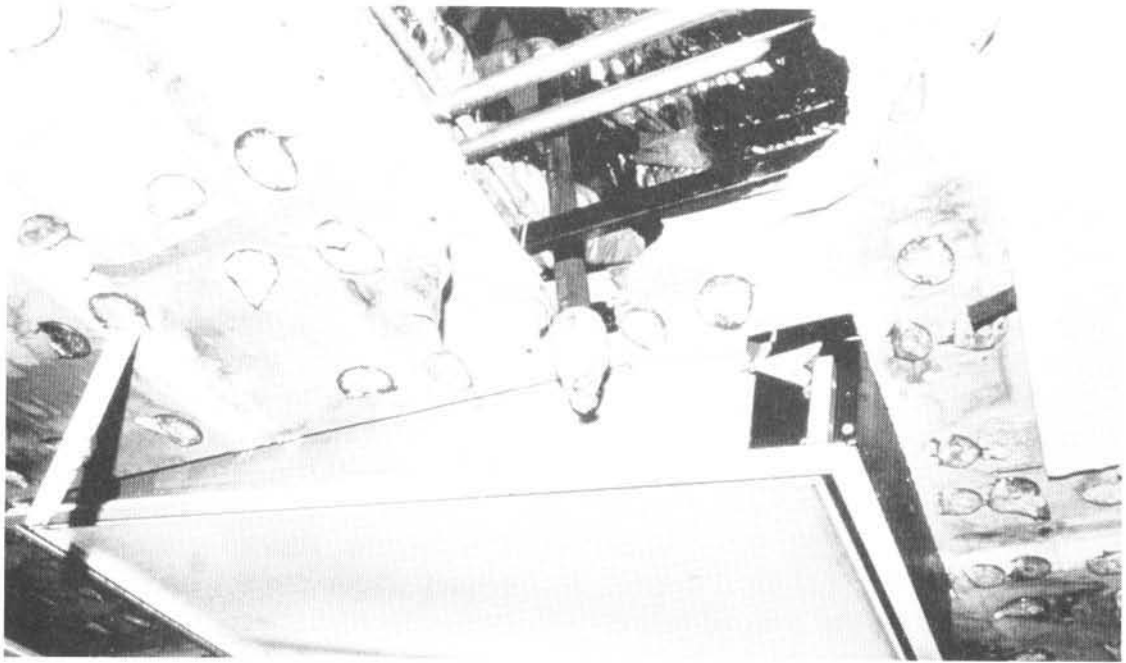


Complete loss of suspended ceiling and light fixtures
Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Damage to inventory on industrial storage racks
Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.

Figure 4 - Examples of Property Loss Due to Nonstructural Damage



Broken sprinkler pipe at Olive View Hospital in Sylmar—pipe ruptured at the elbow joint due to differential motion within the ceiling plenum. Water leakage from broken fire sprinklers and water lines forced the hospital to close for several days.
Earthquake Damage: 1994, Northridge, California
Photo Credit: Robert Reitherman



HVAC damage at Holy Cross Medical Center in Sylmar—damage to signage and louvers caused when suspended fans in the mechanical penthouse swung and impacted the louver panels. HVAC service outage caused the temporary evacuation of all patients.
Earthquake Damage: 1994, Northridge, California
Photo Credit: Robert Reitherman

Figure 5 - Examples of Loss of Function Due to Nonstructural Damage

in some cases 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, 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, Los Angeles County Olive View Medical Center and Holy Cross Medical Center, both in Sylmar, California, had suffered severe structural damage or collapse during the 1971 San Fernando earthquake and had been demolished and entirely rebuilt [3]. (See Figure 5).

- Of 32 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; at least 3 facilities with Uninterruptible Power Supplies (UPS) or Emergency Power Systems (EPS) did not suffer any downtime. Reported damage included overturning of equipment (2 facilities); damage to access floors (4 facilities); movement of large pieces of computer equipment over distances ranging from a few inches to 4 feet (26 facilities); and dislodged ceiling panels (13 facilities). Twenty of these facilities reported having an earthquake preparedness program in place at the time of the earthquake, 3 reported no program, and information was unavailable for 9 facilities [2].

- 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 where 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, and while these provisions appear to have helped reduce the damage, there were still many instances of counterweight damage in the San Francisco area following the 1989 Loma Prieta earthquake [2], and 688 cases in the Northridge earthquake [3].

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 to maintain essential services and 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 all facilities with essential functions that must remain operational after an earthquake; damage to their nonstructural elements can be a major cause of loss of functionality.

CAUSES OF NONSTRUCTURAL DAMAGE

Earthquake ground shaking has three primary effects on nonstructural elements in buildings. These are inertial or shaking effects on the nonstructural elements themselves, distortions imposed on nonstructural components when the building structure sways back and forth, and separation or pounding at the interface between adjacent structures (Figure 6).

Inertial Forces When a building is shaken during an earthquake, the base of the building moves in unison with the ground, but the entire building and building contents above the base will experience inertial forces. These inertial

forces can be explained by using the analogy of a passenger in a moving vehicle. As a passenger, 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 that of the acceleration. If the vehicle is decelerating or braking, you may be thrown forward in your seat. Although the engineering aspects of earthquake inertial forces are more complex than a single principle of physics, the law first formulated by Sir Isaac Newton, $F = ma$, or force is equal to the mass times the acceleration, is the basic principle involved. In general, the earthquake inertial forces are greater if the mass is greater (if the building or object within the building weighs more) or if the acceleration or severity of the shaking is greater.

File cabinets, emergency power-generating equipment, freestanding bookshelves, office equipment, and items stored on shelves or racks can all be damaged because of inertial forces. When unrestrained items are shaken by an earthquake, inertial forces may cause them to slide, swing, strike other objects, or overturn. Items may slide off shelves and fall to the floor. One common misconception is that large, heavy objects are stable and not as vulnerable to earthquake damage as lighter objects, perhaps because we may have difficulty moving them. In fact, many types of objects may be vulnerable to earthquake damage caused by inertial forces: since inertial forces during an earthquake are proportional to the mass or weight of an object, a heavily loaded file cabinet requires much stronger restraints to keep it from sliding or overturning than a light one with the same dimensions.

Building Distortion During an earthquake, building structures distort, or bend, from side to side in response to the earthquake forces. For example, the top of a tall office tower may lean

over a few feet in each direction during an earthquake. The distortion over the height of each story, known as the story drift, might range from ¼ inch to several inches, depending on the size of the earthquake and the characteristics of the particular building structure. Windows, partitions, and other items that are tightly locked into the structure are forced to go along for the ride. As the columns or walls distort and become slightly out of square, if only for an instant, any tightly confined windows or partitions must also distort the same amount. The more space there is around a pane of glass where it is mounted between stops or molding strips, the more distortion the glazing assembly can accommodate before the glass itself is subjected to earthquake forces. Brittle materials like glass, plaster or drywall partitions, and masonry infill or veneer cannot tolerate any significant distortion and will crack when the perimeter gaps close and the building structure pushes directly on the brittle elements. Most architectural components such as glass panes, partitions, and veneer are damaged because of this type of building distortion, not because they themselves are shaken or damaged by inertial forces.

There have also been notable cases of structural-nonstructural interaction 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 distortion of the structural framing and cause premature failure of column or beam elements. While this is a serious concern for structural designers, the focus of this guide is on earthquake damage to nonstructural components.

Building Separations Another source of nonstructural damage involves pounding or movement across separation joints between

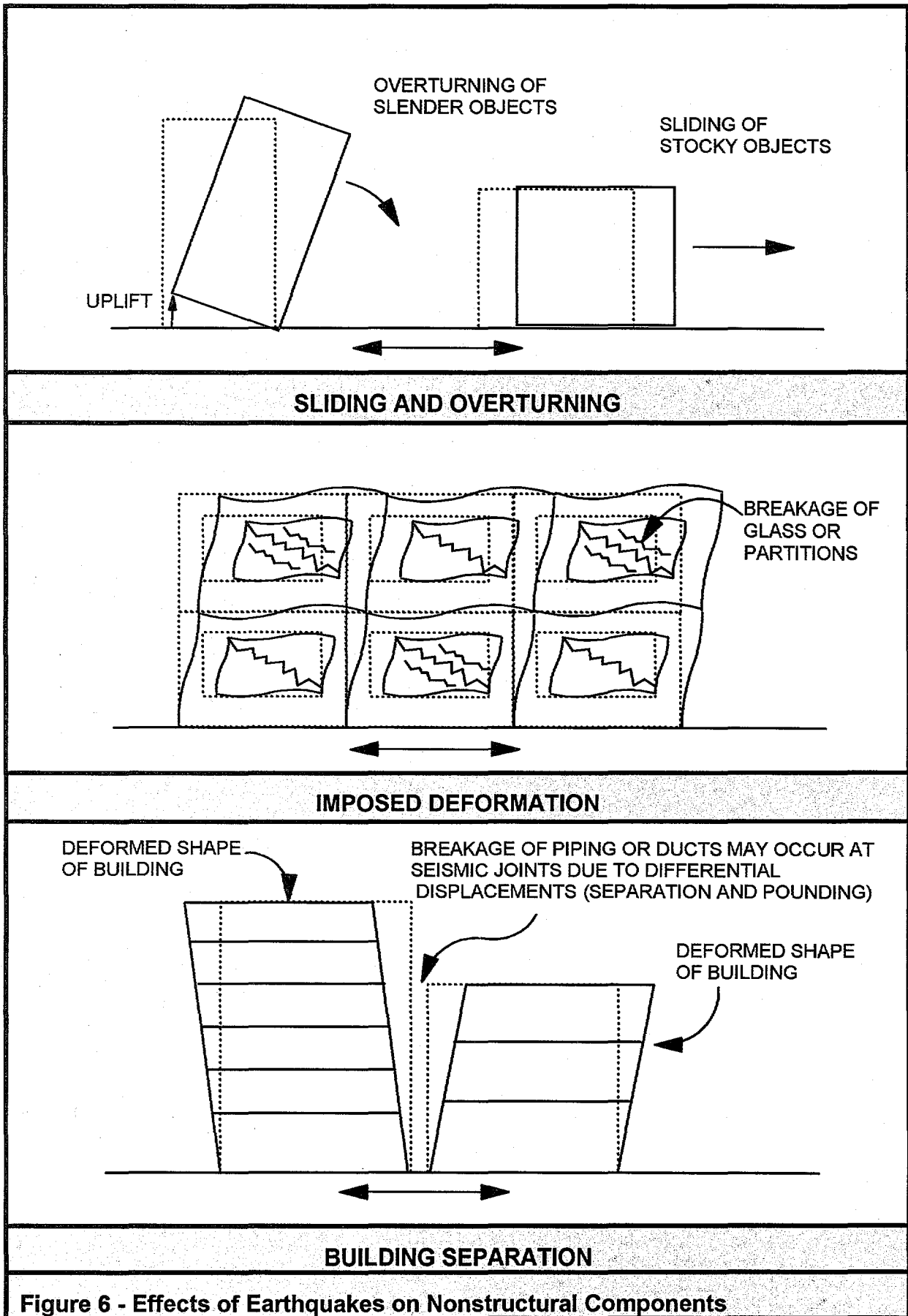


Figure 6 - Effects of Earthquakes on Nonstructural Components

adjacent structures. A separation joint, is the distance between two different building structures, often two wings of the same facility, that allows the structures to move independently of one another. A seismic gap is a separation joint provided to accommodate relative lateral movement during an earthquake. In order to provide functional continuity between separate wings, building utilities must often extend across these building separations, and architectural finishes must be detailed to terminate on either side. For base-isolated buildings that are mounted on seismic shock absorbers, a seismic isolation gap occurs at the ground level, between the foundation and the base of the superstructure. The separation joint may be only an inch or two in older construction or as much as a foot in some newer buildings, depending on the expected horizontal movement, or seismic drift. Flashing, piping, fire sprinkler lines, 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 gaps is a common type of earthquake damage. If the size of the gap is insufficient, pounding between adjacent structures may result in damage to structural components but often causes damage to nonstructural components, such as parapets, veneer, or cornices on the facades of older buildings.

METHODS FOR REDUCING NONSTRUCTURAL HAZARDS

There are a variety of methods available to reduce the potential risks associated with earthquake damage to nonstructural components. These methods range from simple commonsense steps one can take oneself to complex solutions requiring professional help. Simple steps might include relocating top-heavy furniture away from the doorway or bed in a bedroom and installing some of the simple do-it-yourself

anchorage details presented in this guide. Large organizations with complex facilities may need to hire professional consultants to design engineering details for building utilities and architectural components. For facilities such as hospitals, museums, libraries, research laboratories, and industrial facilities, professional consultants would probably be needed to provide specific design details for specialized building contents as well.

Facility Survey Nonstructural hazards may be present in any type of facility--a home, an office, a church, a day care center, a retail store, a nursing care facility, a school, a light manufacturing plant. Chapter 3 includes guidelines for performing a facility survey to identify potential nonstructural hazards. The forms and checklists provided in this guide are intended for use by laypersons, i.e., nonengineers, who are familiar with the building or facility to be surveyed. The process of conducting the survey should help to increase user awareness of the potential problems. The results of the survey should help building owners, managers, and/or occupants understand the scope of the potential problems and assess the building's seismic vulnerability, or present level of risk of nonstructural earthquake damage.

Commonsense Measures A facility survey may identify many items that represent a high or moderate risk in their present location but that could readily be relocated to reduce the potential risk. The answers to the following questions may help identify commonsense measures that can be used to reduce many of the potential risks.

- Where do you, your family, and your employees spend the most time? Are there heavy, unstable items near your desk or bed that could be moved? What is the probability that someone will be injured by various items if they fall? Which areas of the building have a higher occupant load and hence a potentially higher life

safety risk? Are there items that no longer serve a useful function and can be removed? What items can be relocated to prevent possible injury and do not need to be anchored to prevent damage or loss?

- If something slides or falls, in what direction is it likely to go? While the answer to this question is not always obvious, it may be useful to rearrange some furniture and move tall or heavy objects to where they cannot block a door or an exit. Shelved items might be rearranged so that heavier items are near the bottom and lighter ones near the top. Incompatible chemicals can be moved to prevent mixing if the containers break. Excess supplies or inventory could be stored in the original shipping containers until ready for use, in order to reduce the possibility of breakage.

Upgrade Details There are many techniques available to reduce potential nonstructural earthquake damage. Possible upgrade schemes might include one or more of the following measures: use anchor bolts to provide rigid anchorage to a structural floor or wall; brace the item to a structural wall or floor; provide a tether or safety cable to limit the range of movement if the item falls or swings; provide stops or bumpers to limit the range of movement if the item slides; provide flexible connections for piping and conduit where they cross seismic joints or connect to rigidly mounted equipment; attach contents to a shelf, desktop, or countertop; provide 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 particular context.

Critical and expensive items warrant specialized attention. For essential facilities in areas where severe shaking is anticipated, any or all of the following elements may be needed in order to provide an appropriate level of nonstructural protection: specialized engineering expertise, higher design forces than those required by the code, experienced specialty contractors, special construction inspection, load-rated hardware, vendor-supplied equipment that has been tested on a shaking table, special design details such as base isolation for individual pieces of equipment, 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.

Organizational Planning Programs In an organizational setting, an effective program to reduce nonstructural earthquake hazards may have to be integrated with other organizational functions, including earthquake preparedness, emergency response, facilities maintenance, procurement, long-term planning, and/or facilities development. Some organizations might choose to embark on an ambitious program to anchor all of their existing equipment and contents, while others may concentrate on new facilities and new equipment. Many different implementation strategies are possible. Programs to develop employee awareness and provide emergency training might be in order for some organizations, since a successful nonstructural hazards reduction program has to address the many human factors issues along with the engineering issues.

BUILDING CODE REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS

By and large, advances in earthquake engineering made in recent decades have been successfully applied to the task of making

building structures safer. In comparison, there has been much less application of this technical knowledge to the nonstructural components of buildings, although this is gradually changing. Design professionals, code committees, and building owners are learning that the seismic resistance of critical nonstructural components must be addressed as part of the design process, since failures of nonstructural components may threaten the safety of building occupants and result in significant financial loss.

Code Philosophy Surveys of existing buildings indicate that many nonstructural items are never explicitly designed to resist horizontal forces. Instead, they are installed in accordance with common construction practice, which varies little from seismic to nonseismic areas. Modern building codes typically include some seismic provisions that apply to a limited list of nonstructural items. Many nonstructural items are not specifically addressed in the provisions and may therefore be interpreted as being exempt from code requirements. For example, some specific code provisions apply to concrete masonry unit fences taller than 6 feet, but a 5 foot tall masonry wall without proper reinforcing can also be a hazard.

The fact that the building code is not as specific about nonstructural items as it is about the structural portions of buildings is indicative of the general intent of the earthquake provisions to provide a minimum level of life safety and to avoid legislating property damage control measures. In general, the concepts of life safety and prevention of structural collapse have been used almost interchangeably in the thinking underlying the earthquake regulations in the building code, although it is apparent that there are significant nonstructural dangers to life and limb as well. In some cases, the potential for nonstructural property loss or outage is a strong reason for obtaining more than the code minimum level of protection. Indeed, even code requirements in early 1994 for the design

of nonstructural items in medical facilities in California, which were more stringent than those for office and residential occupancies, were apparently not restrictive enough to completely prevent disruption of service following the January 1994 Northridge earthquake.

The point of this discussion is to emphasize the life safety focus of current building code provisions, which are intended primarily to reduce potential injuries, not to prevent costly damage or loss of function. Code provisions for nonstructural components are subject to revision every three years, and in the future these provisions may be revised to aim for a higher level of nonstructural protection.

Engineering Design To design protective devices such as bolted connections, snubbers, or restraining cables, engineers use a percentage of the weight of the object as the horizontal earthquake force that must be resisted by the design details. Design guidelines developed by the National Earthquake Hazards Reduction Program (NEHRP) are contained in *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* [9]. Many state and local codes have adopted similar design provisions for nonstructural components. These provisions specifically address earthquake inertial forces. The engineer must also account for the effects of building distortion (i.e., seismic relative displacements between two connection points in the same building or structural system) and the effects of building separations (i.e., seismic relative displacements between two connection points on separate buildings or structural systems) in the design.

The following is a brief description of the simplest type of engineering design procedure. Minimum design levels for architectural, mechanical, and electrical systems and components are described in the NEHRP provisions. The provisions specify horizontal

seismic force factors to be used for the design of specific items, such as partitions, parapets, chimneys, ornaments, tank supports, storage racks over 8 feet tall, equipment or machinery, piping, and suspended ceilings. According to the NEHRP procedure, the design force depends on a variety of factors such as, the seismic zone, the type of component, the location of the item within a building, and the type of occupancy. Design forces are generally greater for emergency generators than for HVAC equipment, greater for police and fire stations than for ordinary office buildings, and greater at the roof than at the ground.

To use a specific case, the specified horizontal force for a piece of rigid equipment situated at ground level in a commercial facility in the Los Angeles area is 40% of the weight of the item. If the equipment weighs 1000 pounds, the engineer must design the bracing and floor or wall anchorage details to resist 400 pounds of horizontal force acting through the center of gravity of the item in any direction. If the item is used to store hazardous contents or is located on a floor above ground level, the NEHRP provisions require higher design forces. Under some circumstances, an owner who is particularly concerned about postearthquake operations may want a greater level of protection than is provided by the minimum requirements in the NEHRP provisions. In this case, the owner and engineer or equipment vendor should discuss the performance criteria at the beginning of the project, as described in Chapter 7.

This discussion of seismic forces is intended to illustrate the design procedure and the magnitude of the loads, not to turn the layperson into an engineer. This guide does not advocate the use by nonengineers of the calculation procedure described above.

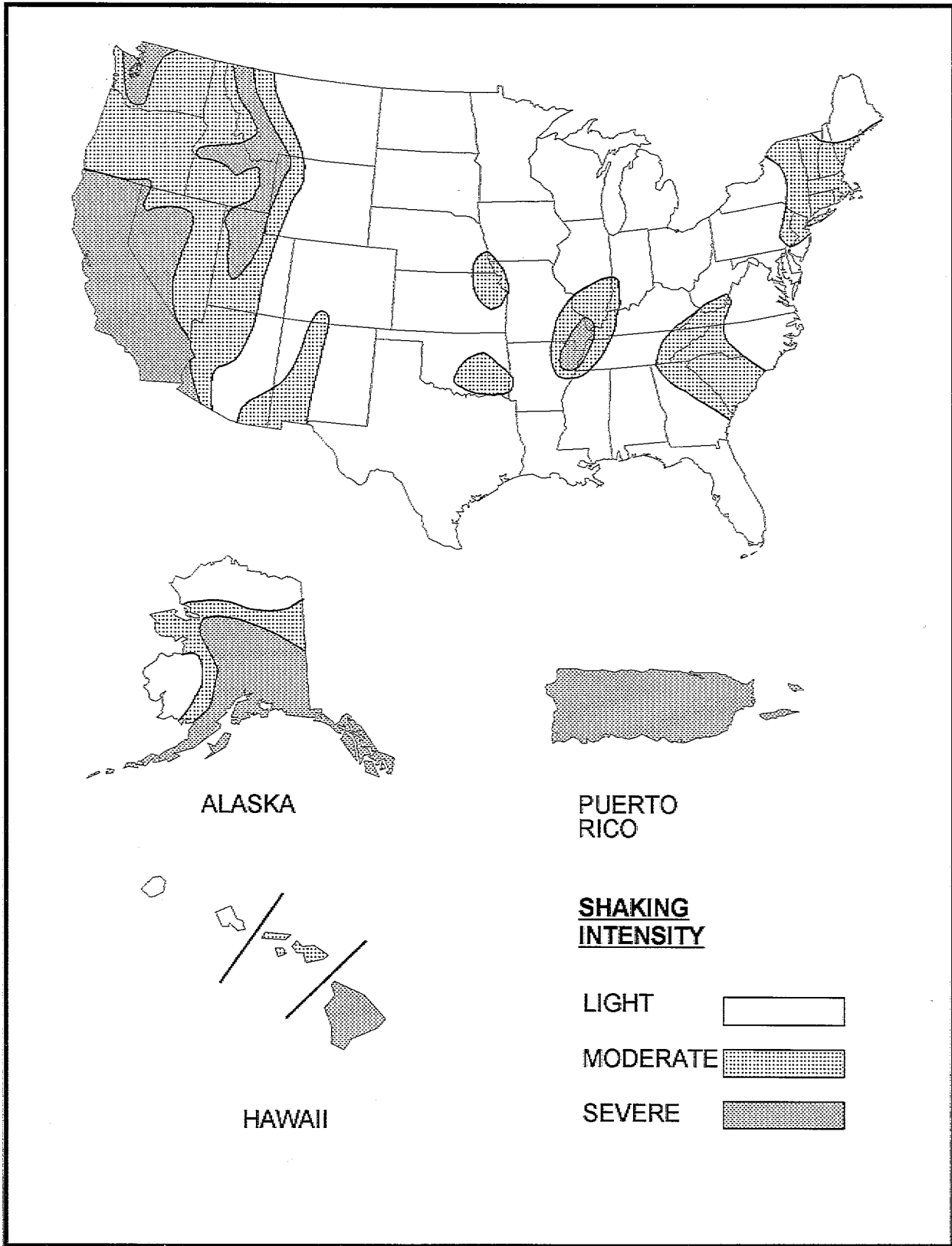
SEISMIC HAZARD

The seismic risk for a particular nonstructural component at a particular facility is governed by a variety of factors, including the regional seismicity, the proximity to an active fault, the local soil conditions, the dynamic characteristics of the building structure, the dynamic characteristics of the nonstructural component and any connections to the structure, the location of the nonstructural component within the building, the function of the facility, and the importance of the particular component to the operation of the facility. While all of these factors may have to be considered in the evaluation of equipment in a hospital or nuclear facility, we will consider only the issue of regional seismicity for the purposes of this discussion.

The seismic hazard in a given region or geographic location is related both to the severity of ground shaking expected in the area and to the likelihood, or probability, that a given level of shaking will occur. Seismologists review historical earthquake activity, locations and characteristics of mapped faults, and regional geology to estimate the seismic hazard. This information is often depicted on a seismic hazard map.

For the purposes of this guide, seismic hazard has been characterized in terms of three levels of shaking intensity: namely light, moderate, and severe. The seismic hazard maps presented in Figure 7 show the geographic areas in the United States where light, moderate and severe shaking are likely to occur in future earthquakes.

For engineering purposes, earthquake shaking is often characterized by an effective peak acceleration (EPA), measured as a percentage of the acceleration of gravity. The effective peak



Note: There is approximately a 10% chance in 50 years that any given site will experience the shaking intensity shown. Map adapted from the following sources: 1991 NEHRP Recommended Provisions (primary source) and 1994 Uniform Building Code (basis for western states).

Figure 7 - Map of Probable Shaking Intensity for the United States

acceleration is often less than the maximum acceleration recorded during an earthquake. The three shaking intensity levels correspond approximately to the following EPA ranges:

- Light, less than 0.15g
- Moderate, between 0.15g and 0.3g
- Severe, greater than 0.3g

Several examples of earthquake motion recorded during the 1994 Northridge earthquake may help to put these acceleration ranges in perspective. The Northridge earthquake had a magnitude of 6.7. The magnitude of an earthquake is a measure of the amount of energy released by the fault rupture or ground shaking; it does not provide any information about the intensity of shaking at any particular location. During this earthquake, the intensity of ground shaking was severe in Northridge, near the earthquake epicenter. Several stations recorded ground motion with maximum accelerations in excess of 0.9g. Nevertheless, the majority of stations in downtown Los Angeles, at distances of approximately 30-40 kilometers from the epicenter, recorded moderate ground shaking--between 0.15g and 0.30g. Stations in Long Beach, approximately 60 kilometers from the epicenter, recorded light ground shaking--less than 0.15g [10]. EPA's from the Northridge earthquake records are lower than the maximum recorded accelerations indicated above, but the EPA's also show the same trend, that is, the

shaking intensity became less severe as the distance from the epicenter increased. While few people outside California may need to worry about the intensity of shaking experienced in Northridge, many areas of the country may experience the moderate or light shaking that was felt in downtown Los Angeles and Long Beach during the Northridge earthquake.

One further note regarding shaking intensity will serve to illustrate what appears to be one of the most extreme cases to date of recorded earthquake shaking intensity. A peak horizontal acceleration of 1.7g was recorded at the roof level of the Los Angeles County Olive View Medical Center in Sylmar during the Northridge earthquake. The roof acceleration was 2.6 times higher than the ground acceleration (0.65g) measured near the building [11]. The horizontal forces on items at the roof level were 170% of their weight, if only for an instant. Although some roof-mounted items at the hospital were severely damaged, most of the anchored items performed well because they were designed using the special seismic requirements of the California Hospital Seismic Safety Act. While this is an extreme case, standard code provisions are not adequate to protect items in essential facilities from shaking of this intensity. Even the above-average requirements of special codes, such as California's Hospital Act, are being revised to include lessons from the Northridge earthquake.

3 NONSTRUCTURAL SURVEY PROCEDURES

What types of nonstructural components are present in a particular facility? How does the owner or manager know what the potential problems are? How will a specific nonstructural item perform in an earthquake, and what are the consequences of failure in terms of life safety, property loss, and interruption or loss of function? If the decision is made to upgrade a facility, which problems should be addressed first? This chapter includes guidelines that will help answer these questions.

TYPICAL NONSTRUCTURAL COMPONENTS

The nonstructural components listed in the tables and checklists provided in the appendixes 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 addressed in this guide. The common components can be divided into three general categories as follows.

- **Building Utility Systems**

These are typically built-in nonstructural components that form part of the building. Examples include mechanical and electrical equipment and distribution systems, piping and conduit, fire detection and suppression systems, elevators or escalators, HVAC systems, and roof-mounted solar panels.

- **Architectural Components**

These are typically built-in nonstructural components that form part of the building. Examples include partitions and ceilings, windows, doors, lighting,

interior or exterior ornamentation, exterior panels, veneer, and parapets.

- **Furniture and Contents**

These are nonstructural components belonging to tenants or occupants. Examples include office, computer, and communications equipment; cabinets and shelving for record and supply storage; library stacks; kitchen and laundry facilities; furniture; movable partitions; lockers; and vending machines.

Not every conceivable item is included in these lists, so some judgment is needed to identify the critical items in a particular facility. In general, items that are taller, heavier, or important to operations, items that contain hazardous materials, and items that are more expensive should be included before items that are shorter, lighter, nonessential, inexpensive, and do not contain hazardous materials.

FACILITY SURVEY

As a first step, it may be useful to perform a survey of your facility to identify nonstructural components that may be vulnerable to earthquake damage. As noted earlier, consultant expertise may be advisable. Keep in mind three basic questions as each nonstructural item is considered:

- Would anyone get hurt by this item in an earthquake?
- Would a large property loss result?
- Would interruptions and outages be a serious problem?

For some items, the answers to these three questions may not be immediately obvious,

since failure of an item may result in both direct damage and consequential damage. For example, 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 did not sustain any other damage, the occupants may not be able to use the facility until the fire safety system is repaired. The potential direct and indirect property loss in this case is much greater than the repair cost for the sprinkler system. As another example, 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 all fall on the floor, resulting in a total loss for the battery rack. The direct life safety threat, that is, the threat of injury, is probably low, but if the emergency generator doesn't work, 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. Gas-fired residential water heaters rarely fall and hit anyone, but they have caused many postearthquake fires due to ruptured gas lines. In short, 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.

A word of caution is in order regarding the field survey. When looking at mechanical equipment or office machines, it is sometimes easy to confuse a leveling bolt, which merely rests on the floor, with an anchor bolt, which is securely fastened to the floor. 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. Anchor bolts that are $\frac{1}{4}$ inch in diameter may be adequate to restrain a light file cabinet but are probably too small to

effectively restrain any large piece of mechanical equipment. Thus, if any braces or anchors are visible, it is important to consider whether they will be effective for the expected shaking intensity.

Survey Forms The field survey may be performed by using the forms and checklists in Appendixes A, B, and C. Appendix A contains a blank nonstructural inventory form that can be used to record field observations. The questions in the checklist provided in Appendix B will help identify vulnerable nonstructural items and potential hazards associated with each item. The questions on the checklist are all stated in such a way that a "no" answer is indicative of a potential problem. Items with potential problems should be listed on the nonstructural inventory form. The space provided for notes may be used to identify the type of problem observed, e.g., "unanchored," "unbraced," "bolts undersized," "bolts no good, missed stud," etc. Information regarding the existing vulnerability, upgrade costs, and priority may be added to the form later, after the initial field survey is complete. Appendix page A-3 illustrates a sample nonstructural inventory form.

During the initial survey, it may be helpful to create a list containing a large number of items. The initial list may be shortened later, perhaps by dropping low-priority items. At the initial stage, it is better to be conservative and overestimate vulnerabilities than to be too optimistic.

ASSESSMENT PROCEDURES

Following the initial field survey, additional information must be added to complete the nonstructural inventory form. Estimated risk ratings for many common items are listed in Appendix C. Upgrade costs for selected items are found with the details shown in Chapter 4.

Estimating the Shaking Intensity For the purposes of this nonstructural survey, the seismic risk, or shaking intensity, for a particular geographic location may be estimated by using the seismic maps shown in Figure 7. This figure shows the areas in the United States that are likely to experience light, moderate, or severe ground shaking during a future earthquake. Some of the areas that may experience severe shaking are California; the area near New Madrid, Missouri; the islands of Hawaii, Puerto Rico, and Guam (not shown); and portions of western Washington and southern Alaska. Locations such as southern Illinois, South Carolina, and much of New England may experience moderate shaking, although most of the Continental United States east of the Rockies will likely experience light shaking.

Shaking-intensity estimates based on the seismic risk maps in Figure 7 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.

Estimating the earthquake forces 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 one or more of the following factors: the proximity of the building site to an active fault, the soil conditions at the site, 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 of the item, 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. One reason the use of professional consultants

for complex facilities is recommended is that the seismic risk maps in Figure 7 do not take any of these additional factors into consideration. Clearly, the complexity and detail of engineering calculations should be commensurate with the complexity and importance of the facility and the item in question.

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 instance, a major earthquake with severe shaking might be likely to occur about once every 1000 years at a particular site, whereas the maps in Figure 7 are weighted toward more probable events and may show only moderate shaking for the site. While some installations may have to anticipate the most severe shaking, others may find it more economical to plan for a smaller, more frequent event.

Estimating Seismic Risk The risk ratings provided in Appendix C are based on a review of damage to nonstructural components in past earthquakes and the judgement 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 one where the potential risk is high, more detailed analyses should be performed by an in-house engineer or professional consultant.

The seismic risks for life safety, property loss, and loss of function have been rated simply as high, moderate, or low for different levels of shaking intensity. Appendix C 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 repair or replacement cost as a result of damage to the item; Loss of Function Risk is the risk that the item will not function as a result of the damage incurred. The estimated risk ratings shown in Appendix C 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.

Estimating Upgrade Costs Upgrade cost estimates are provided with selected details in Chapter 4. These unit cost estimates can be used to produce subtotals for each category itemized on the nonstructural inventory form, and then added together to estimate the total seismic upgrade cost for the entire facility. If a number of repetitive protective measures are to be installed in a large facility, the unit cost may be lowered.

The cost estimates can only be considered rough guides, since it is not possible to account for all the specific differences in construction conditions found in buildings or to allow for the variation in contractors' costs in changing construction market conditions and different regions of the country, or the difference between in-house labor versus outside contractor costs. The cost estimates cover labor and materials only and do not include any engineering or architectural services that may be required.

More detailed cost estimates should include the impact of any disruption that the installation of upgrade devices might necessitate, and any inconvenience associated with the daily use of the devices. For example, some of the upgrade measures described can be installed only when

the building is not in normal use, and a scale factor might be needed to account for increased labor rates for work to be done during nonbusiness hours. The installation of straps or other removable restrainers for movable equipment implies that users will reattach the strap each time the anchored item is moved, perhaps resulting in an increase in the cost of operations in some facilities.

Detail Type Two types of upgrade details are presented in Chapter 4 of this guide and indicated in the lists presented in Appendix C. These two types of details are designated *Do-It-Yourself* and *Engineering Required* and are described in more detail in Chapter 4. The nonstructural inventory form includes space to indicate the detail number or detail type.

Priority Rating 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 the items 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 where all three risk ratings are high. If loss of function is not a serious concern, the highest priority might be assigned to items where 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 guide merely provides some guidelines that can be used to establish a ranking system.

Cross-References Chapter 4 contains specific damage examples and anchorage details for a number of the listed items. For those items, cross-references are provided between the examples and the checklists in Appendixes B

and C.

COMPARISON OF ALTERNATIVES

Separate lists might be prepared to compare relative cost estimates for different approaches. One list could describe a complete upgrade package covering all the vulnerable items identified in the survey, while another might consist of a minimally protective and less expensive package that addresses only the most critical problems. On the other hand, separate lists might be prepared considering different levels of shaking intensity. In this way, costs can be compared for two different levels of protection. The nonstructural inventory form provided in Appendix A can easily be reproduced with the use of spreadsheet or database software to facilitate the process of estimating upgrade costs, sorting in order of

priority, comparing costs for different intensity levels, and so on.

General advice on the subject of where to draw the line between completeness and quality, on the one hand, and cost, on the other, is difficult to provide. It is better to focus on the most significant problems and address them effectively than to develop an all-inclusive list that is too extensive to implement. A two-phase approach may be desirable: Draw up a short list of the most critical items and address these first. After evaluating the success of the first phase, develop a second-phase program to address less critical items further down the list. The installation of seismic upgrade details is often easier than it might first appear. The important thing is to make a start and to do the first effort well.

4 NONSTRUCTURAL EXAMPLES: EARTHQUAKE DAMAGE AND UPGRADE DETAILS

This chapter includes specific examples of selected nonstructural items. In most cases, the example includes a photograph of earthquake damage that occurred to an unanchored or inadequately anchored item paired with a drawing of suggested upgrade details that can be used to reduce the seismic vulnerability of the item. Some of these are simple, generic details that can be installed by a handyman; these details are marked *Do-It-Yourself*. Others are schematic details that need to be developed by a design professional for a particular situation and in some instances will require installation by a specialty contractor; these details are marked *Engineering Required*. Enough examples have been provided to allow for an effective initial survey of most ordinary-occupancy buildings. The end of this chapter includes installation guidelines to accompany the *Do-It-Yourself* details.

NONSTRUCTURAL EXAMPLES

Photos of earthquake damage and suggested upgrade details are presented for a variety of common nonstructural items. While these examples do not cover every case, many items not included here would be damaged and/or upgraded in a manner similar to one that is shown. For example, the detail shown for an air compressor is applicable to many pieces of mechanical or HVAC equipment that are mounted on vibration isolation springs. Similarly, the wall and floor anchorage details shown for tall shelving or file cabinets are applicable to other items, such as storage cabinets or personnel lockers. The detail shown for a fire extinguisher could also be applied to a fire hose cabinet. Many types of desktop or

countertop equipment found in offices, hospitals, or laboratories could be restrained by using the suggestions for desktop computers, although special detailing may be warranted for expensive equipment. Seismic protection schemes for newly installed items are often similar to the anchorage or restraint details shown.

The examples have been divided into three categories: utility systems that are part of the building; built-in architectural components; and furniture and contents, which are typically the property of the occupants or tenants rather than a permanent part of the building. The examples are listed in Figure 8.

Earthquake Damage The photographs presented here cover a variety of situations and have been taken over a 25-year period. Photographs from the 1971 San Fernando earthquake generally show damage to items that were not restrained, while some of the more recent photographs depict damage to items that appeared to be braced or anchored but whose bracing and anchoring details were apparently inadequate to resist the severity of the shaking.

Upgrade Details The examples presented in this chapter show representative details for protecting common items from earthquake damage. The two different types of details are described below.

- ***Do-It-Yourself*** These are simple, generic details for typical nonstructural items. Enough information is provided that a handyman can install them using common tools and readily

available materials. Most of the examples for furniture and contents include simple details that are marked *Do-It-Yourself*. These details are applicable for many common items found in the home, office, or small business. At the end of this chapter are guidelines on the proper use and installation of these details.

- **Engineering Required** These are schematic details showing common solutions for the items in question. These sketches do not contain sufficient information for installation; they are provided primarily as an illustration of the required scope of work. The designation *Engineering Required* has been used for items where the self-help approach is most likely to be ineffective. The recommendation of this guide is that design professionals be retained to evaluate the vulnerability of these items and design appropriate anchorage or restraint details, particularly where safety is an issue. As stated earlier, this recommendation may apply to all items in 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 where fire sprinkler and other water lines, HVAC equipment, emergency generators, water tanks, ceilings, parapets, glazing, and so on 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 building utilities and architectural components in

facilities that are expected to remain functional during and after a major earthquake, is a complex undertaking that should be addressed by engineers and architects with specific expertise in this area. As a result, most building utility systems and architectural components have been given the designation *Engineering Required*. Several of the items listed under furniture and contents have also been given this designation.

The upgrade details for these items are schematic only and are presented here with estimated installation costs, primarily for planning and/or budgeting purposes. Facilities personnel can use this information in conjunction with the survey forms and checklists included in this guide to estimate the scope of the work needed and obtain initial cost estimates for planning purposes.

Upgrade Cost The cost estimates provided with the details in this chapter may be used as a rough guide for planning or budgeting purposes. The values are intended to cover the costs of materials and labor. They do not include any allowance for architectural or engineering fees, permits, special inspection, etc. These estimated costs represent a professional opinion based on information available at the time of publication in 1994. Actual construction costs may vary significantly, depending on the timing of construction, changes in conditions, the availability of materials, regional cost variations, and other factors.

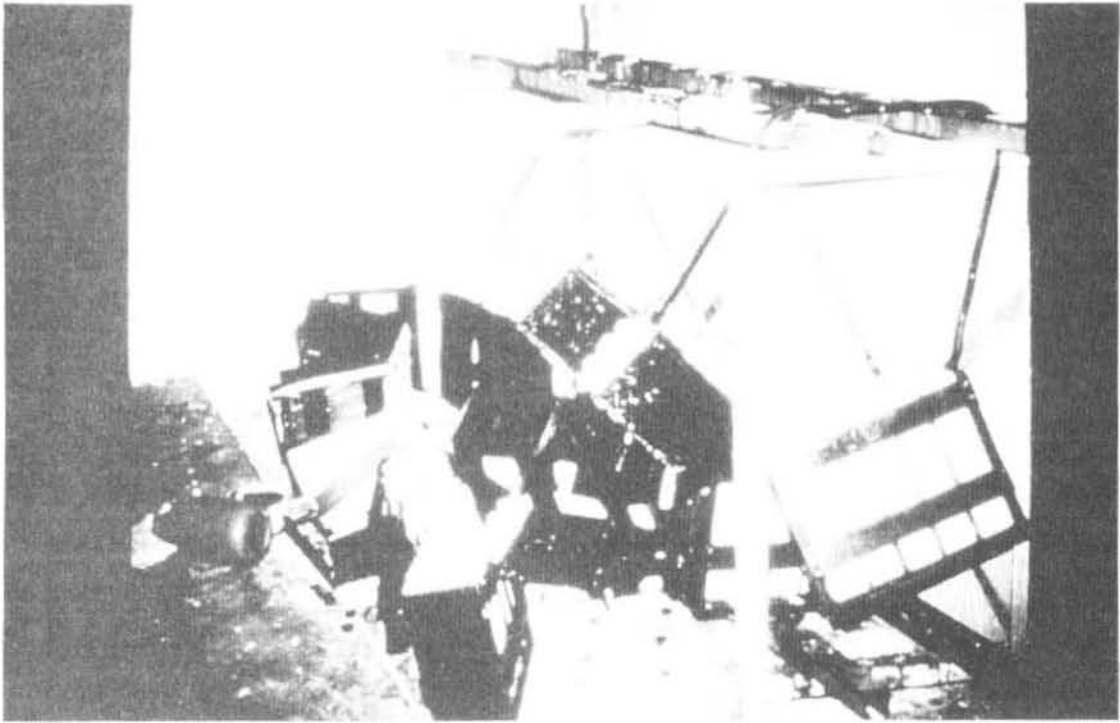
Figure 8 : Nonstructural Examples

Detail	Nonstructural Item	Type of Detail	Page
U	BUILDING UTILITY SYSTEMS		
U2	Batteries and Battery Rack	Engineering Required	30
U3	Diesel Fuel Tank	Engineering Required	31
U8	Electrical Bus Ducts and Primary Cable System	Engineering Required	32
U10	Fire Extinguisher and Cabinet	Do-It-Yourself	33
U15	Propane Tank	Engineering Required	34
U19a	Water Heater: Corner Installation	Do-It-Yourself	35
U19b	Water Heater: Wall Installation	Do-It-Yourself	36
U21	Piping	Engineering Required	37
U29	Chiller	Engineering Required	38
U32	Air Compressor (or other HVAC Equipment)	Engineering Required	40
U35	Suspended Space Heater	Engineering Required	41
U36	HVAC Distribution Ducts	Engineering Required	42
U37	Air Diffuser	Do-It-Yourself	43
U38	Residential Chimney	Engineering Required	44
A	ARCHITECTURAL ELEMENTS		
A2a	Built-In Partial-Height Partitions	Engineering Required	45
A2b	Built-In Full-Height Partitions	Engineering Required	46
A3	Suspended T-Bar Ceilings	Engineering Required	47
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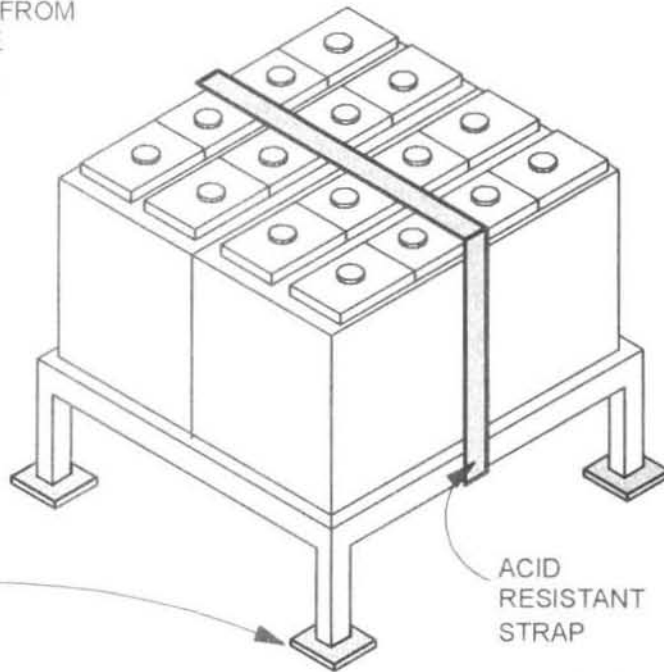
BATTERIES AND BATTERY RACK

ENGINEERING REQUIRED



Earthquake Damage: 1971, San Fernando, California
Photo Credit: John F. Meehan

SEISMIC RESISTANT BATTERY RACKS ARE AVAILABLE FROM VENDORS THAT MAY BE BOLTED TO THE FLOOR AND/OR WALL.



BOLTED TO FLOOR,
BRACING OF LEGS
MAY BE REQUIRED.

ACID
RESISTANT
STRAP

Schematic Upgrade Detail U2
Approximate Cost: \$200

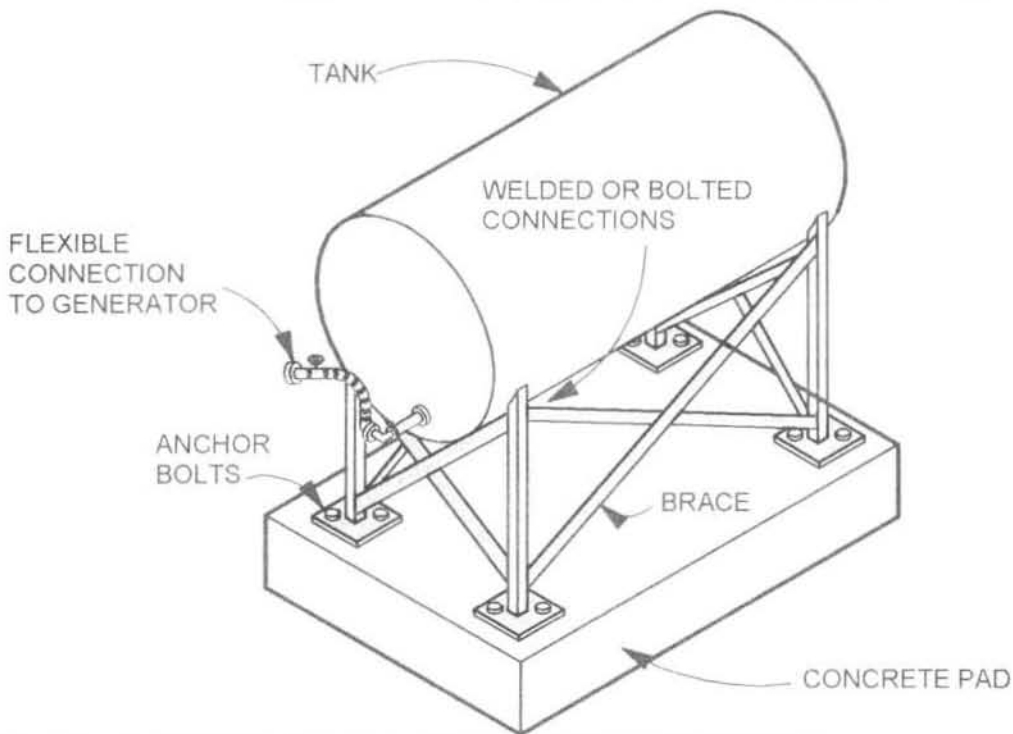
U2

DIESEL FUEL TANK

ENGINEERING REQUIRED



Unbraced Day Tank, Hospital, Puerto Rico
Photo Credit: Wiss, Janney, Elstner Associates, Inc.

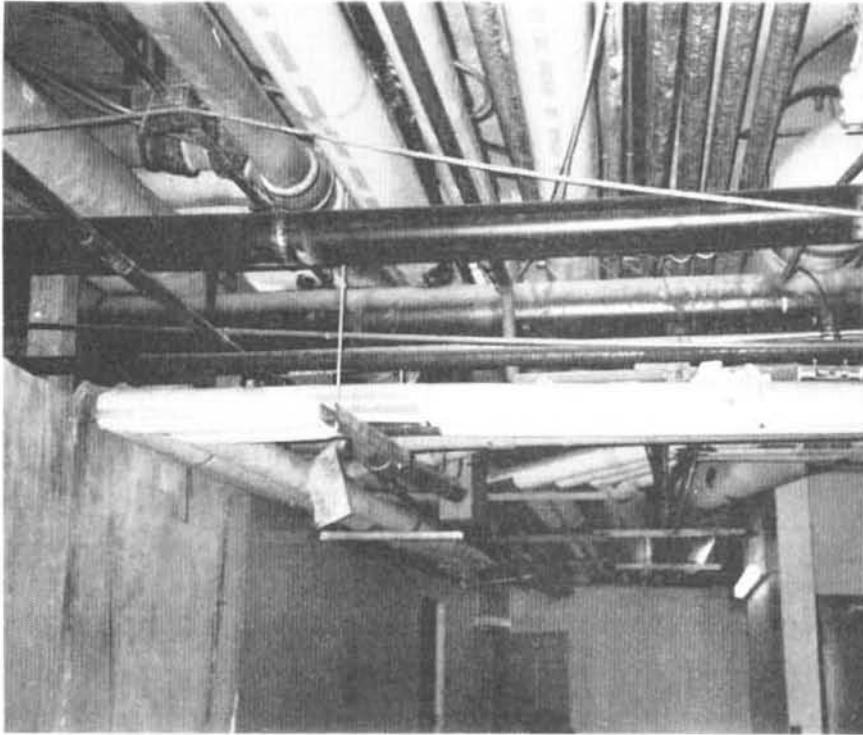


Schematic Upgrade Detail U3
Approximate Cost: \$500 - \$1000

U3

ELECTRICAL BUS DUCTS AND PRIMARY CABLE SYSTEM

ENGINEERING REQUIRED



Unbraced Overhead Conduit and Pipes

Photo Credit: Wiss, Janney, Elstner Associates, Inc.

- ELECTRICAL BUS DUCTS AND CABLE LINES SHOULD BE ABLE TO ACCOMMODATE MOVEMENT AT LOCATIONS WHERE THEY CROSS SEISMIC JOINTS BETWEEN BUILDING WINGS. PROVIDE FLEXIBLE CONNECTIONS AT SEISMIC JOINTS.
- PROVIDE FLEXIBLE CONNECTIONS AT LOCATIONS WHERE DUCTS OR CABLE ARE ATTACHED TO RIGIDLY MOUNTED EQUIPMENT.
- DUCTS AND CABLE LINES SHOULD HAVE BOTH TRANSVERSE AND LONGITUDINAL SEISMIC BRACING SIMILAR TO THAT RECOMMENDED FOR PIPING. SEE PIPE BRACING DETAIL U21.

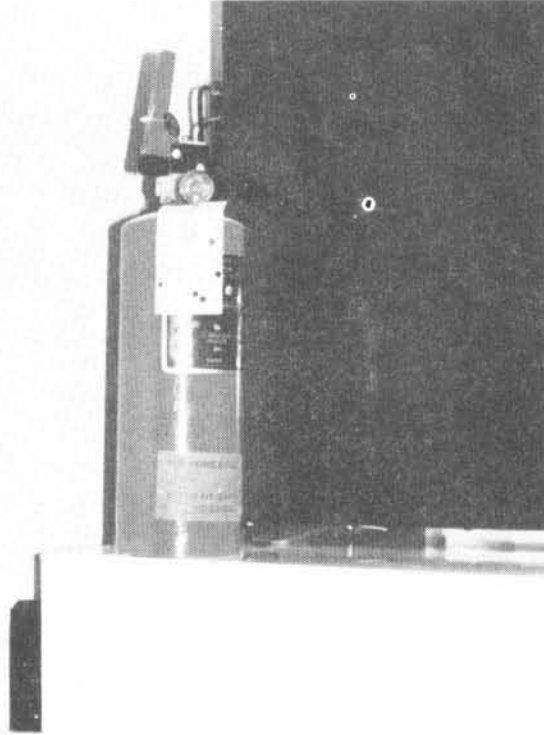
Schematic Upgrade Detail U8

Approximate Cost: \$200 - \$500 per brace

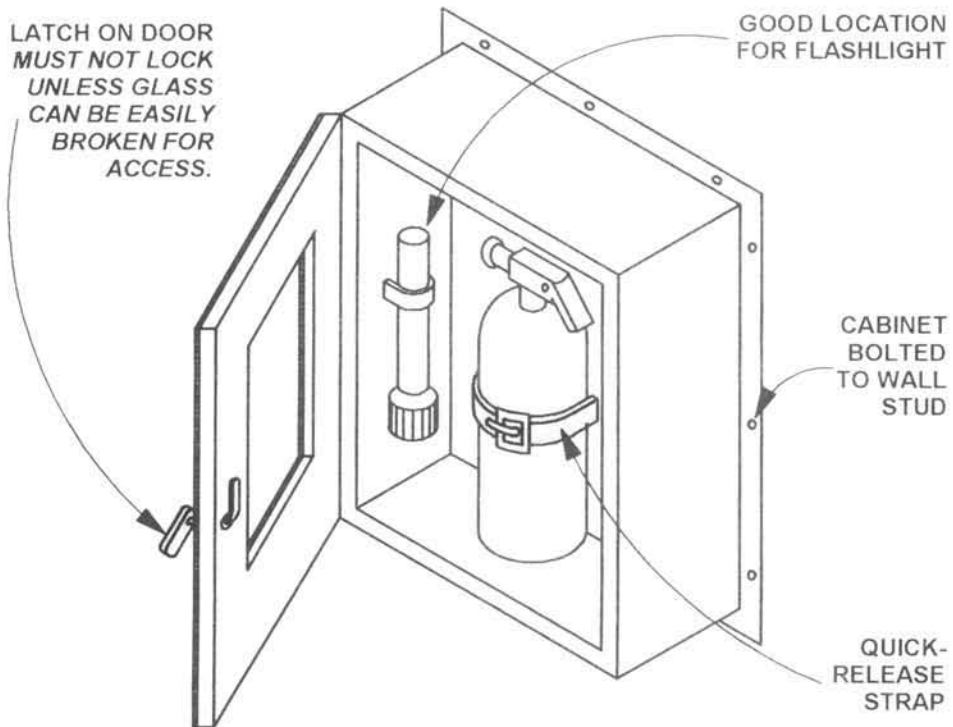
U8

FIRE EXTINGUISHER AND CABINET

DO-IT-YOURSELF



Unrestrained Extinguisher
Photo Credit: Wiss, Janney, Elstner Associates, Inc.

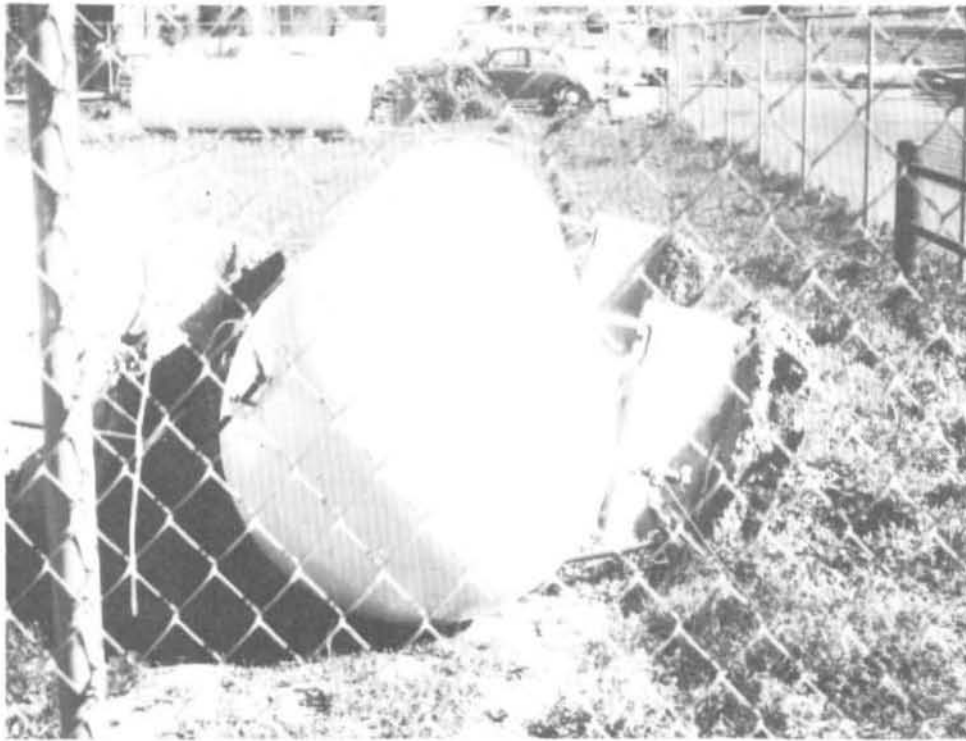


Upgrade Detail U10
Approximate Cost: \$300

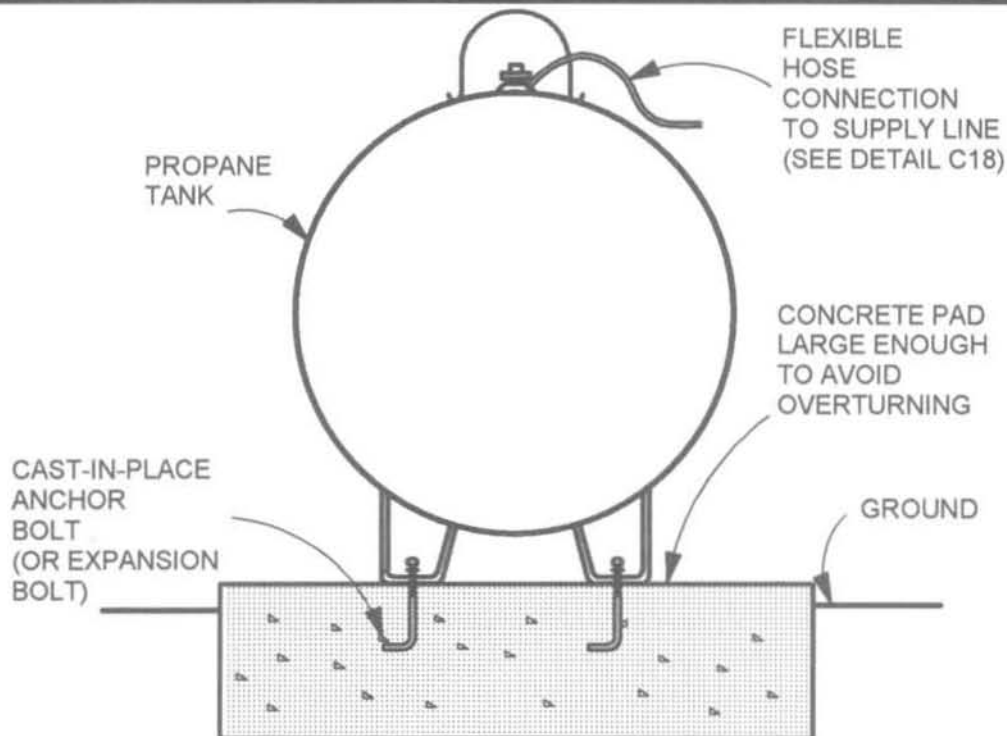
U10

PROPANE TANK

ENGINEERING REQUIRED



Earthquake Damage: 1971, San Fernando, California
Photo Credit: Scientific Service, Inc.



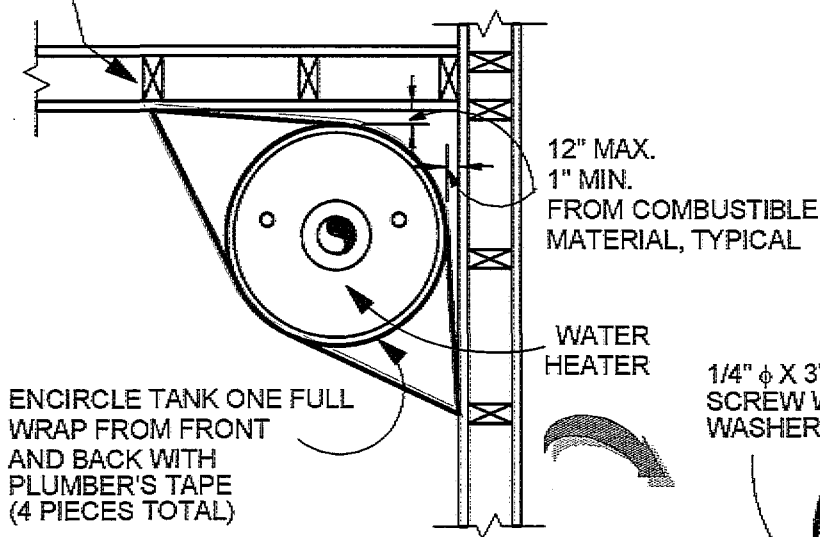
Schematic Upgrade Detail U15
Approximate Cost: \$900

U15

WATER HEATER: CORNER INSTALLATION

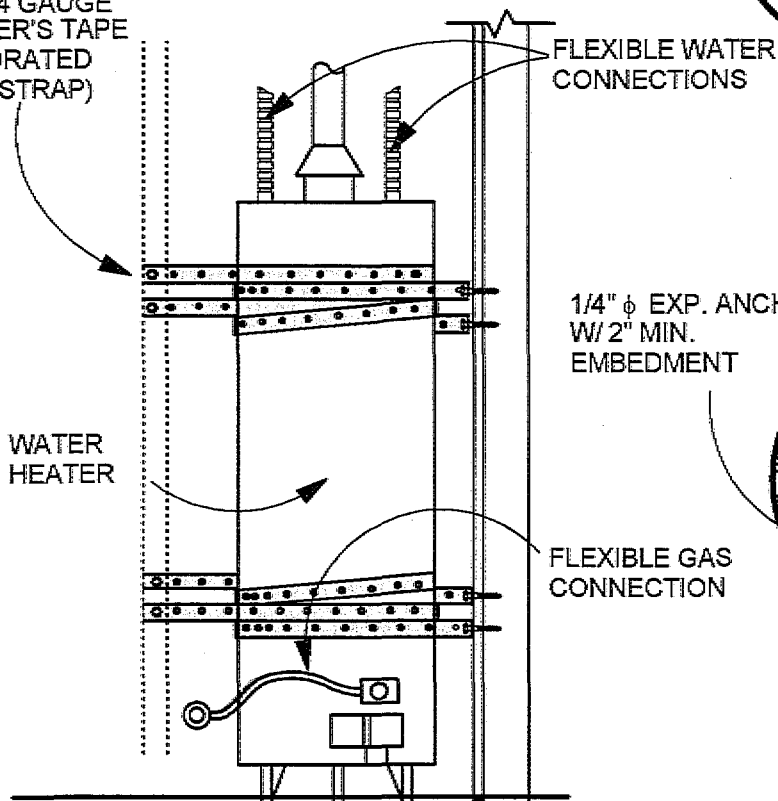
DO-IT-YOURSELF

FIRST STUD NOT BEHIND HEATER



PLAN

3/4" X 24 GAUGE
PLUMBER'S TAPE
(PERFORATED
METAL STRAP)



ELEVATION

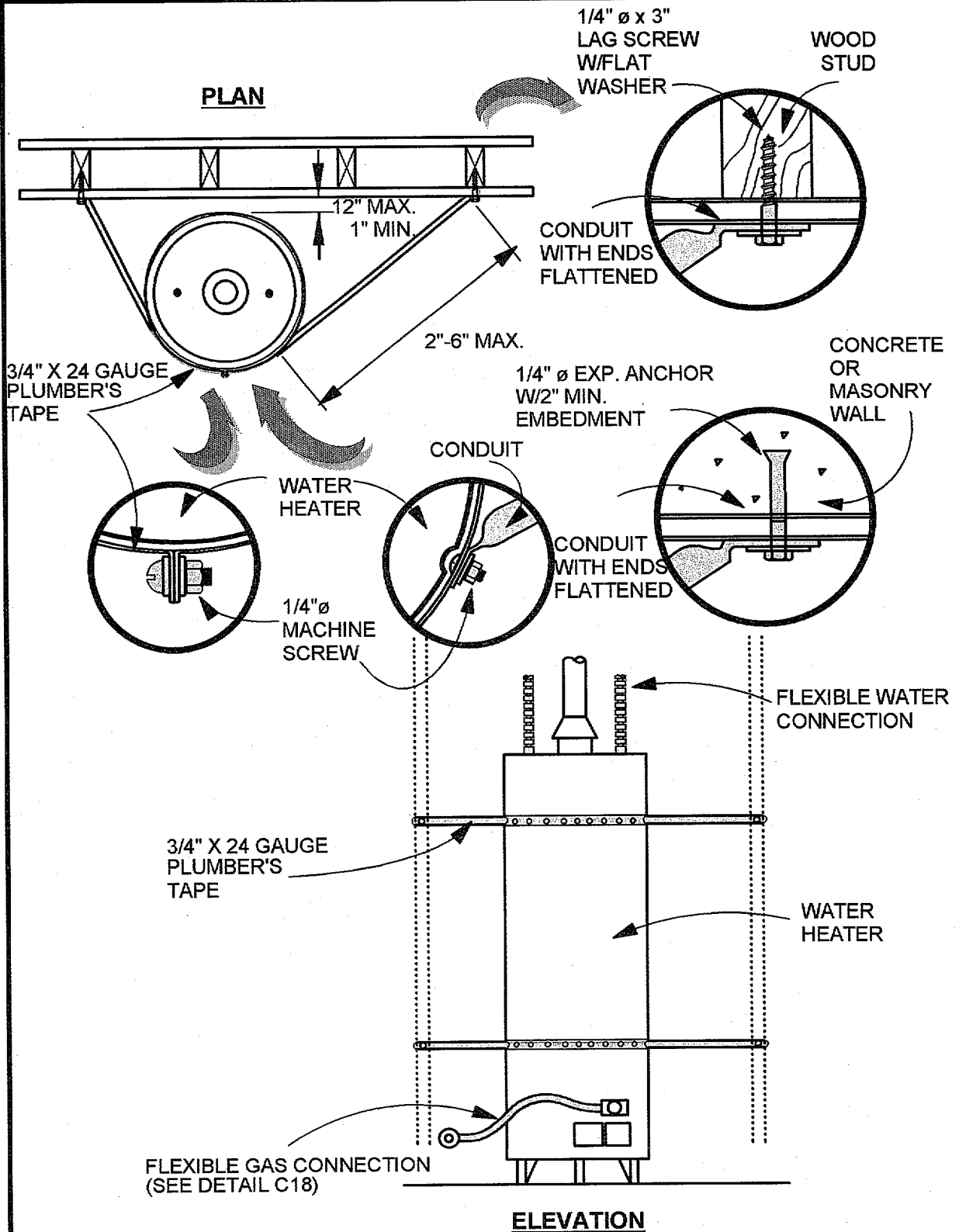
Upgrade Detail U19a

Approximate Cost: \$80

U19a

WATER HEATER: WALL INSTALLATION

DO-IT-YOURSELF

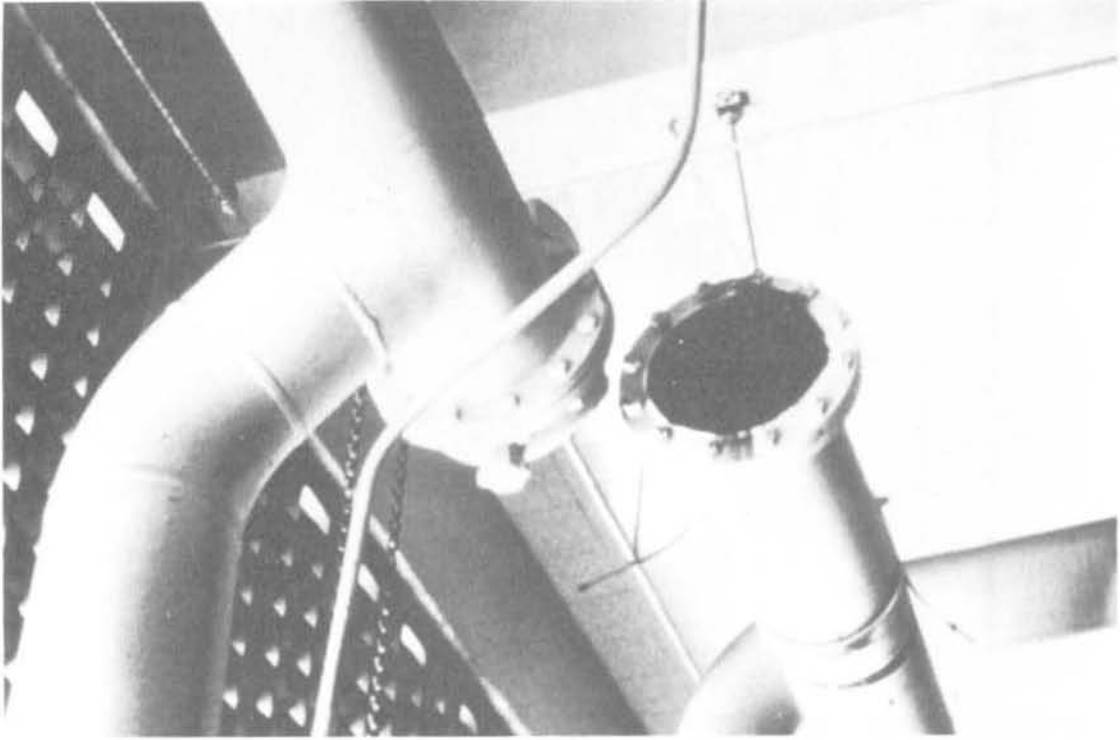


Upgrade Detail U19b
Approximate Cost: \$200

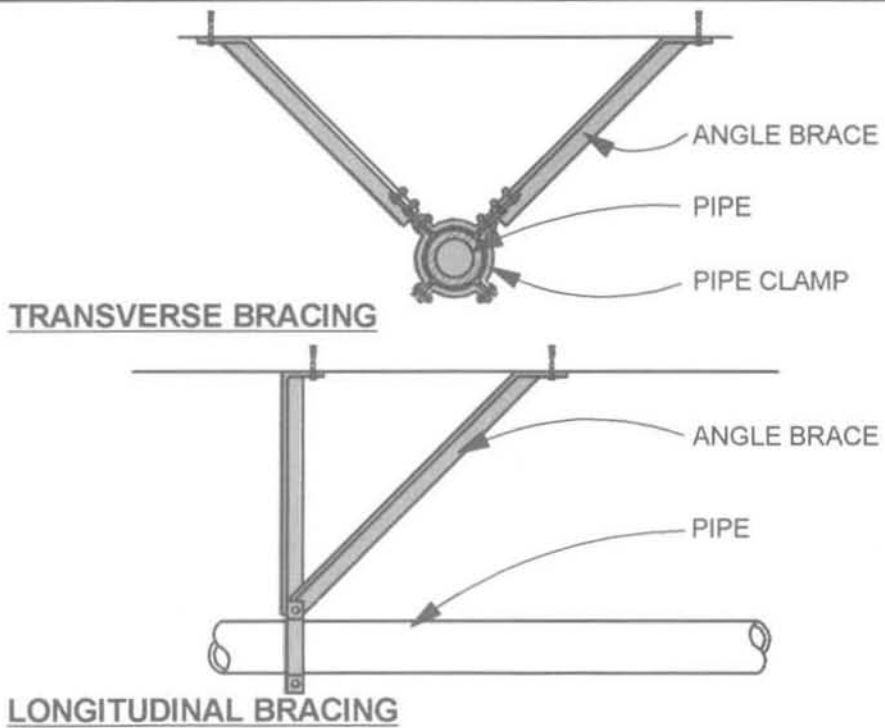
U19b

PIPING

ENGINEERING REQUIRED



Earthquake Damage: 1971, San Fernando, California
Photo Credit: John F. Meehan



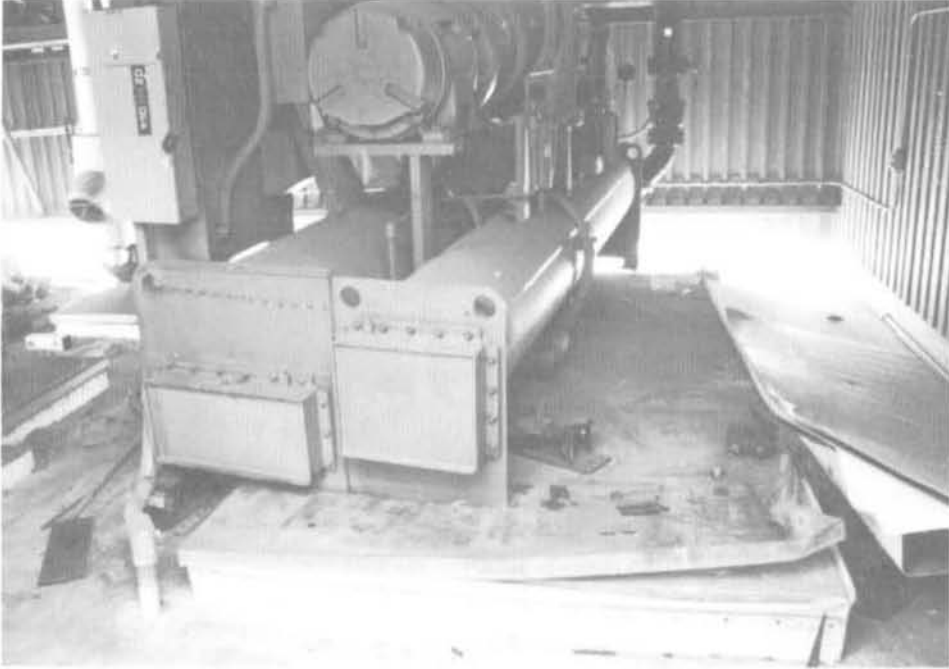
Schematic Upgrade Detail U21

Approximate Cost: \$200 - \$500 per brace

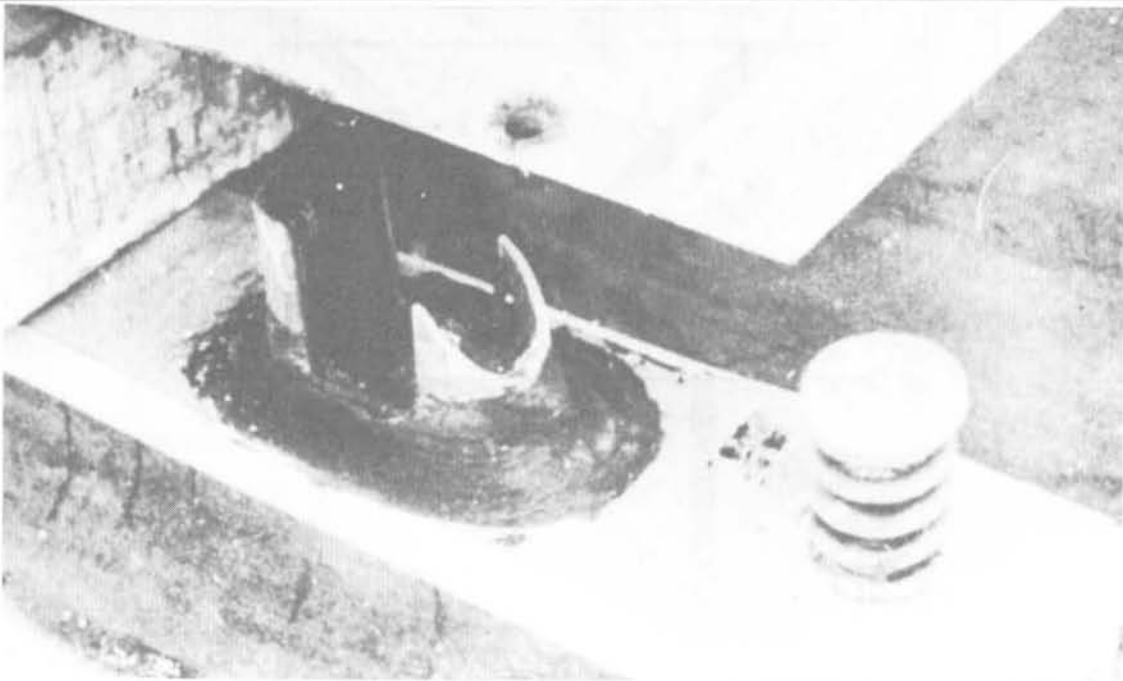
U21

CHILLER

ENGINEERING REQUIRED



Failed chiller mounts due to insufficient uplift resistance.
Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



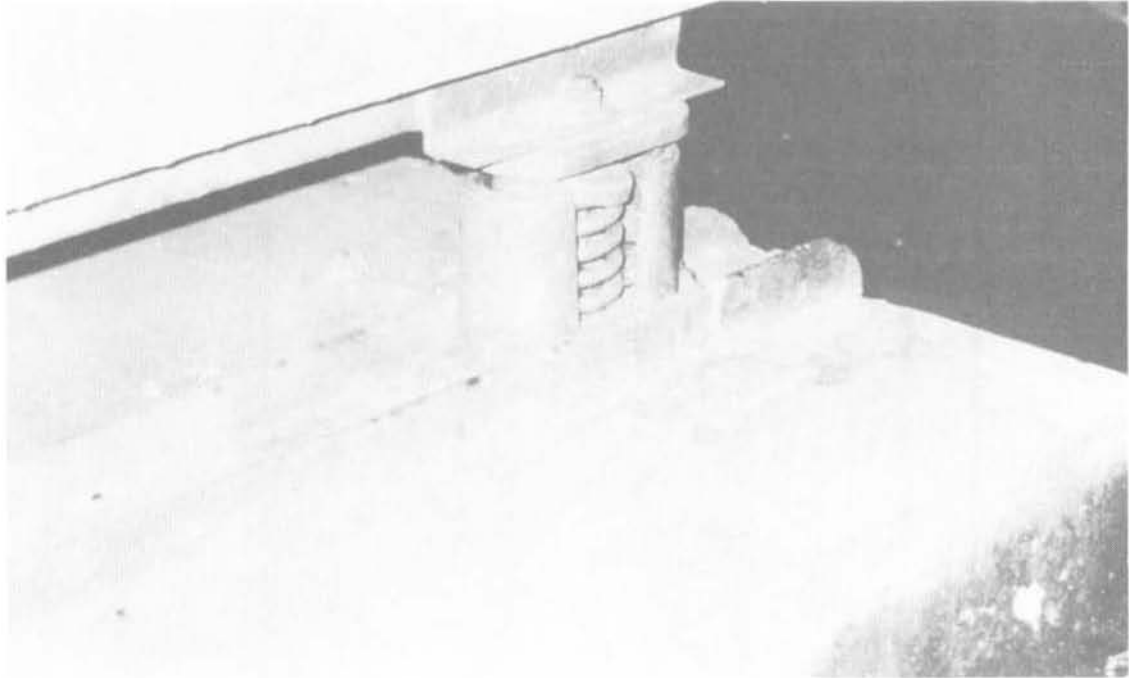
Failed chiller due mount due to insufficient shear resistance.
Earthquake Damage: 1980, Livermore, California
Photo Credit: William T. Holmes

Schematic Upgrade Detail: See Detail U32, Air Compressor

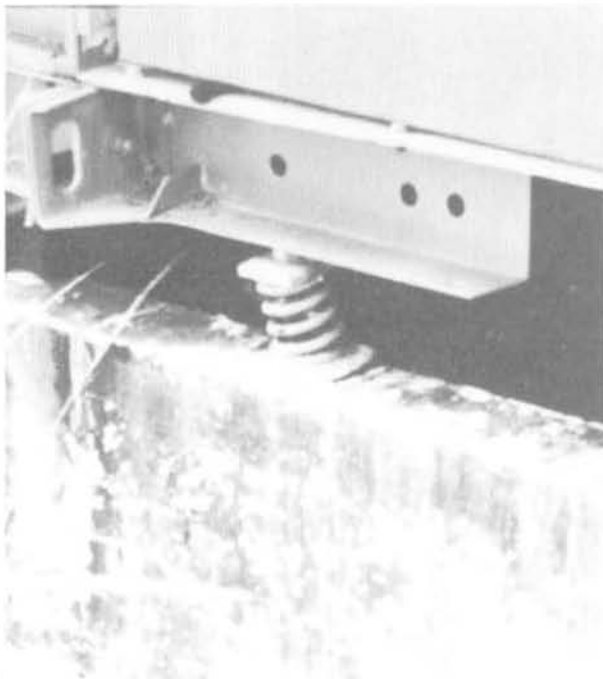
U29a

CHILLER

ENGINEERING REQUIRED



Chiller mount with no uplift resistance and insufficient shear resistance.
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



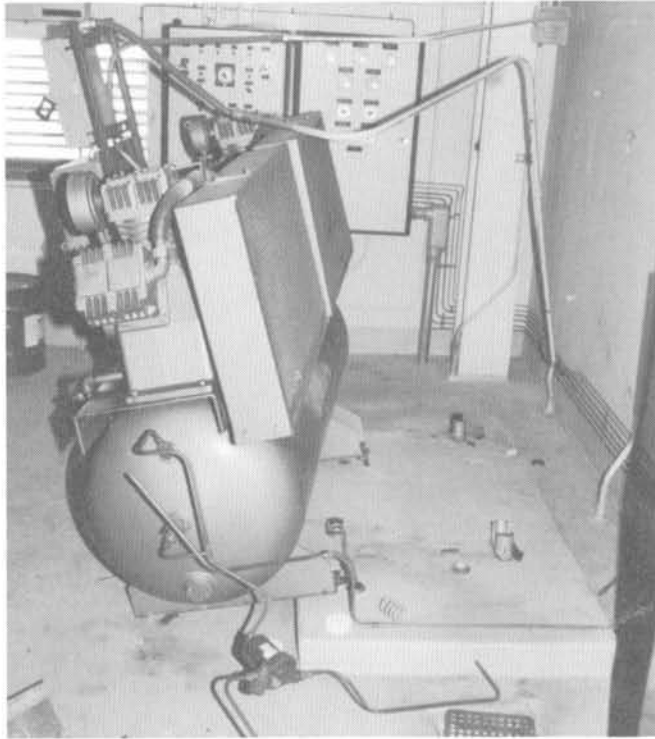
Chiller mount with no uplift resistance and insufficient or no shear resistance.
Photo Credit: Wiss, Janney, Elstner Associates, Inc.

Schematic Upgrade Detail: See Detail U32, Air Compressor

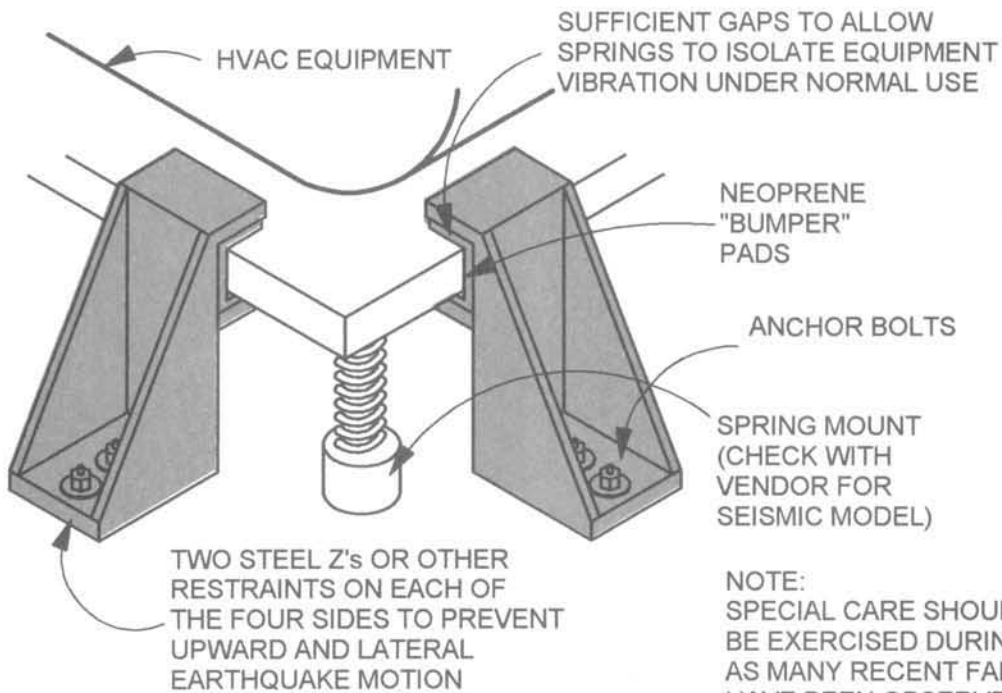
U29b

AIR COMPRESSOR (OR OTHER HVAC EQUIPMENT)

ENGINEERING REQUIRED



Earthquake Damage: 1994, Northridge, California
 Photo Credit: Wiss, Janney, Elstner Associates, Inc.



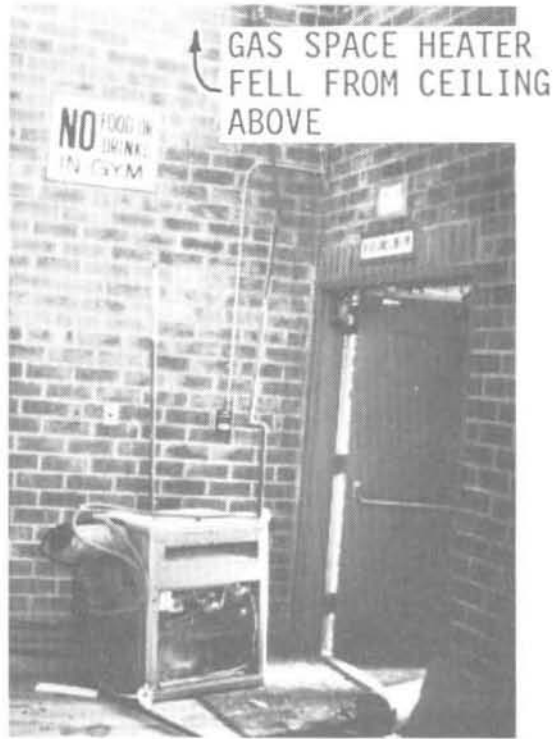
Schematic Upgrade Detail U32

Approximate Cost: Depends on individual case; \$300 - \$1,200

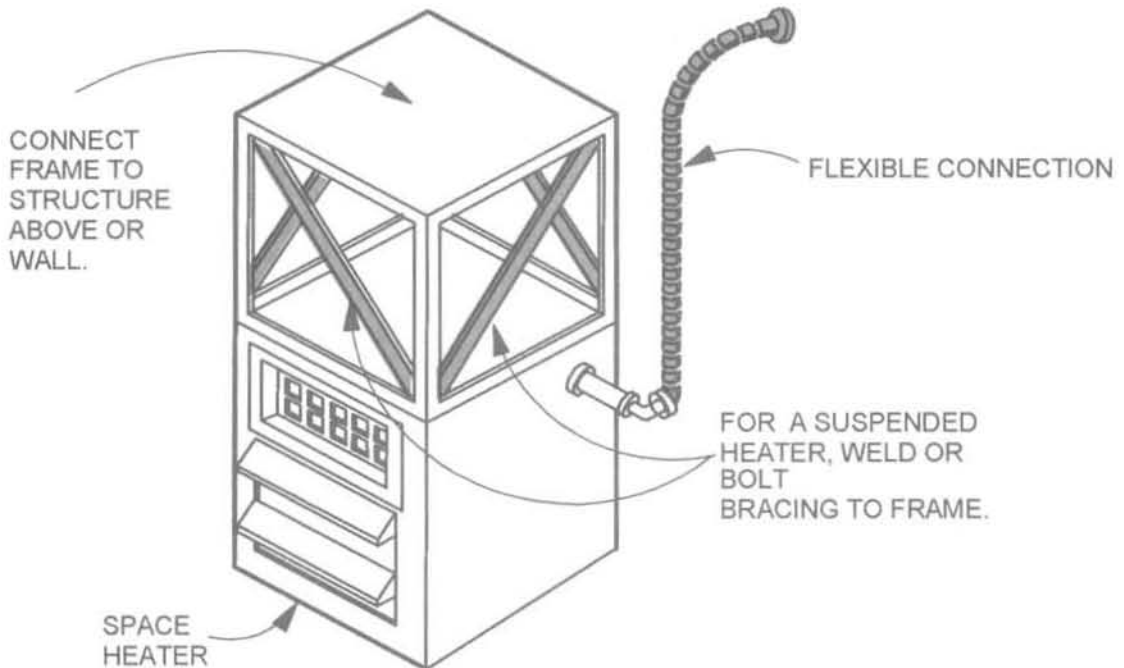
U32

SUSPENDED SPACE HEATER

ENGINEERING REQUIRED



Earthquake Damage: 1971, San Fernando, California
Photo Credit: C. Wilton, Scientific Service, Inc.

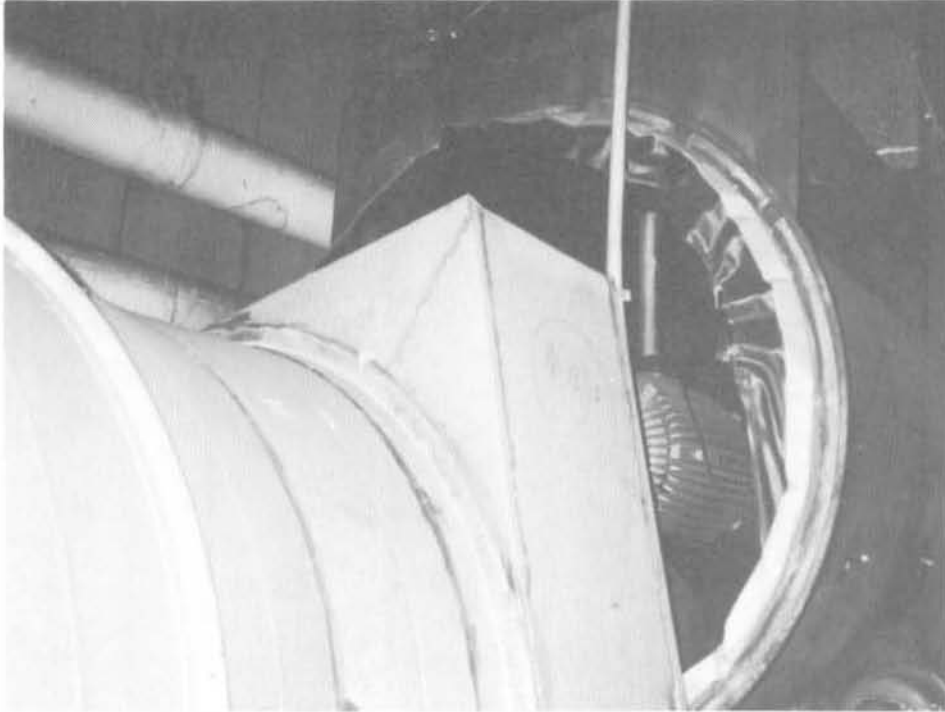


Schematic Upgrade Detail U35
Approximate Cost: \$200

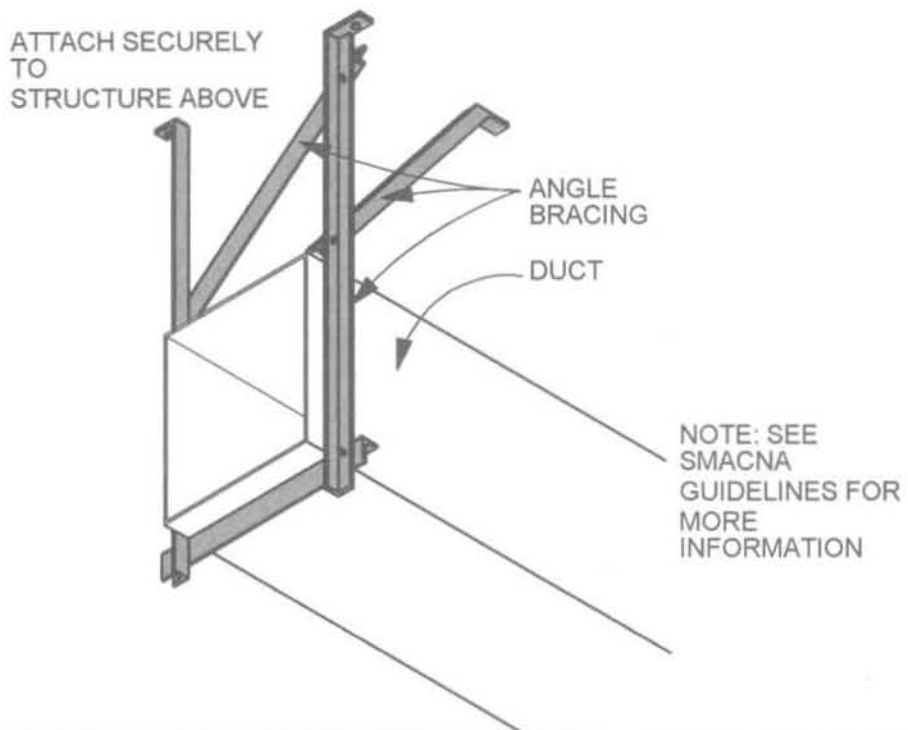
U35

HVAC DISTRIBUTION DUCTS

ENGINEERING REQUIRED



Sheet metal duct separated from fan unit.
Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Schematic Upgrade Detail U36
Approximate Cost: \$200 - \$500 per support

U36

AIR DIFFUSER

DO-IT-YOURSELF



Air diffusers fell to the floor.
Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc

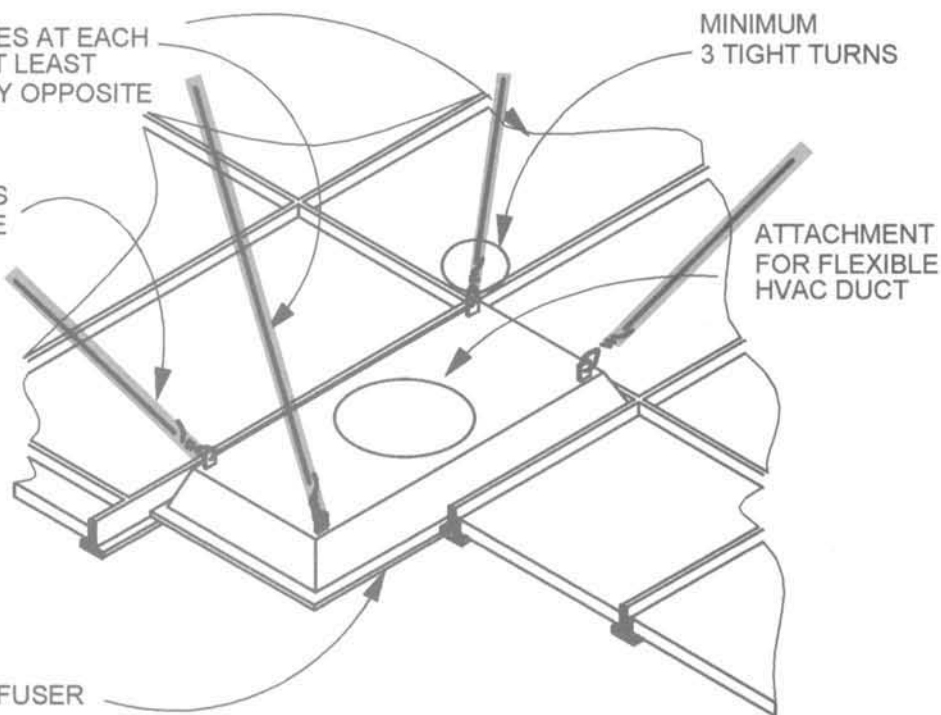
12 GAUGE WIRES AT EACH
CORNER OR AT LEAST
AT DIAGONALLY OPPOSITE
CORNERS

ANCHOR WIRES
TO STRUCTURE
ABOVE

MINIMUM
3 TIGHT TURNS

ATTACHMENT
FOR FLEXIBLE
HVAC DUCT

DIFFUSER



Upgrade Detail U37
Approximate Cost: \$50

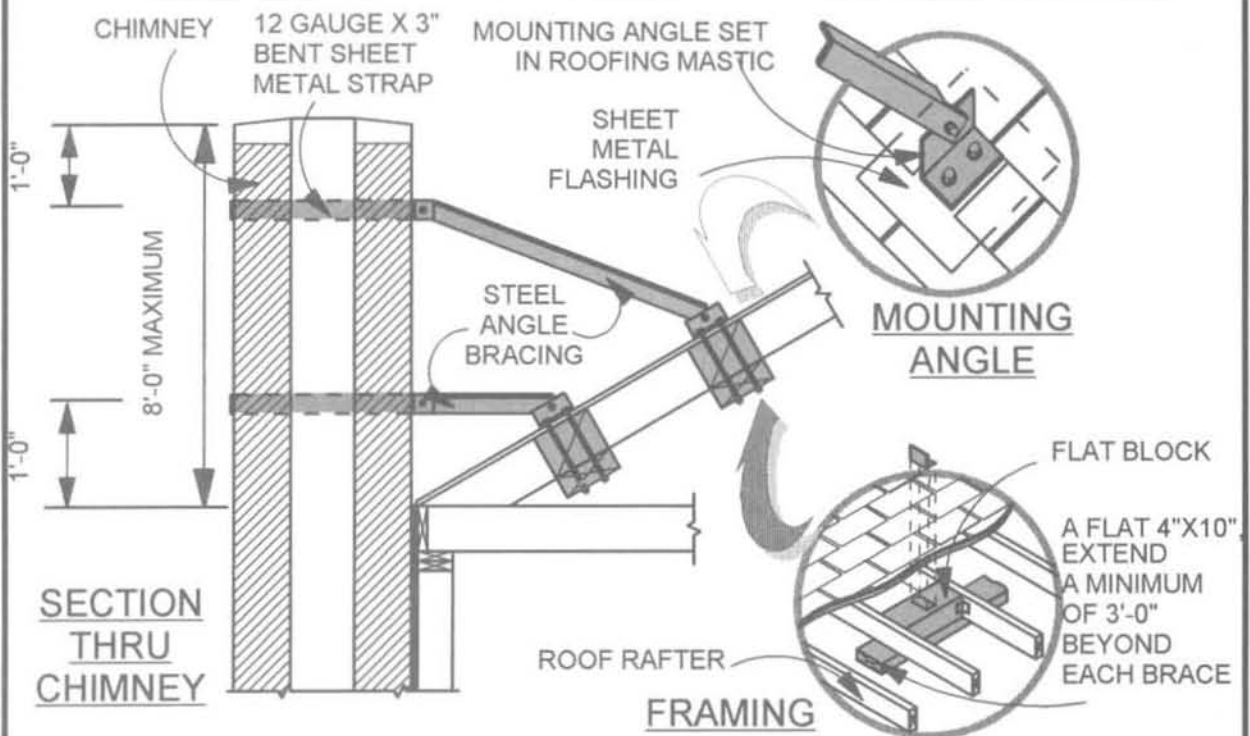
U37

RESIDENTIAL CHIMNEY

ENGINEERING REQUIRED



Earthquake Damage: 1989, Loma Prieta, California
 Photo Credit: California Office of Emergency Services, Earthquake Program



Upgrade Detail U38 (Recommended only for areas of low to moderate seismicity).
 Approximate Cost: \$1,000

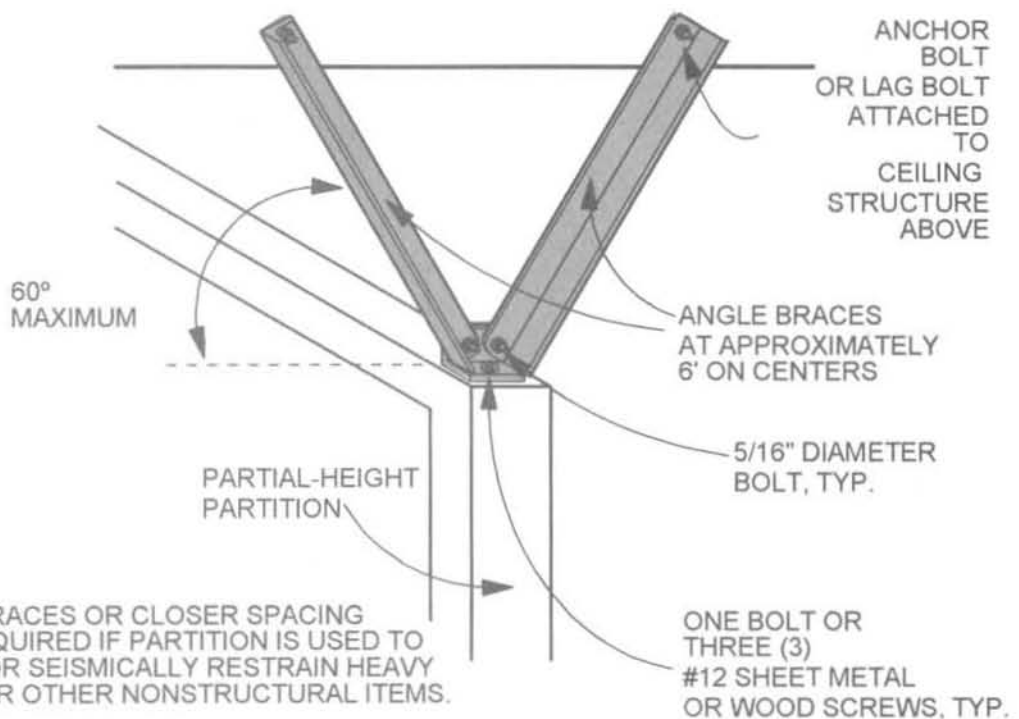
U38

BUILT-IN PARTIAL-HEIGHT PARTITIONS

ENGINEERING REQUIRED



Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Schematic Upgrade Detail A2a

Approximate Cost: Varies - \$20 - \$40 per lineal foot

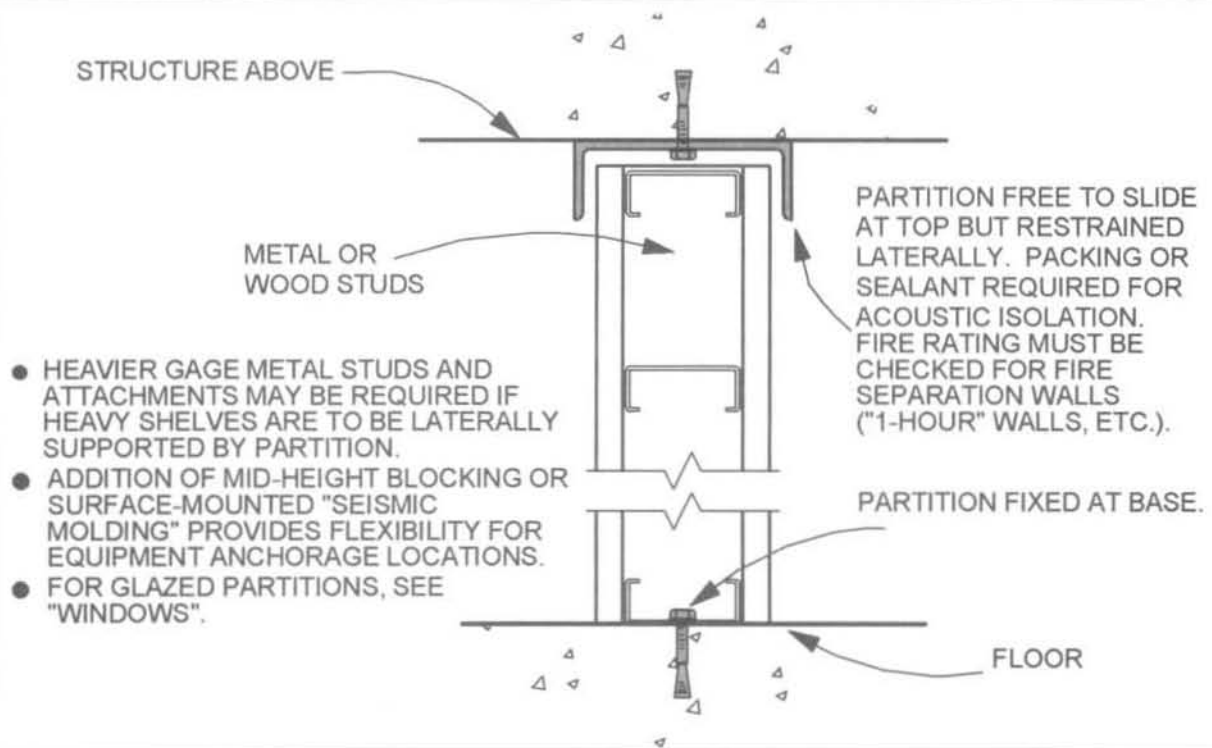
A2a

BUILT-IN FULL-HEIGHT PARTITIONS

ENGINEERING REQUIRED



Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Schematic Upgrade Detail A2b

Approximate Cost: Varies, depending on design

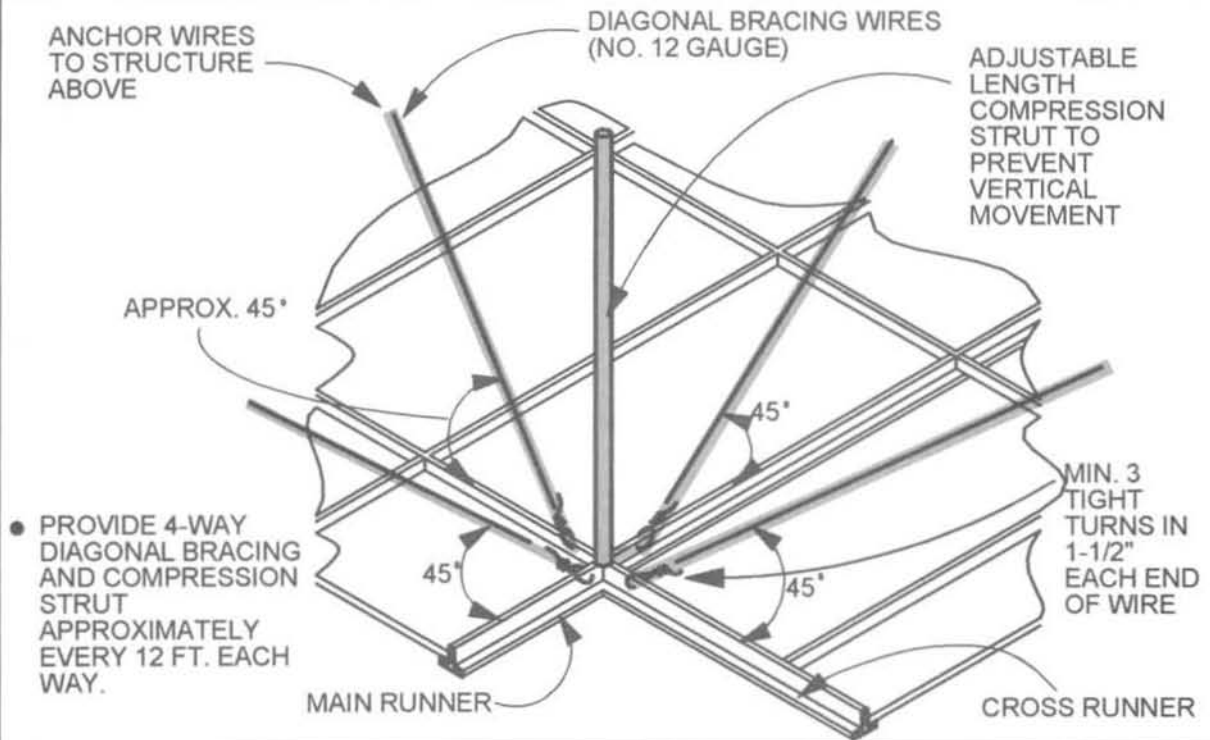
A2b

SUSPENDED T-BAR CEILINGS

ENGINEERING REQUIRED



Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Schematic Upgrade Detail A3
Approximate Cost: \$50 per brace

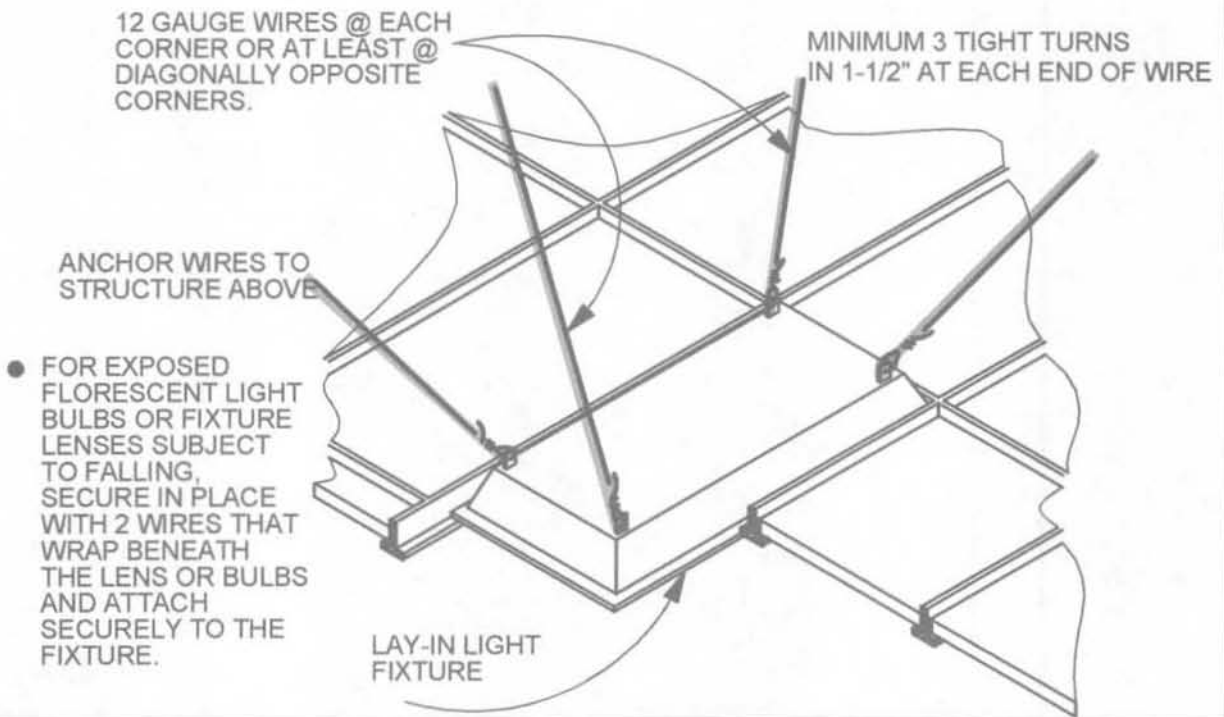
A3

SUSPENDED LIGHT FIXTURES

DO-IT-YOURSELF



Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Upgrade Detail U5a

Approximate Cost: \$50 per fixture

A5a

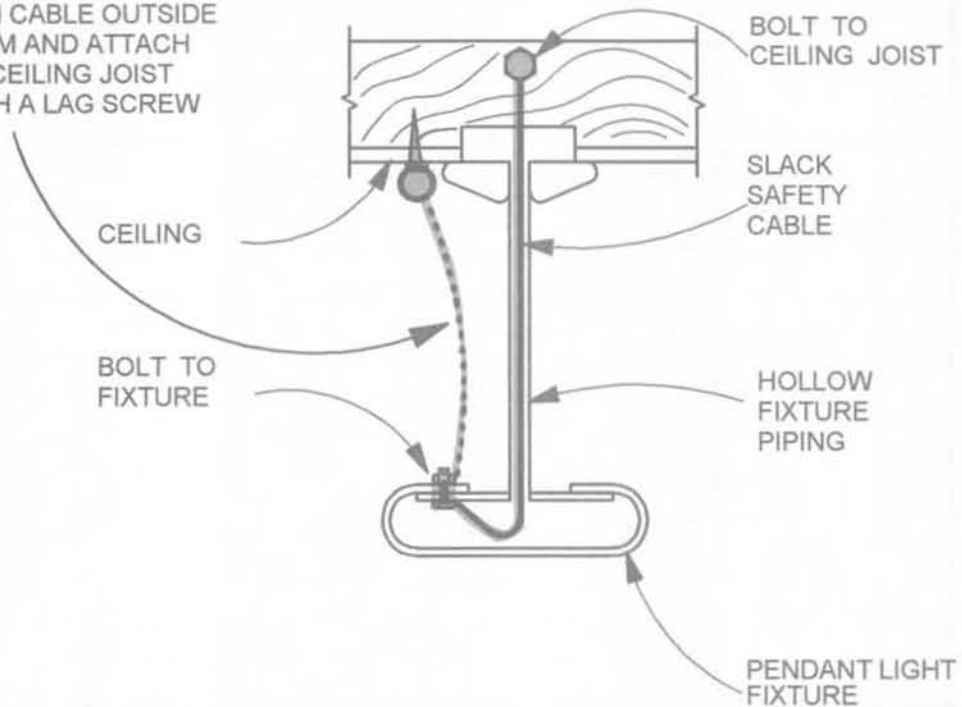
PENDANT LIGHT FIXTURES

DO-IT-YOURSELF



Failure of light fixtures at Northridge Junior High School
Earthquake Damage: 1994, Northridge, California
Photo Credit: Earthquake Engineering Research Institute, Gary L. McGavin

ALTERNATE:
RUN CABLE OUTSIDE
STEM AND ATTACH
TO CEILING JOIST
WITH A LAG SCREW



Upgrade Detail A5b
Approximate Cost: \$80

A5b

STAIRWAYS

ENGINEERING REQUIRED



Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.

- TO PREVENT DAMAGE TO STAIRS THEY SHOULD BE MODIFIED TO ALLOW THEM TO SLIDE AT LANDINGS WITH "GANG PLANK" DETAILS; THIS IS DESIRABLE FOR FLEXIBLE FRAME BUILDINGS.
- IF STAIR ENCLOSURES ARE CONSTRUCTED USING BRITTLE MATERIALS, SUCH AS, HOLLOW CLAY TILE, GLASS BLOCK PARTITIONS, OR SKYLIGHTS, IT IS RECOMMENDED THAT THEY BE ENCAPSULATED OR REPLACED TO PREVENT FALLING HAZARDS AND DEBRIS IN THE STAIRWELL.
- PROVIDE ANCHORAGE FOR PIPES, LIGHTING OR DUCTS IN STAIRWELLS TO PREVENT FALLING HAZARDS AND DEBRIS.

Schematic Upgrade Detail A9

Approximate Cost: Depends on design

A9

WINDOWS

ENGINEERING REQUIRED



Earthquake Damage: 1994, Northridge, California
Photo Credit: Wiss, Janney, Elstner Associates, Inc.

- USE OF TEMPERED GLASS WILL GREATLY REDUCE THE SEISMIC HAZARD. TEMPERED GLASS MAY STILL BREAK, BUT WILL BREAK INTO SMALL DULL FRAGMENTS INSTEAD OF LARGE DANGEROUS SHARDS.
- POLYESTER SHATTER RESISTANT FILMS ARE AVAILABLE THAT HELP HOLD TOGETHER FRAGMENTS OF ANY PANES THAT CRACK IN AN EARTHQUAKE. (TYPICAL SOLAR FILM MAY NOT BE ADEQUATE FOR THIS PURPOSE).
- USE OF LAMINATED GLASS FOR STOREFRONTS REDUCES SEISMIC RISK AND ALSO INCREASES PROTECTION FROM BURGLARY OR VANDALISM.
- SMALLER, OPERABLE, AND WOODEN FRAMED WINDOWS TOLERATE MORE LATERAL DRIFT.
- FOR NEW CONSTRUCTION, STIFFER BUILDINGS AND GLAZING WITH MORE THAN THE STANDARD EDGE CLEARANCES MAY BE DESIRABLE. CHECK WHETHER OR NOT THE BUILDING'S CALCULATED SEISMIC DRIFT HAS BEEN CONSIDERED IN THE DESIGN OF THE GLAZING.

Schematic Upgrade Detail A12

Approximate Cost: Depends on design

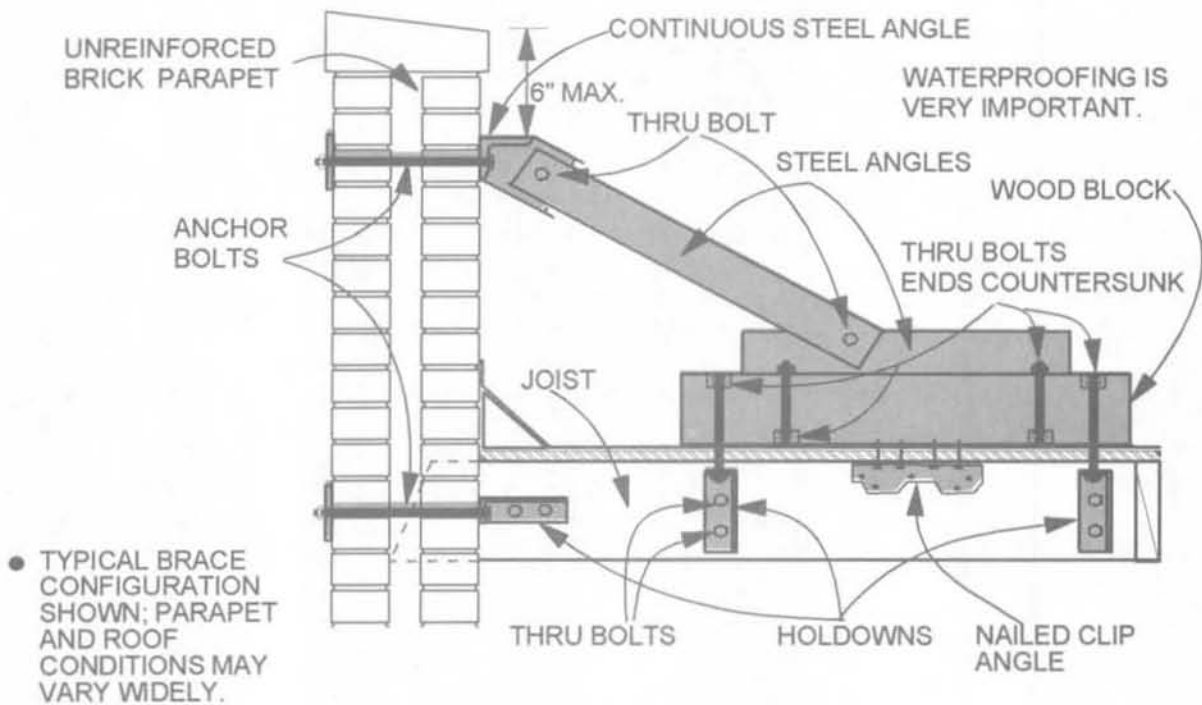
A12

UNREINFORCED BRICK PARAPETS

ENGINEERING REQUIRED



Earthquake Damage: 1989, Loma Prieta, California
 Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Schematic Upgrade Detail A15a
 Approximate Cost: \$50 per foot

A15a

VENEER

ENGINEERING REQUIRED



Earthquake Damage: 1994, Northridge, California
Photo Credit: Robert Reitherman

- SEE APPLICABLE BUILDING CODE REQUIREMENTS FOR LIMITATIONS REGARDING THE HEIGHT, AREA, UNIT SIZE, AND UNIT WEIGHT OF EITHER ADHERED OR ANCHORED VENEER SYSTEMS. REFER TO THE CODE SECTIONS FOR SPECIFIC REQUIREMENTS FOR BACKING, TIES, AND REINFORCEMENT. (FOR EXAMPLE, SECTION 1403 OF THE 1994 UBC).
- VENEER SYSTEMS MUST ALSO AT LEAST MEET THE MINIMUM LATERAL FORCE REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS. (FOR EXAMPLE, THE REQUIREMENTS FOR EXTERIOR AND INTERIOR ORNAMENTATION AND APPENDAGES IN CHAPTER 16 OF THE 1994 UBC).
- REMOVAL OF VENEER MOUNTED OVER ENTRANCES OR OTHER POTENTIALLY CROWDED LOCATIONS IS THE MOST RELIABLE UPGRADE SOLUTION.

Schematic Upgrade Detail A15b
Approximate Cost: Varies

A15b

FREESTANDING WALLS OR FENCES

ENGINEERING REQUIRED



Earthquake Damage: 1994, Northridge, California

Photo Credit: Robert Reitherman

- MANY MILES OF POORLY CONSTRUCTED CONCRETE MASONRY UNIT (CMU) FENCES WERE DAMAGED DURING THE 1994 NORTHRIDGE EARTHQUAKE. COLLAPSE OF WALLS WITH INADEQUATE OR ABSENT REINFORCING AND/OR FOUNDATIONS WAS COMMON IN NORTHRIDGE AND SYLMAR. IN MANY CASES, MOST OF THE SIDEWALK WAS COVERED WITH DEBRIS, AS SHOWN ABOVE.
- FREESTANDING WALLS OR FENCES BUILT OF CMU, BRICK, OR STONE NEED TO BE ENGINEERED AND CONSTRUCTED WITH APPROPRIATE FOUNDATIONS, ADEQUATE REINFORCEMENT, AND GOOD QUALITY MORTAR.
- STANDARD DETAILS FOR LOW FENCES OR SHORT RETAINING WALLS MAY BE AVAILABLE FROM THE LOCAL BUILDING DEPARTMENT.

Schematic Upgrade Detail A16

Approximate Cost: Depends on the design

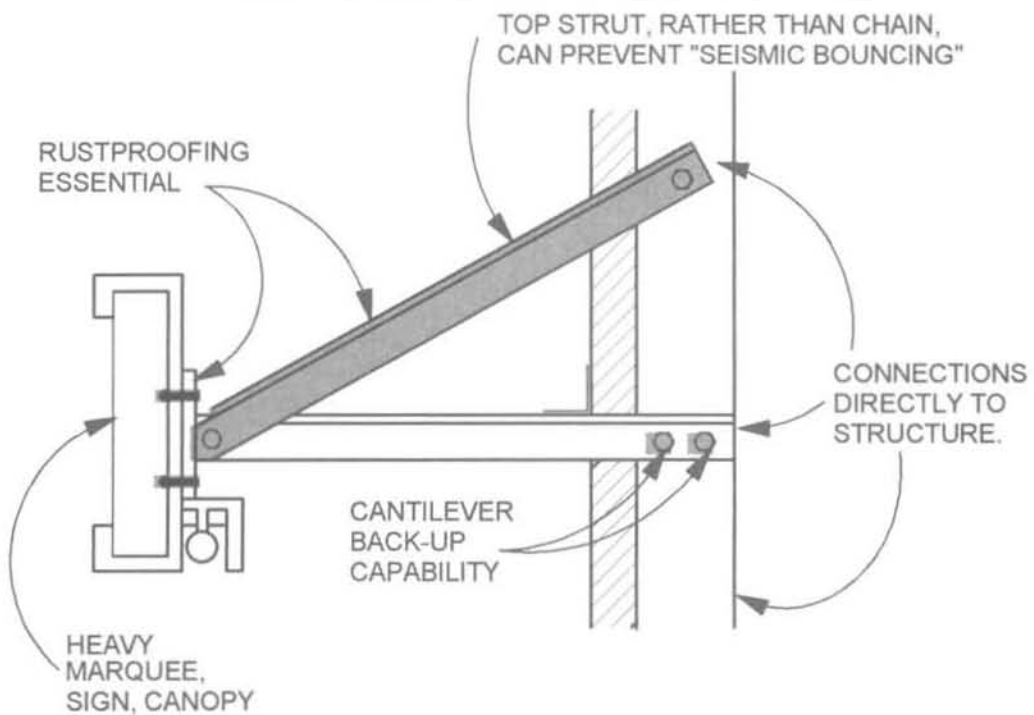
A16

EXTERIOR SIGNS

ENGINEERING REQUIRED



Earthquake Damage: 1979, Imperial Valley, California
Photo Credit: Robert Reitherman/BSD, Inc.

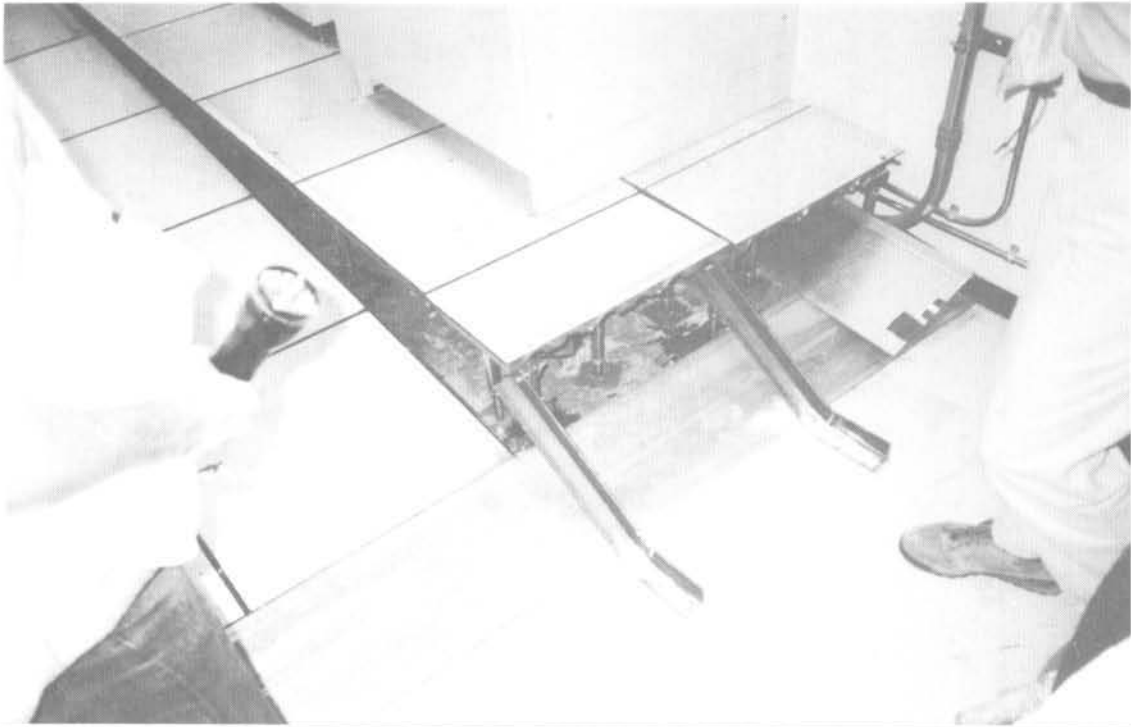


Schematic Upgrade Detail A21
Approximate Cost: \$500 - \$800

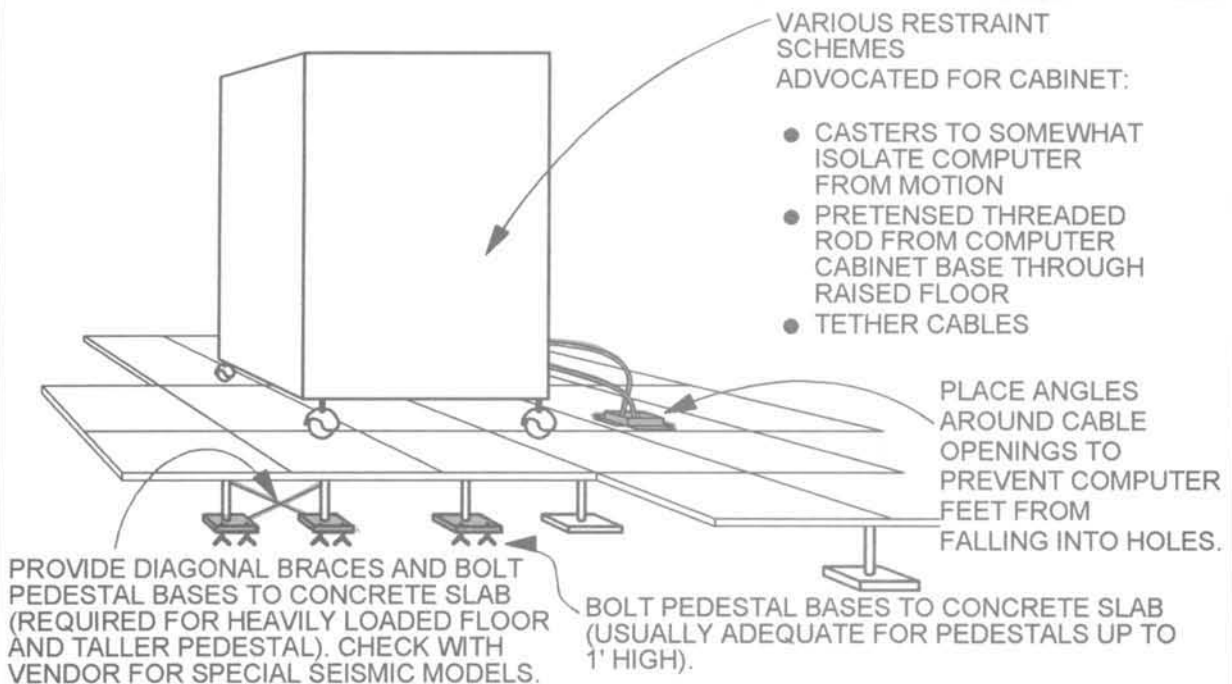
A21

LARGE COMPUTERS AND ACCESS FLOORS

ENGINEERING REQUIRED



Temporary bracing for collapsed access floor
 Earthquake Damage: 1994, Northridge, California
 Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Schematic Upgrade Detail C8

Approximate Cost: Access floor alone -- \$3 - \$7 per square foot
 Cabinet restraint -- \$300 - \$500 per cabinet

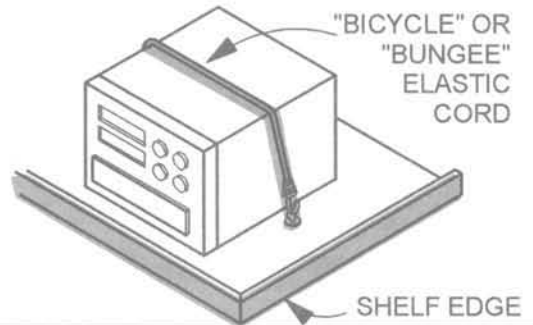
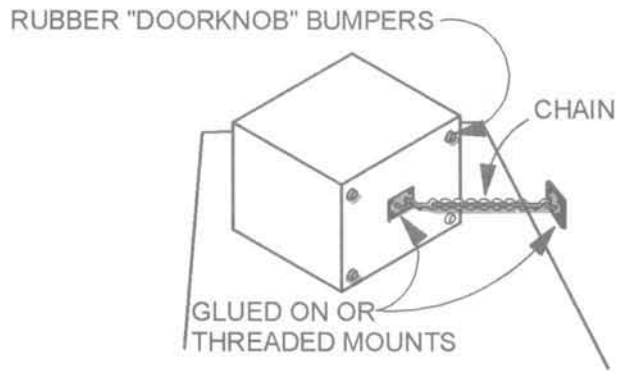
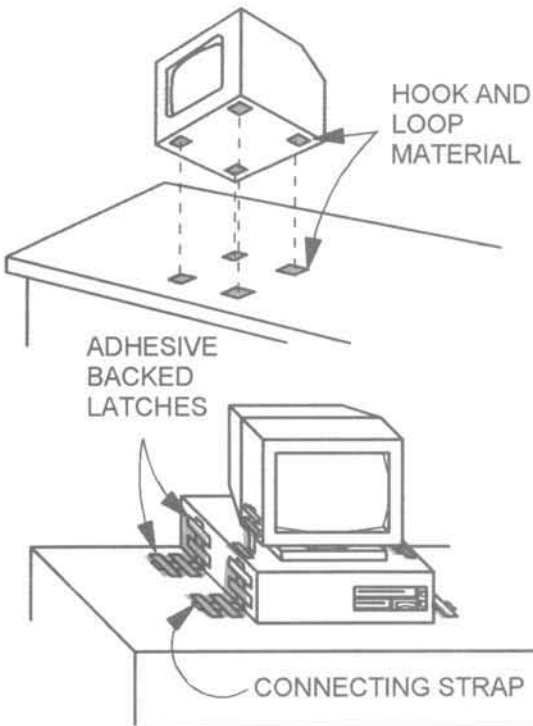
C8

DESKTOP COMPUTERS AND OFFICE EQUIPMENT

DO-IT-YOURSELF



Unsecured computers may fall and suffer damage
Photo Credit: Wiss, Janney, Elstner Associates, Inc.

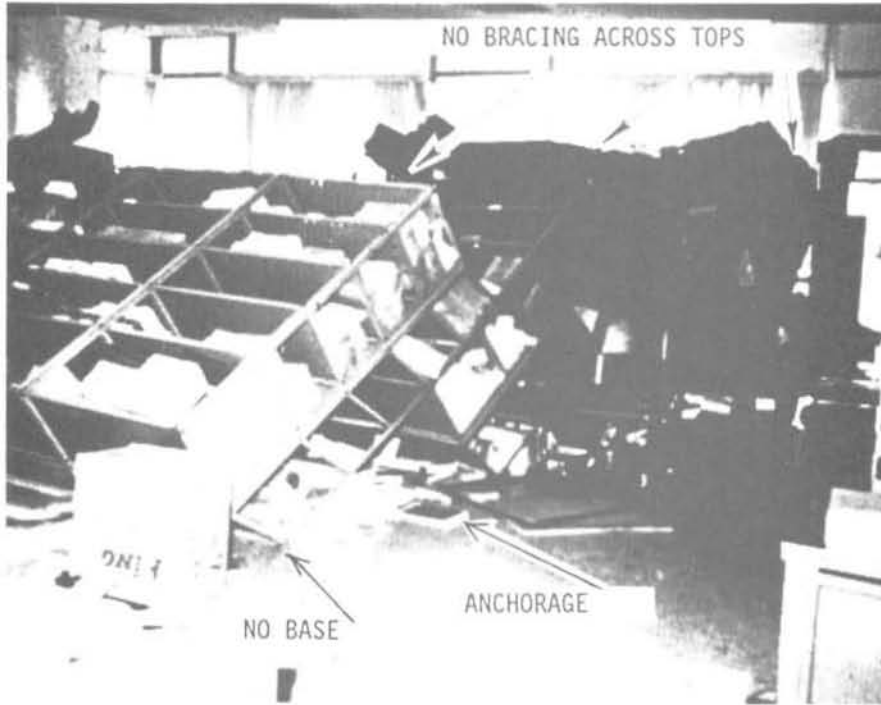


Upgrade Detail C10
Approximate Cost: \$50 per computer

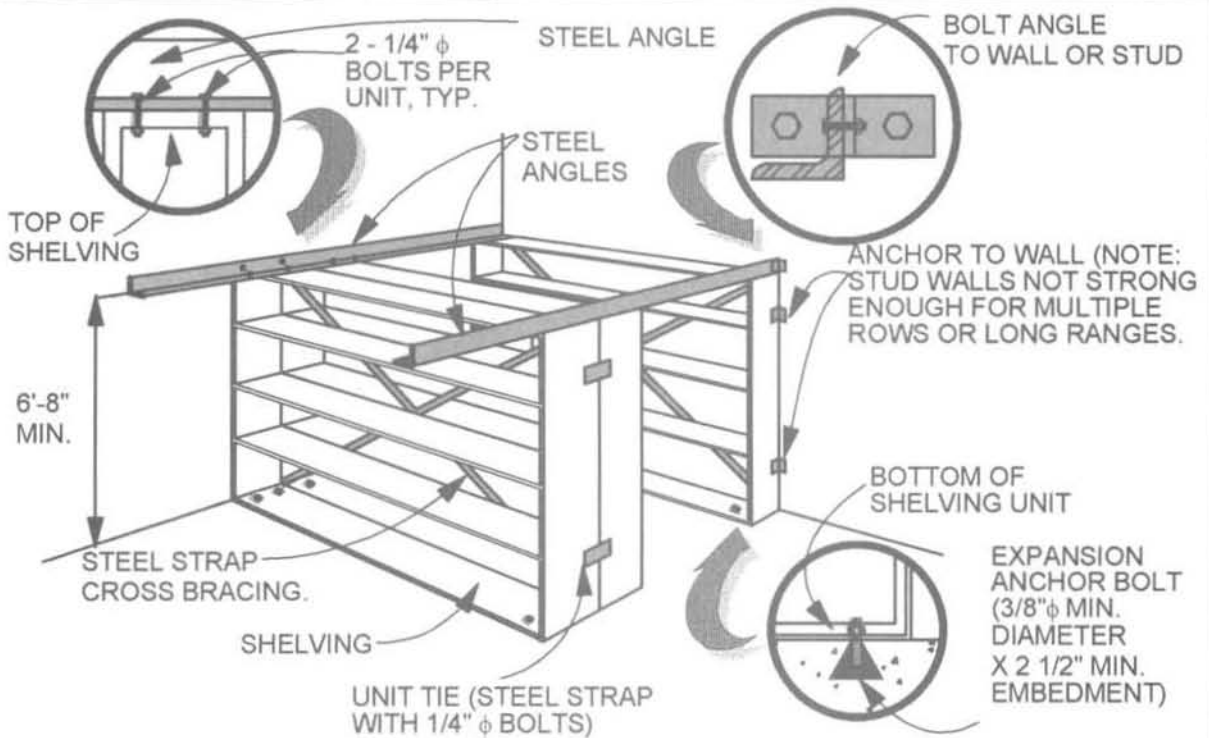
C10

TALL SHELVING: FREESTANDING

ENGINEERING REQUIRED



Earthquake Damage: 1972, Managua, Nicaragua
 Photo Credit: John F. Meehan



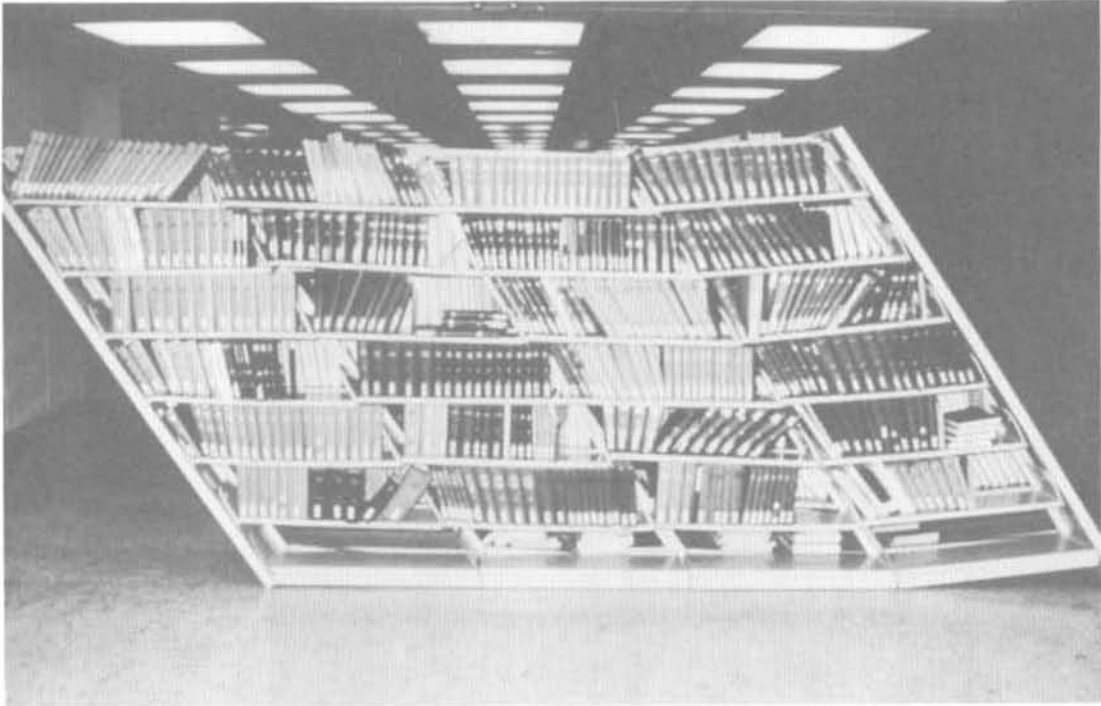
Schematic Upgrade Detail C12a

Approximate Cost: \$20 per lineal foot of shelving

C12a

LIBRARY STACKS

ENGINEERING REQUIRED



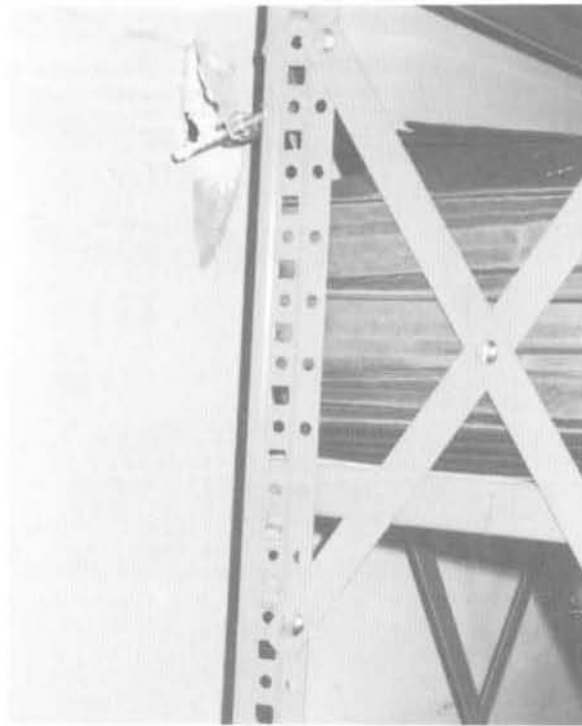
Failure of library shelving
Earthquake Damage: 1987, Whittier Narrows, California
Photo Credit: Earthquake Engineering Research Institute, Larry Parsons



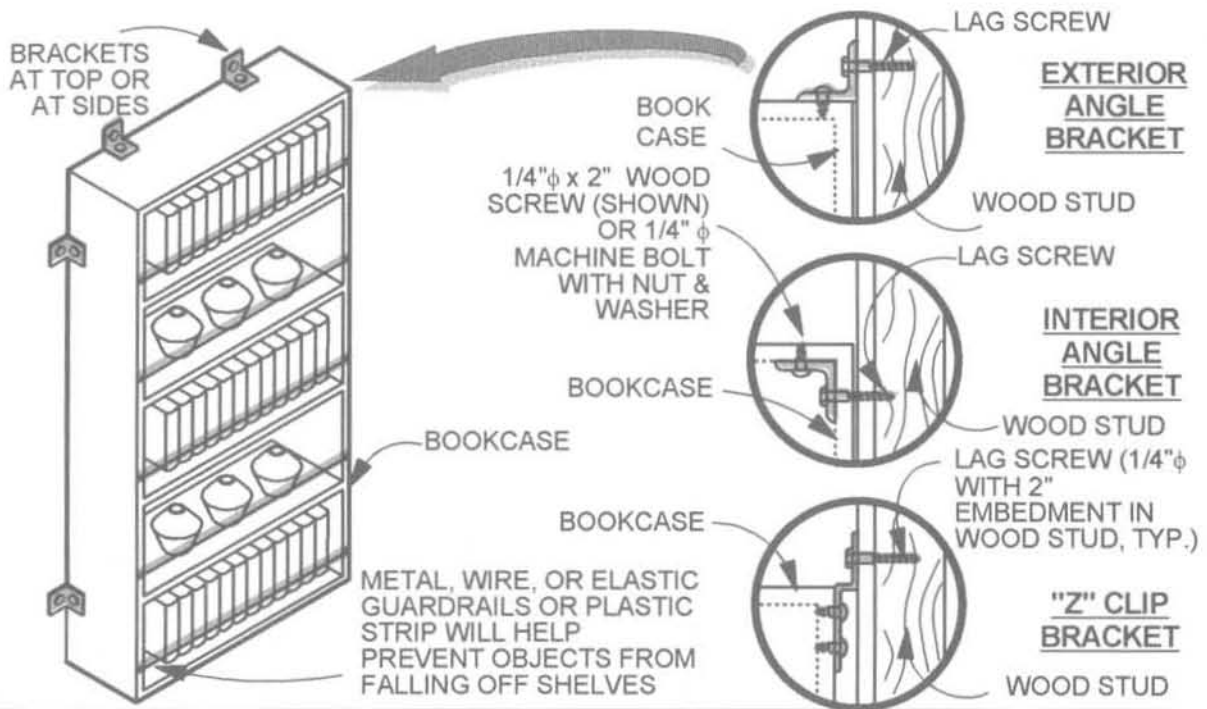
Failure of inadequately upgraded library shelving
Earthquake Damage: 1987, Whittier Narrows, California
Photo Credit: Earthquake Engineering Research Institute, Marshall Lew & Greg Brandow **C12b**

TALL SHELVING: WALL UNIT

DO-IT-YOURSELF



Failure of inadequately upgraded shelving; toggle bolt pulled out of gypsum board.
 Earthquake Damage: 1994, Northridge, California
 Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Upgrade Detail C12c

Approximate Cost: \$20 per lineal foot of shelving

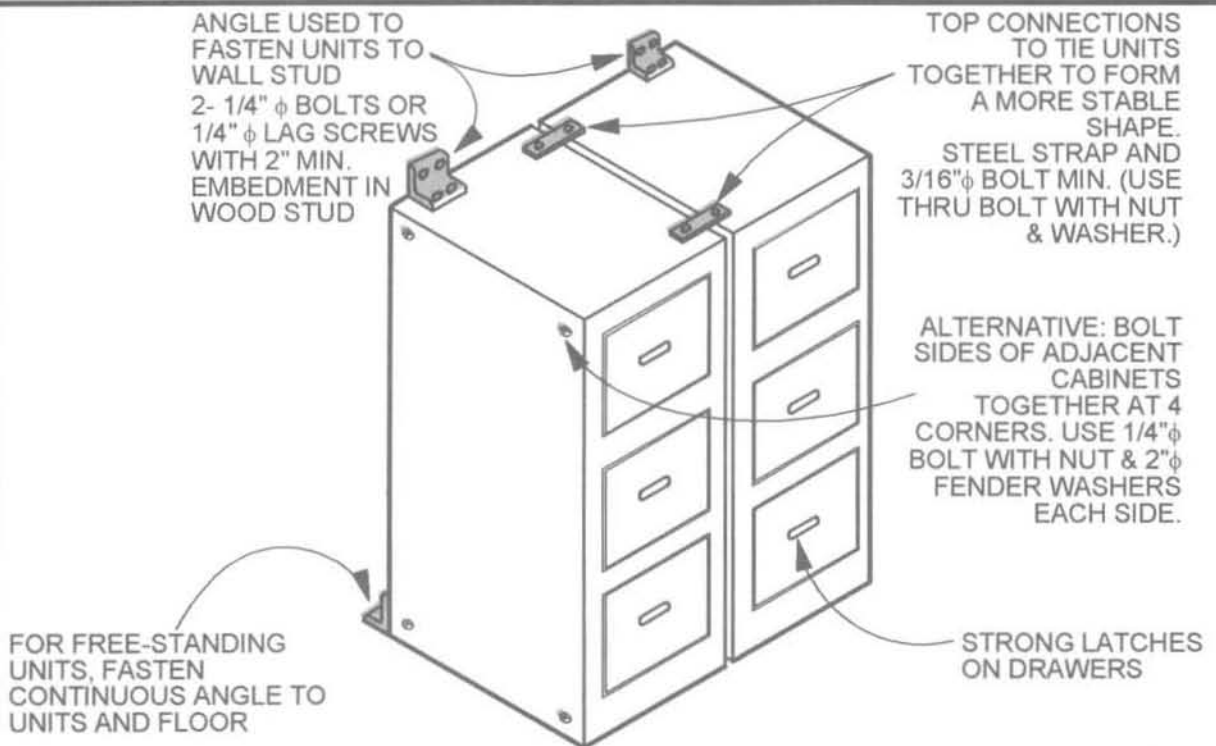
C12c

TALL FILE CABINETS

DO-IT-YOURSELF



Earthquake Damage: 1994, Northridge, California
 Photo Credit: Wiss, Janney, Elstner Associates, Inc.



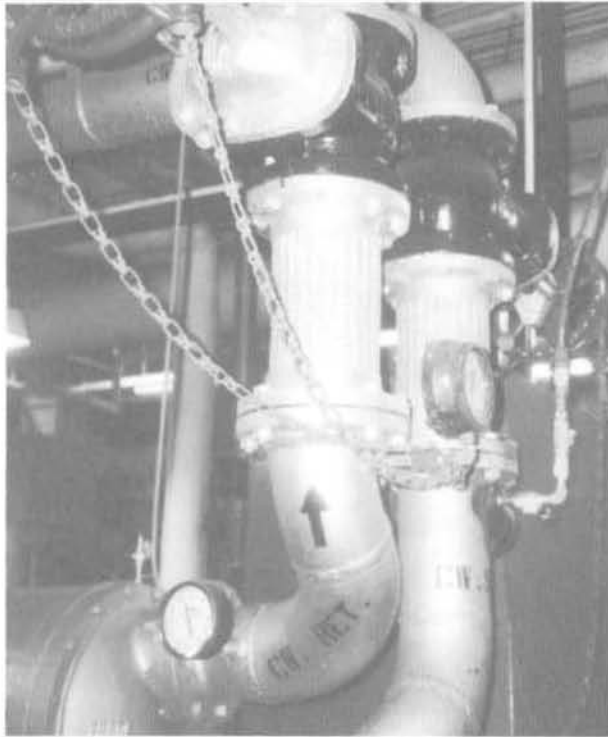
Upgrade Detail C13

Approximate Cost: \$20 per lineal foot

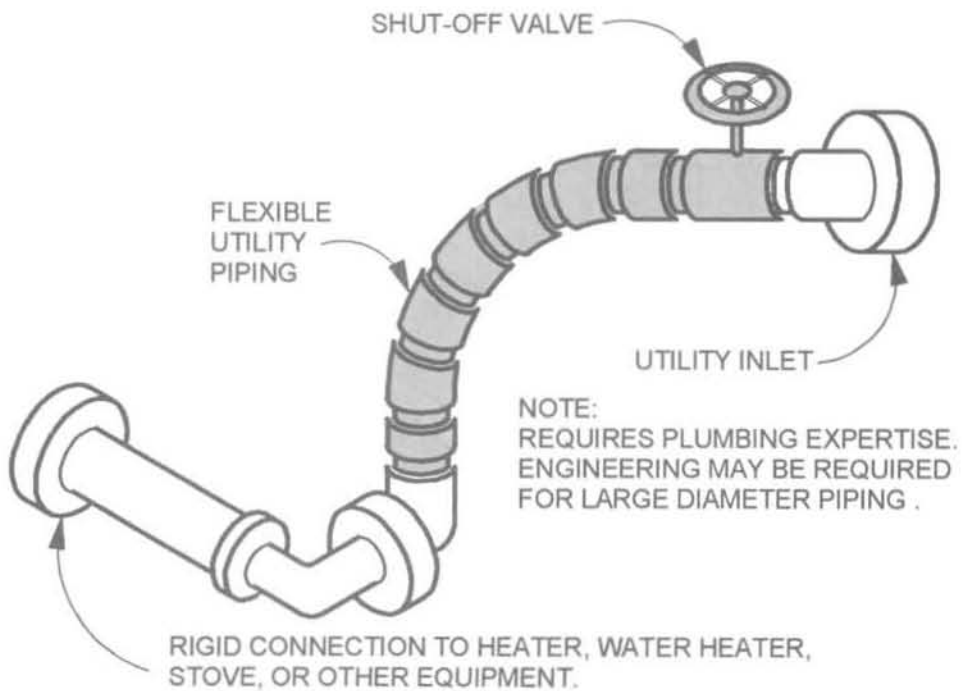
C13

FLEXIBLE CONNECTION FOR GAS OR FUEL LINES

DO-IT-YOURSELF



Flexible connection at pipe attachment to tank
Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Upgrade Detail C18

Approximate Cost: \$100 for residential appliance; varies for larger items

C18

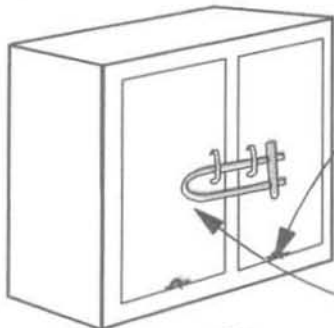
DRAWER AND CABINET LATCHES

DO-IT-YOURSELF



Unrestrained drawers and cabinets

Photo Credit: Wiss, Janney, Elstner Associates, Inc.



INSTALL STRONG MECHANICAL CABINET CATCHES (SAFETY HASP, SLIDE BOLT, TOUCH-DOOR CABINET CATCH, CLIP-ROLLER OR SNAP-ACTION CABINET CATCH, ETC.)

ALTERNATIVE: PROVIDE BABY-PROOF CLOSURE



INSTALL MECHANICAL DRAWER CLOSURE (BABY-PROOF LATCHES, DRAWER LOCKS, OR OTHER SPECIALTY LATCHES)

Upgrade Detail C19

Approximate Cost: \$50 per cabinet

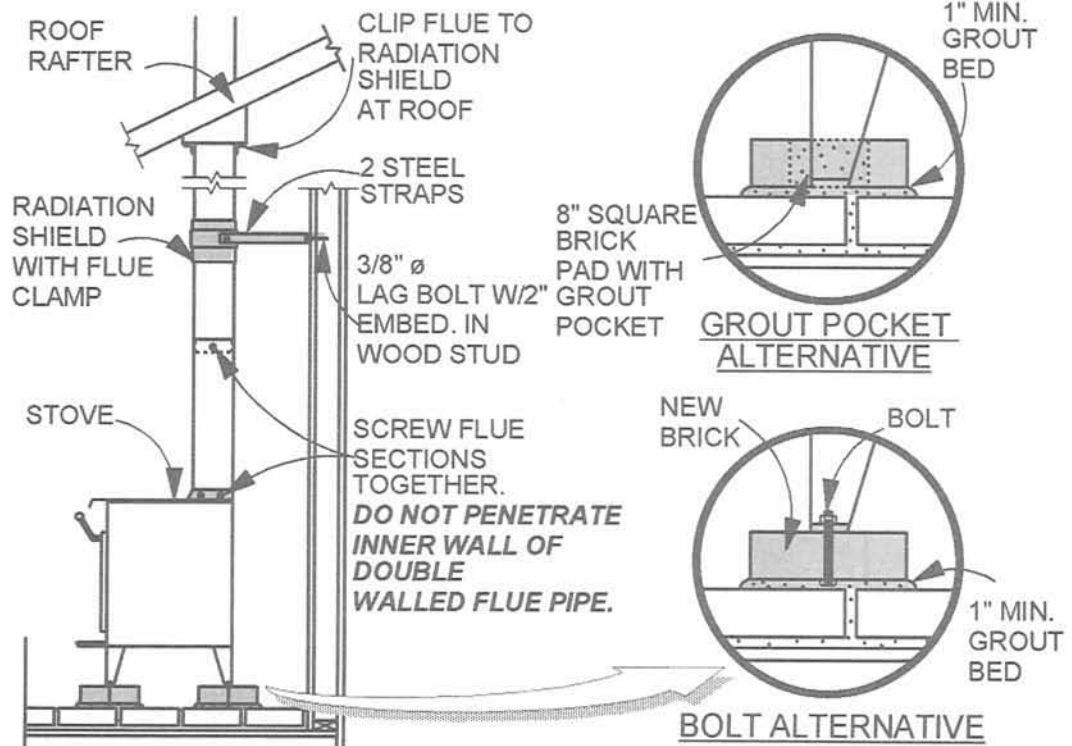
C19

FREESTANDING WOOD STOVE

DO-IT-YOURSELF



Unrestrained wood burning stove
 Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Upgrade Detail C20
 Approximate Cost: \$500

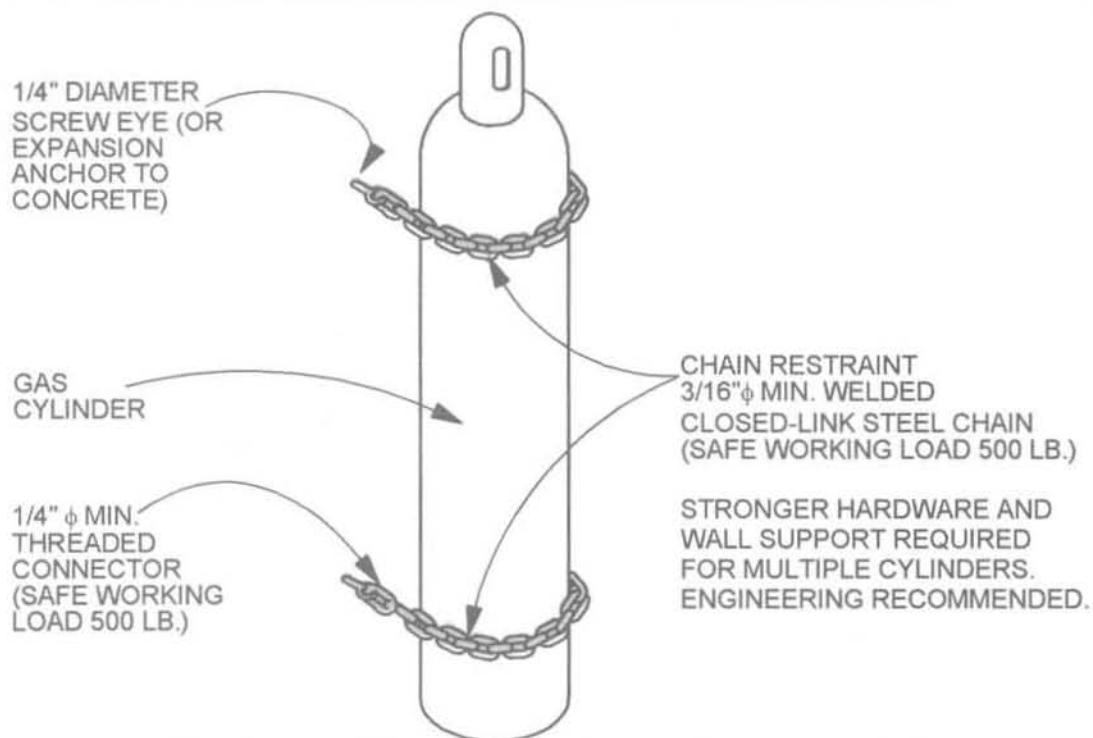
C20

COMPRESSED-GAS CYLINDERS

DO-IT-YOURSELF



Earthquake Damage: 1971, San Fernando, California
Photo Credit: Scientific Service, Inc.



Upgrade Detail C21

Approximate Cost: \$30 per lineal foot; \$50 for single units

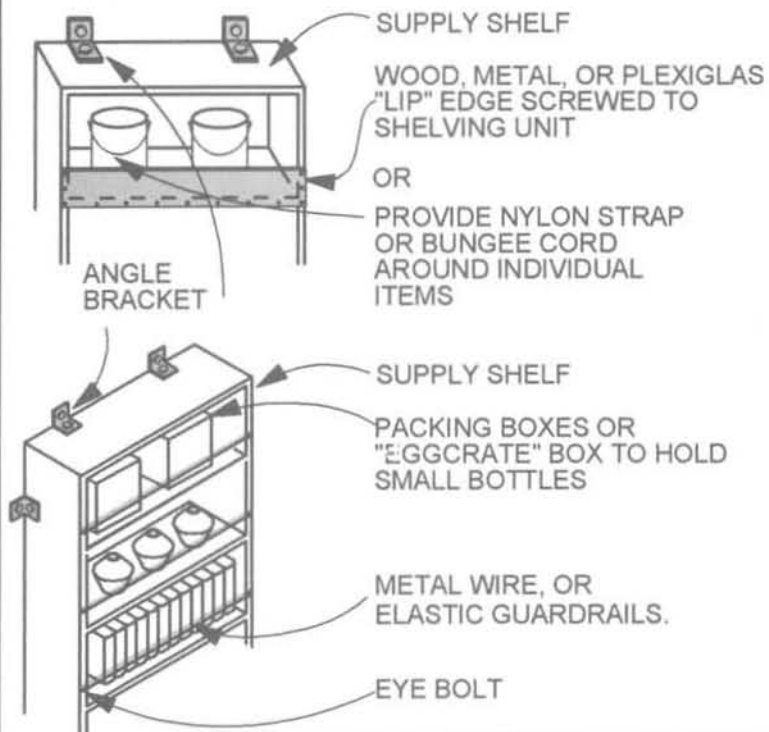
C21

CONTAINERS OF HAZARDOUS MATERIALS

ENGINEERING REQUIRED



Spilled pharmaceutical and medical supplies.
 Earthquake Damage: 1994, Northridge, California
 Photo Credit: Robert Reitherman



- ANCHOR STORAGE SHELVES
- PROVIDE SAFETY LIP OR SHELF EDGE
- PROVIDE MECHANICAL LATCHES FOR CABINETS AND DRAWERS
- STORE SMALL OR BREAKABLE ITEMS IN ORIGINAL PACKING OR EGGCRATE BOXES, NOT LOOSE ON SHELF OR IN DRAWER
- STORE INCOMPATIBLE MATERIALS AT A SAFE DISTANCE TO AVOID MIXING IF THE CONTAINERS FALL
- ORDER HAZARDOUS LAB CHEMICALS IN UNBREAKABLE PLASTIC BOTTLES OR IN GLASS BOTTLES WITH AN EXTERIOR PLASTIC SAFETY COATING

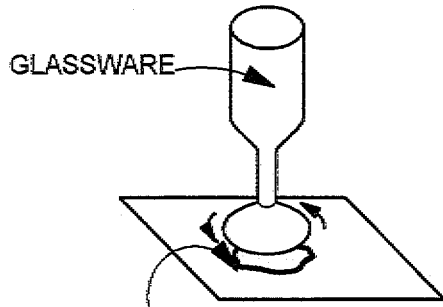
Schematic Upgrade Detail C22

Approximate Cost: Varies

C22

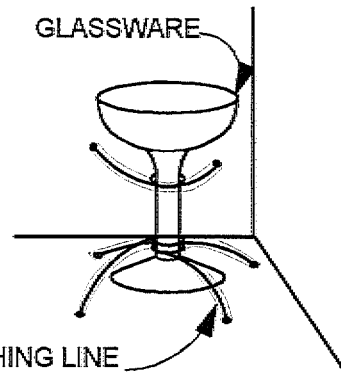
FRAGILE ARTWORK

DO-IT-YOURSELF



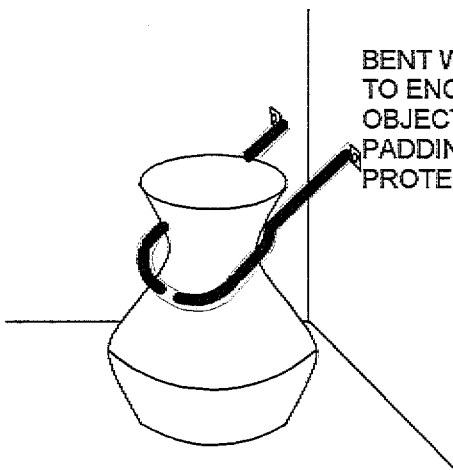
GLASSWARE

BEE'S WAX OR DENTAL WAX CAN RESTRAIN SMALL LIGHTWEIGHT OBJECTS. (REMOVE WITH CARE - WAX MAY LEAVE SMALL STAIN ON BASE OF OBJECT).
ALTERNATIVE: USE PATCHES OF HOOK AND LOOP MATERIAL. [CAUTION - GLUE MAY AFFECT FINISH ON BASE OF OBJECT].

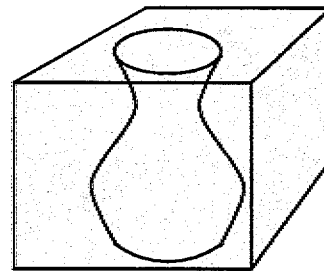


GLASSWARE

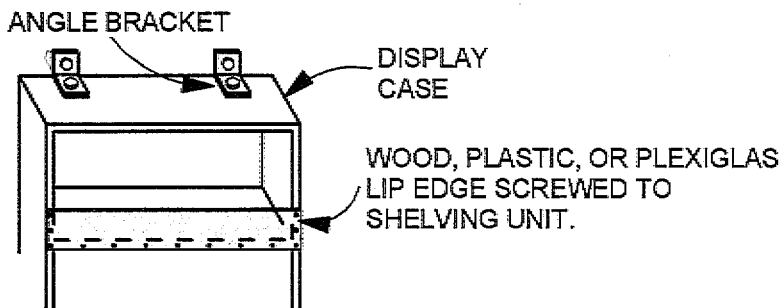
MONO-FILAMENT FISHING LINE USED FOR GUY WIRES



BENT WIRE ARMS TO ENCIRCLE THE OBJECT. PROVIDE PADDING TO PROTECT ARTWORK.



PLACE OBJECT IN CLOSE-FITTING GLASS OR PLEXIGLASS DISPLAY CASE. PEDESTAL MUST BE ANCHORED.



ANGLE BRACKET

DISPLAY CASE

WOOD, PLASTIC, OR PLEXIGLAS LIP EDGE SCREWED TO SHELVING UNIT.

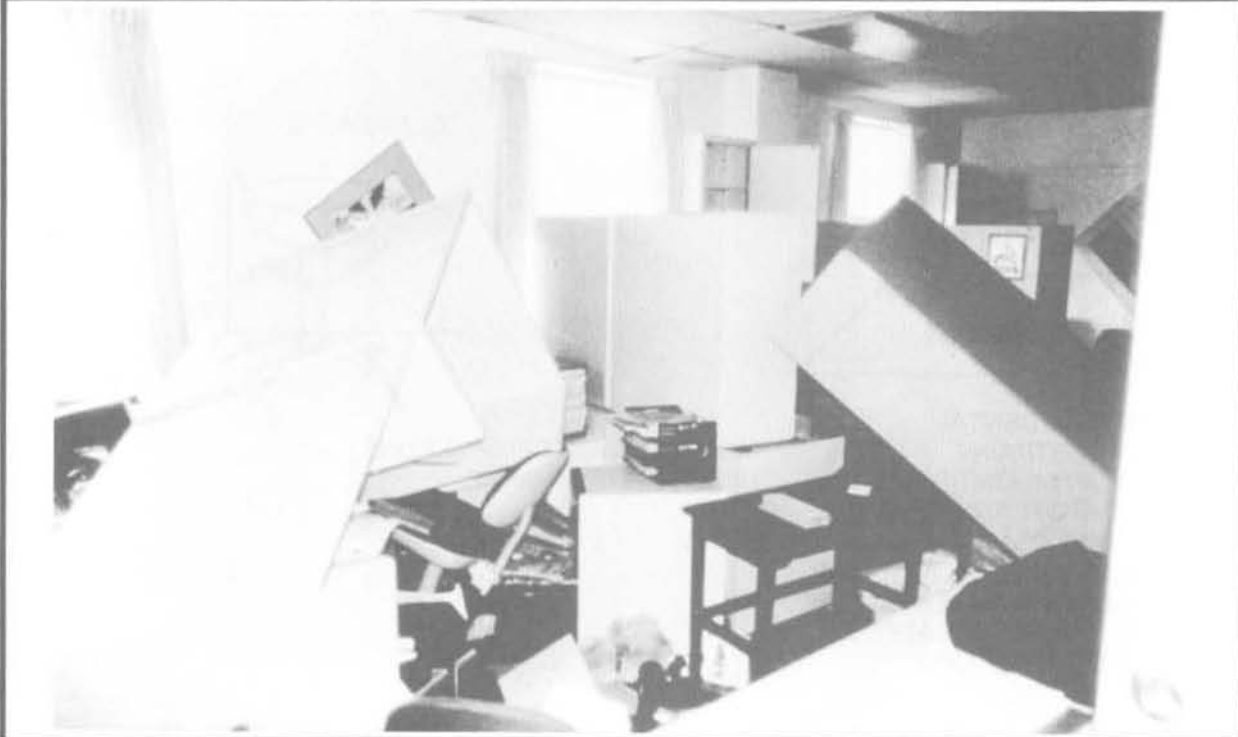
Upgrade Detail C26

Approximate Cost: Varies

C26

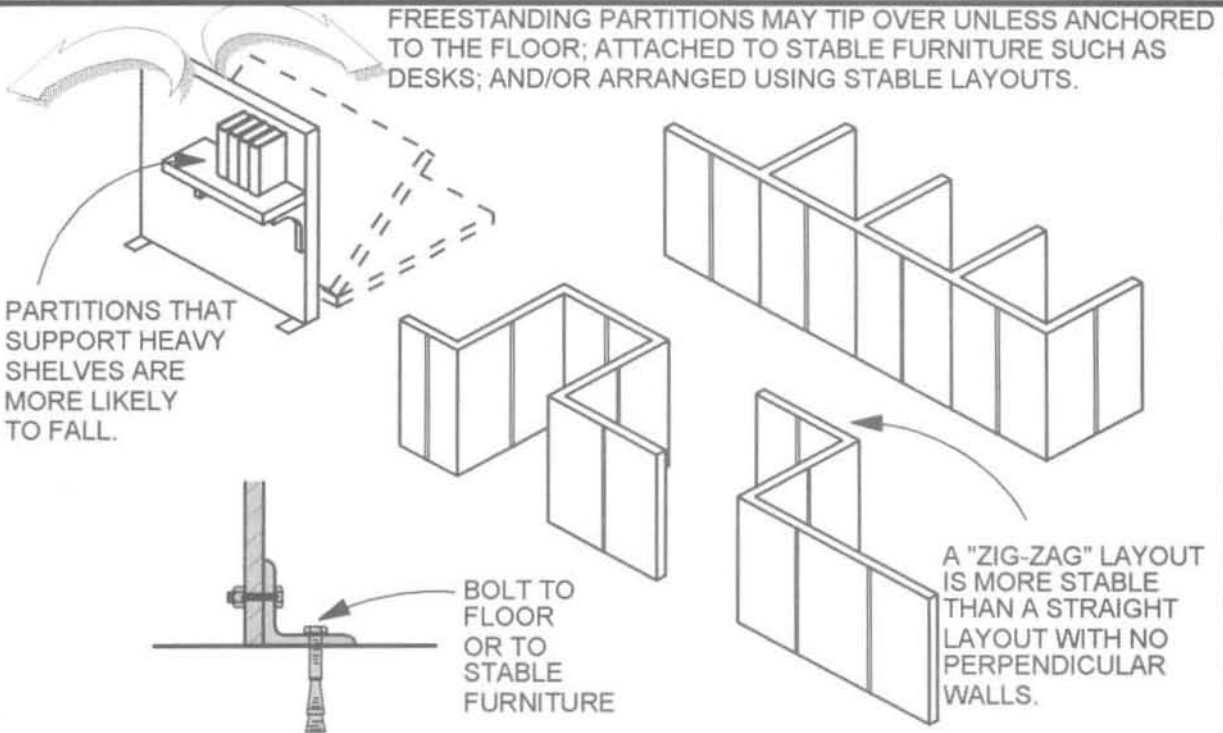
FREESTANDING HALF-HEIGHT PARTITIONS

DO-IT-YOURSELF



Partition damage at Veterans Administration Medical Center in Sepulveda.
 Earthquake Damage: 1994, Northridge, California
 Photo Credit: Earthquake Engineering Research Institute, James O. Malley

FREESTANDING PARTITIONS MAY TIP OVER UNLESS ANCHORED TO THE FLOOR; ATTACHED TO STABLE FURNITURE SUCH AS DESKS; AND/OR ARRANGED USING STABLE LAYOUTS.



Upgrade Detail C27

Approximate Cost: \$10 per lineal foot

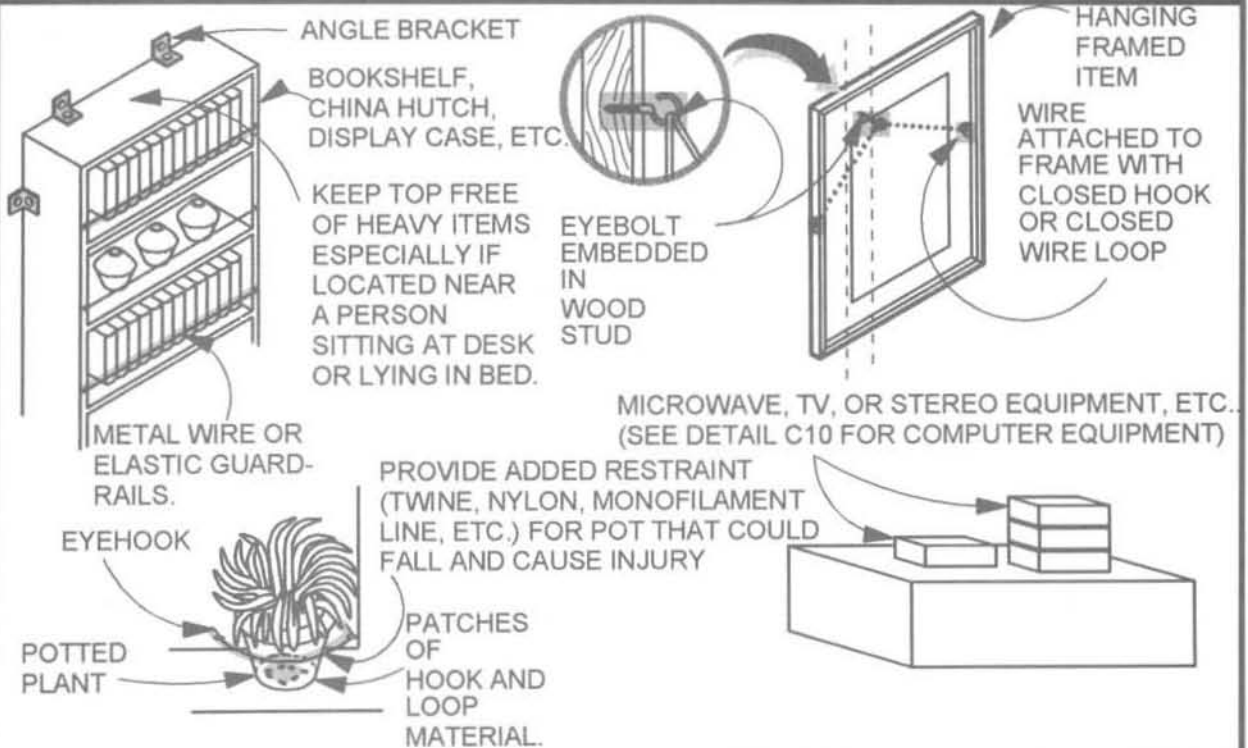
C27

MISCELLANEOUS FURNITURE

DO-IT-YOURSELF



Earthquake Damage: 1994, Northridge, California
 Photo Credit: Wiss, Janney, Elstner Associates, Inc.



Upgrade Detail C28

Approximate Cost: Varies, approximately \$50 per item

C28

INSTALLATION NOTES

For those details where the self-help 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 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 1¼-inch-diameter hole you drill for the bolt will essentially eliminate the 1½-inch-wide stud. The following discussion provides general guidelines on hardware selection and installation procedures for the *Do-It-Yourself* details shown in this chapter.

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 solid 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. Positive connections do not rely on the frictional resistance produced by the effects of gravity. Neither the frictional resistance between the base of an object and the floor or other support nor such mechanical friction connections as C-clamps or thumbscrew clamps can be considered a positive connection.

The most common nonstructural connection details are for wall attachments, floor or ceiling attachments, countertop attachments for smaller items, and attachments between adjacent items to create a more stable configuration.

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 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 the gypsum board or 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. Most likely, a toggle bolt or nail will simply pull out during an earthquake, leaving a hole in the wall.

Typical wood and metal stud walls are constructed with vertical studs located at either 16 inches or 24 inches on centers. Many interior partition walls 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 see 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 the stud locations. A mounting strip may be constructed of a structural-grade wood 2x4 or 2x6 or a continuous steel channel or angle.

Recommended Hardware:

- Attach steel angle directly to wood studs using a minimum ¼-inch-diameter by 3-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 to sheet-metal shelving or cabinets may be made by using a minimum ¼-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 on centers. For attachments to the molding strip, do not screw or bolt anything within 1 inch of each edge of a 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. These items may be useful for tethering small office equipment.

Not Recommended:

- Toggle bolts mounted in gypsum board or plaster are not recommended for any of the

details presented here.

- Nails have little capacity in tension or withdrawal, i.e., when you pull directly on the head of the nail. Thus, nails are not recommended for any of these details either.

ANCHORAGE TO CONCRETE OR MASONRY WALLS

Connections to existing concrete or grouted masonry walls should be made with concrete anchor bolts. 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 install the anchors in accordance with the manufacturer's recommendations. Holes into concrete or masonry walls should be drilled with care 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 rebar*.

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. In order to develop the full capacity of a concrete anchor, the spacing should be at least 12 diameters, with a minimum edge distance of 6 diameters. The minimum embedment length is typically 8 bolt diameters. The bolt will have a greatly reduced capacity if it is too near an edge or too close to an adjacent bolt or if it has insufficient embedment into the concrete.

The most common anchor bolts are wedge anchors, where part of the shank expands to press against the sides of the hole as the nut is tightened. Other types of anchors include sleeve anchors and epoxy 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 where 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. Epoxy 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; otherwise the bolt will never reach the manufacturer's rated capacity. Quality control is critical for these bolts, and they are not recommended unless the installation is performed by experienced personnel.

Recommended Hardware and Procedures:

- Do not cut reinforcing steel or electrical conduit in concrete or masonry walls. Locate the steel or conduit with a magnetic device prior to drilling.
- 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 the most common and easiest to install. Typical sizes for wall anchorage of nonstructural items might be a 3/8-inch-diameter A307 bolt with 3-inch minimum embedment (allowable seismic loads 1450 pounds shear and 650 pounds tension) or a 1/2-inch-diameter A307 bolt with 4-inch minimum embedment, 5-inch edge distance, and 6-inch spacing (allowable loads 2000 pounds shear and 1850 pounds tension) [12].
- To check the installation procedures and quality of workmanship, test a sample of installed bolts with a proof load.
- 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. 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, i.e. locations 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 than in concrete walls. Unreinforced masonry walls, particularly cantilever partition walls, may not have adequate strength to anchor heavy nonstructural items. For light loads, up to 100 pounds or so, masonry toggle bolts can be used in ungrouted cells.

- For unreinforced brick 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.

Not Recommended:

- Adhesive or epoxy anchors are not recommended unless installed by experienced personnel. Proper quality control is critical for this type of anchor bolt.
- 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.

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 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.

Recommended Hardware and Procedures:

- Locate the floor or ceiling joists prior to beginning work. If wood beams or joists are not situated within a convenient distance, 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.

Not Recommended:

- Do not anchor 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.

Recommended Hardware:

- 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, this type of hardware might 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 a structural floor slab. For heavy loads or concrete slabs less than 4-inches thick, it may be preferable to use through-bolts, i.e., machine bolts that go through the concrete slab and are fastened with nuts and steel plate washers on the underside of the slab.

Recommended Hardware and Procedures:

- Refer to discussion of expansion anchors under concrete wall anchorage details.
- *Do not cut reinforcing steel in concrete slabs or beams.* Locate the reinforcing steel and electrical conduit with a magnetic device 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 drill a small pilot hole first. While short expansion bolts may be adequate to prevent sliding of low 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.

- Typical hardware for floor anchorage of lighter nonstructural items might be with a ½-inch-diameter A307 bolt with 4-inch minimum embedment and 6-inch spacing (allowable loads 1500 pounds shear and 1400 pounds tension). For heavy items, larger bolts are needed. For example, a 1-inch-diameter A307 bolt with 7-inch minimum embedment and 12-inch spacing (allowable loads 3750 pounds shear and 2850 pounds tension) [12]. Engineering assistance is recommended for very heavy items.

- If equipment is resting on leveling bolts or must be level for proper operation, vertically slotted connections may be needed to allow for adjustment.

Not Recommended:

- A ¼-inch-diameter expansion anchor has an allowable capacity for seismic loading of 650 pounds shear and 250 pounds tension [12]. (Note that the capacities cited above are for pure shear or pure tension. Combinations of shear and tension must be considered simultaneously, resulting in reduced capacity. For example, if you pull on the bolt with 200 pounds of tension, it will have the capacity to resist only approximately 300 pounds of shear.) These bolts are generally too small for most equipment or for fully loaded file cabinets, unless a number of bolts are used in combination.

Typical Shelf or Countertop

Attachment Details If important or essential contents are to be secured, 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 or various types of security devices designed to prevent theft.

Recommended Hardware and Procedures:

- 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 their wall or shelf brackets. Wood shelves that rest on wall-mounted brackets may be secured to the brackets with ½-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 may be purchased at most hardware and fabric stores and can readily be cut into patches or strips.

- Desktop computer equipment usually consists of several independent components. If items are stacked, make sure 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 with nylon strap and then 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 off. In this case, individual items need not be anchored.

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 detailing. Some file cabinets come with predrilled holes for floor anchorage and strong latches on the drawers. Battery racks, industrial storage racks, and computer access floors can

be ordered that meet seismic requirements specified in the building code. It is always useful to inquire about the availability of seismic details when purchasing new equipment.

Patching, Painting, and Corrosion Protection Most of the details shown here assume that the nonstructural item 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, appropriate sealants or localized repair will be needed to avoid roof leakage. If expansion anchors or other steel hardware will be exposed to moist conditions or weathering, 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 to 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 chain or hook needs to be refastened.

Safety Precautions As with any type of

construction work, there are safety precautions that must be followed while installing nonstructural attachment details. Employers and tradesmen must comply with numerous local, state, and federal safety regulations and follow guidelines established for specific trades or industries. The following is not comprehensive but is a brief list of safety precautions that merit emphasis in connection with the nonstructural attachment details shown here.

Recommended Procedures:

- The people doing the installation work 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. It may be necessary to disconnect the power before starting work. Transformers are especially hazardous. Transformers, switchgear, and other electrical cabinets should be handled or opened only by qualified personnel.
- The installation of most nonstructural restraint details involves the use of power tools. Personnel should use safety goggles and other protection recommended by tool manufacturers, and all workplace safety standards should be followed.
- Many heavy pieces of furniture or equipment may have to be moved temporarily in order to install seismic restraint details. Unless proper lifting techniques are utilized, back injuries or other injuries may result [19].

5 DEVELOPING EARTHQUAKE PROTECTION PROGRAMS

The preceding sections of this guide have provided information. The question is how to apply this information effectively. How should protective techniques be implemented? The answer depends on the nature of the physical conditions in the facility and the characteristics of the organization. The following suggestions can be considered by the reader in the context of his or her own situation.

SELF-HELP VS. USE OF CONSULTANTS

Self-help implementation of a program can be adequate where the potential hazard is small or the in-house familiarity with engineering or construction is greater than average. For larger facilities, engineering or architectural engineering consultants may be employed to survey the seismic vulnerability and design specific upgrade details. In some cases, after an initial survey is conducted and a report prepared by an expert, the remainder of the implementation can be handled in-house without further assistance.

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 has been 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 has been 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.

Types of Consultants Various types of consultants are available, each of which may have a different type of expertise. The choice of a particular consultant will depend on the nature and complexity of a particular facility. Many of the consultant designations below correspond both to a specialized field of study or practice and to a category of state license. Not all practicing design professionals are licensed. If building permits are required for the anticipated work, it may be important to ascertain that the consultant has an appropriate license for the state where the facility is located.

- **Earthquake Engineer** This is a commonly used term, but no state has such a license category, and earthquake engineers are not listed in the Yellow Pages. An earthquake engineer is a structural or civil engineer (see below) experienced in earthquake design and analysis.

- **Structural Engineer** A structural engineer is a civil engineer (see below) who has gone on to obtain an additional license based on work experience and examinations specifically on topics relating to structural engineering. Not all states issue a separate license for structural engineers. California is an example of a state where schools, hospitals, and some high-rise structures must be designed by licensed structural engineers. Structural engineers are more likely to be familiar with building construction than many civil engineers, who

specialize in other areas. Some structural engineers have had extensive experience in designing nonstructural anchorages and protective measures, often involving hospitals because of their stricter building code requirements. Structural engineers are listed in the Yellow Pages under "Engineers; structural."

- **Civil Engineer** A civil engineer may be licensed by the state. Some civil engineers specialize in structural engineering. Other civil engineers specialize in fields such as airport and harbor design, utility systems, or soils engineering, which do not involve the structural design and analysis of buildings.

- **Mechanical Engineer** A mechanical engineer may have a state license based on education, experience, and examinations. Some mechanical engineers practice aspects of their discipline completely unrelated to buildings (such as the design of power plants, automotive engines, or machinery). Mechanical engineers who specialize in the design of HVAC systems, or "mechanical" systems, for buildings are often familiar with these types of nonstructural items, but they typically rely on structural engineering consultants for the design of earthquake bracing for mechanical equipment.

- **Architect** An architect may also have a state license based on education, work experience, and examinations. Since architects must be knowledgeable about many aspects of building design and construction, generally only a small part of their education, work experience, and examinations is devoted to structural engineering. Even architects licensed in California generally do not perform seismic computations or make structural detailing decisions but instead rely on in-house or consultant structural engineers. For new construction, the engineer usually works as a subconsultant to the architect, rather than directly for the owner. Architects, not

engineers, are generally responsible for the design of windows, partitions, ceilings, and many other nonstructural items. It is important, therefore, for the architect to be made aware of the client's concerns regarding protection from nonstructural earthquake damage, since the architect will design and provide specifications for most of the nonstructural components.

- **Interior Designer** An interior designer or space planner would not be expected to have any particular background in earthquake engineering, though in some cases this designer will be intimately involved with the specification of file cabinets, furniture, finish materials, and so on. Designs by interior designers can be reviewed by a structural engineer to ensure appropriate detailing for earthquake hazards.

- **Specialty Contractor** Contractors in various specialties, as well as general contractors, may be licensed by the state. Contractors can implement upgrade schemes designed by others or may be able to help devise the upgrade technique if no formal engineering is required. For example, contractors experienced in the installation of new suspended ceilings in accordance with current earthquake code provisions may be capable of installing seismic upgrade details for older, unbraced ceilings. Individuals skilled in the building trades can bring special talents to bear if they are made aware of seismic problems and solutions. At one large research and development facility, for example, all the light fixtures have been thoroughly upgraded for earthquakes over a few years, thanks mostly to the efforts of one electrician.

IMPLEMENTATION STRATEGIES

There are a number of options to consider in implementing a program to reduce the vulnerability of nonstructural components. Some of these are discussed below.

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 properly correct nonstructural hazards that they may discover as they survey the building for other purposes or to correct 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. Note (under the heading Sustaining Protection, below) that a maintenance program can also be used for upkeep of protective measures.

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, air conditioning ducts, or other built-in features. 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. 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.

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. Increasingly, vendors are marketing items with "seismic-resistant" details such as predrilled holes for anchorage. The effective use of these

guidelines requires coordination between the purchasing and facilities functions.

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.

New Construction For new construction, it is possible to anchor, brace, or restrain all the critical nonstructural items at the same time according to a unified design. As noted earlier, it is more efficient and less costly to install anchorage details during construction than to upgrade existing buildings.

For large organizations, the development and adoption of nonstructural guidelines to be used by designers or contractors, as discussed in Chapter 7, could be considered. For small companies or organizations, a letter or conversation with the architect could be used to bring up the matter of designing earthquake resistance into nonstructural items. Providing the architect or other designer with a copy of

this guide might be advisable.

Sustaining Protection Some nonstructural protection devices, such as anchorage hardware for exterior objects, may deteriorate with time if not protected from rust. Over time, interior fastenings and restraints may be removed as people move equipment or other items and fail to reinstall the protection devices. Chains used to restrain gas cylinders or elastic shock cords on bookshelves are effective only when they are in use. It is sometimes more problematic to maintain the human aspects than hardware aspects of nonstructural protection. 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, office equipment, chemicals, and so on, are properly stored.

Maintenance personnel may be the people most likely to periodically survey the building to ascertain whether earthquake protection measures are still effectively protecting mechanical equipment such as emergency generators, water heaters, special equipment, and so on. Supervisors can be made responsible for an annual review of their work spaces. If there is a separate facilities or physical plant office in an organization, that 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 hazard mitigation 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 campuswide 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 [13, 14].

EVALUATION

How good is a nonstructural earthquake protection program? Is it worth the cost? What is the best way to evaluate its strong points and deficiencies?

There are two basic 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 response plan all been implemented? How well have the measures been implemented? Have the upgrade details been correctly installed? Is the training taken seriously?

The second basic evaluation technique is to ask, If the earthquake happened today, how much better off would we be than if we had never developed a nonstructural protection program? This can be done in a rough cost-benefit format by estimating the total cost of the program, including estimated staff time. A fairly crude method, described below, can be used to estimate the potential benefit due to property loss savings.

The risk ratings in Appendix C are presented in terms of a low, moderate, or high potential for property loss. If we consider only direct property loss to the item itself, then these ratings might be approximately equivalent to a loss equal to a percentage of the replacement cost of each item, as follows:

Low	0%-20% (10% average)
Moderate	20%-50% (35% average)
High	50%-100% (75% average)

For areas that expect only light- or moderate-intensity shaking in an earthquake, it can be assumed that direct property losses following the implementation of the upgrade will be negligible. In areas that expect severe shaking, it can be assumed that property losses for upgraded items will be low, with an average loss of 10%, as indicated above. The benefit, then, is the difference between the expected losses without the program and the expected losses with the program in place.

When using this method, it is important to

remember that it covers only direct losses to the item; i.e., the maximum property loss is limited to the replacement cost for each specific item. As stated earlier, property losses due to broken water or fire sprinkler pipes might be well in excess of the cost to repair or replace the piping.

In many cases, the value of not experiencing outages and not sustaining injuries will be very significant, and property loss savings cannot be the sole measure of the benefit. Cost-benefit computations such as those described above should be used only as a guide, not as automatic decision-making devices, since the upgrade costs, damage costs, and potential savings can be estimated only very approximately.

6 EMERGENCY PLANNING GUIDELINES

What types of nonstructural damage should be addressed in an earthquake response plan? How should training and exercises be conducted to take the prospect of nonstructural damage into account?

IMPLICATIONS OF NONSTRUCTURAL DAMAGE FOR EMERGENCY PLANNING

The first step is to develop a valid picture of the probable postearthquake state of the facility. The nonstructural survey and vulnerability analysis will indicate what types of items are present and provide an approximate assessment of their earthquake resistance. The better this survey and analysis are, the more likely it is that the envisaged postearthquake conditions will actually materialize. Less expert assessments will be more likely to either overestimate or underestimate damage. Even with the most thorough of analyses, however, there is still great uncertainty in the process of estimating earthquake performance.

One approach to this uncertainty is to assume the worst. This conservative approach is not warranted and is prohibitively expensive for purposes of allocating construction money to upgrade items, but in the initial stage of the emergency response planning process, it may be inexpensive to at least briefly consider the impact of severe damage to each nonstructural item on the list. What would be the emergency planning implications if each particular nonstructural item were to be severely damaged?

For example, what would be the consequences if an emergency power generator were to be

damaged or if its support services were to be rendered inoperative. This will provide the worst-case scenario.

A particular generator may be anchored to the concrete slab with adequate bolts; it may have an independent fuel supply; the batteries may be restrained; and the cooling water system, if any, may be braced or anchored. The owner or operator may test the generator monthly and may be confident that it will work after an earthquake. However, out of 100 very well protected generators such as the one described above, at least a few would probably fail to run after a large earthquake. The probable outcome is that the generator will work properly, but there is still an outside chance that it won't. In the 1994 Northridge earthquake, a number of facilities, including more than one major hospital that was designed and constructed under the State of California's Hospital Seismic Safety Act, had temporary emergency power outages.

If there are inexpensive backup measures that can be included in the plan or in the training program or exercises, then this may be a form of inexpensive insurance. Such inexpensive measures might include occasionally including in an earthquake scenario the complete absence of electricity (by switching off all electricity except where it would be dangerous to occupants or deleterious to equipment); testing battery-powered exit lights; buying a supply of flashlights and batteries; maintaining a list of local suppliers of rental generators; and exploring whether recreational vehicle generators could supply power to run some essential functions and, if so, including the idea as a backup tactic in the earthquake plan (employees could be quickly queried to see

whether some RVs might be available for use by the company or organization).

After the worst-case outcome has been considered with regard to each nonstructural item, it will then be necessary to consider the probable-case scenario. Because emergency planning resources are limited, extensive effort cannot be devoted to every conceivable problem. Once a facility survey has been completed, the estimated vulnerabilities indicated on the nonstructural inventory form can be used as a guide.

Human Response As protection against almost all types of nonstructural damage, the common advice to take cover beneath a desk or table is generally valid. While the photos of earthquake damage presented in this guide may appear frightening, a careful look will show that if an occupant had been in the vicinity of the damage but kneeling under a desk or table, serious injury would have been unlikely. Taking refuge in a doorway is not recommended, since lintel beams over doorways provide little protection from falling debris, which can occur in and near doorways, particularly in exterior walls of buildings. Taking refuge under a desk or table is a simple measure to undertake, but this advice requires some training and exercises if the technique is to work. Some people may have an immediate impulse to try to run outdoors if the shaking is severe or lasts for more than a few seconds. Many adults will feel embarrassed about crawling under a table. The quarterly earthquake drills for school students, now required by law in both public and private schools in California, appear to be very successful in getting students to take cover quickly and follow instructions during earthquakes. Similar drills, if only annual, are necessary if adult office workers, salespeople, or government employees are to be expected to respond quickly and protect themselves when the need arises.

In settings where there are no desks or tables, occupants should get down beside the next best thing. In an auditorium or public assembly setting, kneeling down between the seats is the best advice. It may be possible to move away from obvious hazards, such as items on tall industrial storage racks, and to put oneself in a safer position at the other side of a room, but in a very severe earthquake it may be impossible to stand up or walk.

EARTHQUAKE PLANS

The following points relating to nonstructural damage should be addressed in an earthquake plan.

Pre-Earthquake Tasks The document can describe the identification and upgrading of nonstructural items and the procedures for routinely checking to see that protective measures are still effective. If emergency training for employees is anticipated, then that should be written into the plan also.

Earthquake Emergency Response Tasks What tasks must be accomplished immediately after an earthquake? The tasks can be made contingent upon the severity of the earthquake and the amount of damage that is immediately seen to have occurred. If the structure of the building is obviously damaged--if there are sizable cracks in concrete walls, floors, or columns; if the building is leaning out of plumb; or if any portion of it has pulled apart or collapsed--then evacuation of the building will obviously be in order. This is not the time for a thorough survey of nonstructural damage. If there is no apparent structural damage, a survey of the mechanical equipment, elevators, and so on, could be listed as the appropriate response. Hazardous material storage areas should be quickly checked for spills.

Responsibilities For each task, someone must be assigned responsibility. If no

responsibility is assigned in the plan, it is likely that no one will carry out the task. Because the earthquake may happen at any time and will have roughly a 75% chance of happening outside normal work hours, backup positions for responsibilities should be listed. To minimize the obsolescence of the plan, it is preferable to list positions rather than individuals' names, but in any event, someone must have responsibility for the plan itself and for keeping it current. Figure 9 provides a blank form for use in collecting information that may be helpful in formulating an earthquake plan.

TRAINING

How should you establish an earthquake training program? Ironically, the best advice may be to avoid establishing a separate earthquake training program and, instead, to integrate earthquake training tasks into other ongoing training programs. Because of the infrequency of earthquakes, even the best earthquake training program may slowly lose its effectiveness or completely die out. In addition, an earthquake training program that requires its own separate funding will probably have a relatively low priority in the overall ranking of training concerns. But it may be possible to find ways of slightly expanding existing training programs—at small cost—to deal with the problems unique to earthquakes.

Fire safety is typically the most common of hazards on which hazard training is based. In the process of instructing employees about extinguishers, alarms, notification procedures, safe storage methods, exiting, and other fire-related topics, it may be possible to incorporate an earthquake safety training unit at the same time. It is essential to have procedures for controlling leaks from fire sprinklers and other pipe lines. Security staffs should be trained in the process of responding to earthquakes at the same time they are familiarized with other emergency plans for theft, fire, or other

hazards. Maintenance personnel must be trained in certain upkeep and operational aspects of the HVAC system, elevators, plumbing, lights, sprinkler system, and so on, and many of these items are precisely the components of a building that will require attention in an earthquake hazard reduction or response plan. Workplace safety training sessions are ideal forums for dealing with earthquake safety.

To minimize the number of earthquake training requirements, consider the unique aspects of earthquake problems that are not already covered by preparations for other hazards. For example, the fact that the phones may not work is one of the key ways in which earthquake response differs from that for fire or other hazards. If an emergency plan addresses building evacuation, it should identify gathering points that at a safe distance from falling hazards adjacent to other buildings. Individual emergency plans may contemplate a telephone outage, an electrical outage, the need to evacuate the building, traffic disruption, injury, pipe leakage, or window breakage, but it is unlikely that the response plan for any other hazard will consider that all these events may occur simultaneously. At a minimum, having an earthquake backup plan for reporting injuries or fires in the event that the telephones are inoperable is one essential feature to include.

The nearest fire station should be located and indicated on a street map so that aid can be quickly summoned in person if the phones are out. Even if emergency medical services are not provided by the fire department, the radio equipment available at fire stations will allow for communication with other agencies.

In addition to adding earthquake training to other ongoing training programs, it may be reasonable to occasionally devote brief training sessions exclusively to earthquake preparedness. An annual training schedule can easily be coordinated with an annual exercise schedule, as

discussed below.

EXERCISES

The vulnerability estimates summarized on the nonstructural inventory form can be used to compile a list of nonstructural damage situations for inclusion in an earthquake scenario to be used for an exercise.

The list of nonstructural damage events may grow lengthy and may include contingencies that would be very costly and disruptive to simulate. For example, full-scale evacuations of high-rise buildings without the use of the elevators are rarely conducted; rather, one or two floors are evacuated periodically. Turning the electricity off will accurately simulate an earthquake-caused power outage and the attendant problems of visibility in windowless office areas, lack of air conditioning, and so on, but this may be too disruptive, or in some cases unsafe, to do throughout an entire office building. In a large company or government office, one department, one wing, or one work area of the building could be included in a more realistic simulation of effects while employees in the remainder of the facility are allowed to function normally or simply participate in a brief "take cover" exercise.

Employees with specialized earthquake response tasks--such as the maintenance personnel who check for water or gas leaks, supervisors who are responsible for checking on the well-being of employees in their areas, and safety or security officers responsible for communications

within the building or with outside emergency services--should have more frequent training and exercises. A brief annual exercise, such as having people take cover beneath desks and reminding them not to use elevators after earthquakes, is probably adequate for most employees, whereas more frequent brief drills may be warranted for employees with specialized tasks. An important test of preparedness for nonstructural damage is to check to see whether the responsible personnel can quickly identify which valves to shut in order to control water pipe leakage in any part of the facility.

PERSONAL EMERGENCY KITS

Each employee should be encouraged to have their own Personal Emergency Kit containing a supply of necessary medical prescriptions, a flashlight, portable battery powered radio, a water bottle or soft drink, and an energy bar or some snack food. For women who wear high heels, it may also be useful to keep a pair of flat shoes handy, since evacuation procedures often require women to remove their high heels. Other items like a jacket, mittens, hat, or thermal blanket might be useful depending upon the local climate.

MASTER EARTHQUAKE PLANNING CHECKLIST

The checklist in Figure 10 provides an overview of the tasks involved in establishing an earthquake protection program to address nonstructural components.

1. **Facility/organization name**
2. **Address**
3. **Building ownership:** _____ owned by occupant, _____ leased by occupant
4. **Type of organization:** _____ company, _____ government agency, _____ other
5. **Organizational structure (overall organizational chart)**
6. **Functional responsibilities**
Who has responsibility for the following:
 - authorization for earthquake program, budgeting
 - detailed administration of earthquake program
 - safety training courses
 - posters, brochures, memos, newsletters
 - workplace safety, compliance with safety regulations
 - fire brigades, emergency response team
 - first aid, health care
 - personnel: absenteeism, help with personal problems
 - insurance
 - risk management, risk control
 - facilities management: new construction and remodeling
 - facilities management: A & E contracts
 - facilities management: maintenance
 - facilities management: operation of mechanical/electrical systems
 - facilities management: postearthquake safety inspections
 - security
 - operational authority for evacuations, building closing
 - public relations, press statements
 - communications
 - food service
 - transportation: personnel, cargo
7. **Relationship to off-site portions of the organization**
Which communication/transportation/interaction links are most essential?
8. **Relationship to other organizations**
Which links are essential?
9. **On-site functions**
Which are essential?

Information-Gathering Checklist: Organizational Characteristics
Figure 9

- 1. Task:** Establish executive policy requiring a nonstructural evaluation, and allocate funds for initial work.
Responsibility: Chief Executive Officer, Board of Directors, Manager, Executive Committee.
- 2. Task:** Survey the facility for nonstructural vulnerabilities.
Responsibility: Outside consultant or in-house engineering, maintenance, safety, or other department.
- 3. Task:** Analyze the conditions, and estimate future earthquake effects.
Responsibility: Same as for number 2.
- 4. Task:** Develop a list of nonstructural items to be upgraded, with priorities and cost estimates. (If a Facilities Development Guideline document is to be produced, coordinate performance criteria to be used on future new construction with upgrade standards).
Responsibility: Same as for number 2; may include bids from contractors.
- 5. Task:** Decide what items will be upgraded, how the work will be done, and by whom.
Responsibility: Same as for number 1, with input from number 2.
- 6. Task:** Implement the upgrade program.
Responsibility: In-house staff or contractors, with administration of contracting or tasking by number 2 or in-house construction administration office.
- 7. Task:** Develop an earthquake response plan that contemplates nonstructural damage, with pre-emergency, during, and post-emergency earthquake tasks and responsibilities itemized.
Responsibility: Consultant or in-house safety or other department, with general policy and budgeting same as for number 1.
- 8. Task:** Train personnel in accordance with the plan developed in number 7.
Responsibility: Training, safety, or other department.
- 9. Task:** Plan and implement exercises that will test the training of number 8 and the planning of number 7.
Responsibility: Same as for number 7 or number 8.
- 10. Task:** Evaluate the performance of the above program, preferably within one year after inception or according to the deadlines set in an implementation schedule, and annually thereafter.
Responsibility: Same as for number 1 in smaller organizations, or same as for number 7.

Master Nonstructural Earthquake Protection Checklist
Figure 10

7 FACILITIES DEVELOPMENT GUIDELINES

For a large organization, the development of formalized nonstructural construction guidelines may be appropriate to control the work of architects, engineers, interior designer/space planners, contractors, and occupants. As a general rule regarding new construction or renovation, if the construction drawings do not show specific attachments and bracing and if the written specifications do not mention earthquake-protective devices, such as anchors, braces, and so on, then it is unreasonable to assume that the contractor who builds or installs the items will devise special protective measures and spend time and materials to incorporate them. Current building code provisions for nonstructural components generally apply to a limited number of items, so compliance with code requirements may not address all the potential hazards. For instance, furniture and contents weighing less than 400 pounds and mounted less than 4 feet above the floor are typically excluded from the provisions [9].

NONSTRUCTURAL CONSTRUCTION GUIDELINES

Written guidelines may be useful for a large organization attempting to prevent or limit nonstructural damage. Such guidelines should be drafted with the assistance of architectural/engineering consultants and might include the elements described below.

Scope To what purchases, remodeling, or new construction do the guidelines apply? Guidelines cannot apply to all nonstructural items, since this broad definition would mean that furnishings such as wastepaper baskets, chairs, wall clocks, curtains, and so on, would all be included. Items that might appropriately

be excluded are lightweight, nonhazardous, unessential, and inexpensive items that are not mounted overhead or above a certain height off the floor. The height criteria typically in use range from 42 inches to 5 feet, though desk or table height (30 inches) may be more appropriate for a facility where young children are present.

The guidelines might apply only to work done by outside designers and contractors, to in-house facilities work and maintenance, or to individual workplace standards. It is preferable to address these three audiences separately. The scope might include new construction only, renovations, or both. Including both cases is recommended.

Responsibility Who has the in-house responsibility for maintaining the guidelines and ensuring their implementation? This should usually be the same office that oversees or coordinates architecture and engineering projects. What responsibilities does the designer or contractor have for notifying or certifying to the owner that provisions of the guidelines are being followed? This responsibility should be written into the contract.

General Intent The importance of the nonstructural earthquake protection program should be stated, preferably in a cover letter or introductory statement from the chief executive, department head, or governing board. If the guidelines are the only ensured means of communicating about the earthquake hazard to designers or contractors, introductory information could be added as well (such as examples of the types of damage that might be

expected to occur if the guidelines are not followed). This guide provides more background information on this topic than most designers or contractors have previously acquired, and portions or all of it could be made available to them to accomplish this purpose.

Performance Criteria If the client wants a design professional (architect or engineer) to do more than merely conform to the minimum requirements of the building code, it is desirable to explicitly describe the higher level of performance desired. This can be done in language such as the following: "In the event that a major earthquake occurs at the site (i.e., an earthquake with a ____ % probability of exceedance in ____ years), the following nonstructural items should remain undamaged and functional, assuming that the structure remains serviceable. For all other nonstructural items, only life safety is important, and the anchorage provisions of the local building code (or applicable code) should be followed, including anchorage of any item weighing more than ____ pounds, or located more than ____ above the floor and weighing more than ____ pounds." Another way to state the basic performance criteria would be, "Within ____ hours/days after the most severe earthquake that is expected to occur on average ____ (e.g., once a century), the following nonstructural items should be at least ____ percent functional."

As an alternative, other published criteria could be referenced. For example, some of the requirements imposed on California hospitals in Title 24 of the California Administrative Code might be appropriate for other essential facilities, but referencing that code would have to be done selectively because it includes many provisions that may not be applicable. Of course, it may not be easy to meet the desired level of performance, so this should be discussed with the engineering consultant prior to developing a specification. It is also

sometimes difficult to verify whether the intent of a performance criterion has been met until the earthquake occurs.

The criteria should include an indication as to how much the client is willing to pay to obtain the higher level of protection. Estimates could be prepared for each job and approved by the client. Or a general statement could be made that "any cost up to ____ percent additional cost" (with the percentage specified in terms of total construction cost or estimated cost for that nonstructural item only) that the architect or engineer thinks reasonable is allowable. Costs estimated to be in excess of this limit would have to be brought to the attention of the client for explicit approval during design.

Quality Assurance What means of verifying and testing compliance with the guidelines will be required? For example, if upgrade details with anchorage into concrete slabs or walls is to be a common element of future projects, specific procedures for load testing (pulling) a percentage of installed anchor bolts could be specified. For installation of drill-in anchor bolts in concrete for hospitals in California, which are subject to stricter earthquake regulations than most buildings, the state requires in-place proof-testing of half of the bolts to twice their allowable loads. If any bolts pull out, then the adjacent bolts must also be tested.

Coordination with Nonseismic Specifications, Codes, and Guidelines

The need to provide earthquake protection without sacrificing fire, security, or other requirements should be stated in the guidelines. One common conflict arises in the acoustically desirable use of vibration isolators to allow equipment such as air conditioning units or generators to operate without transmitting the full force of noisy vibrations into the building. The easiest earthquake solution is to bolt the

equipment rigidly to the supporting structure, but this would compromise the spring-mount vibration isolation system. Restraining angles (snubbers) can be installed; properly designed snubbers will provide seismic restraint while also allowing the acoustic solution to operate unhindered. Another conflict arises in the design of fire and corridor doors. These doors must be tight to meet fire regulations but often jam closed due to interstory drift during an earthquake, making evacuation difficult.

Nonstructural Design Requirements

Most design and construction contract language will require compliance with locally applicable codes. However, since the code provisions apply to a limited number of nonstructural items, most codes would not require earthquake anchorage or restraint for a computer, a tall file cabinet, a heavy mirror, or small containers of chemicals. In addition, a client might desire to provide a higher level of protection than the code minimum to some items that are listed in the code. If the guidelines call for measures that are in excess of local code requirements, this should be clearly stated. "Whichever requirements are more restrictive" is a phrase that could be used to indicate that the code must be met or, if the guidelines so require, exceeded. This is related to the subtopic Performance Criteria above.

The design force level is another question that should be addressed in the guidelines. Force level is the term for the amount of earthquake inertial force an item is designed to resist. The building code specifies different percentages of the weight of an object to be used as the horizontal earthquake force, as described in Chapter 2. Since many items are not covered by the code, the client or design professional must select the inertial force level to be used for the design of items that fall outside the code provisions. A design coefficient of 100% (if the object weighs 100 pounds, then its anchorage must be able to resist a horizontal force of 100

pounds) would be a generally conservative criterion for most items in most buildings in most parts of the United States. The cost of this extra conservatism is often small, since the labor cost will probably be the same and the difference in hardware costs is generally quite small.

Prescriptive Details If there are efficient and reliable specific methods to address repetitive nonstructural problems, then these might be detailed with drawings and required, where applicable. Chapter 4 provides a starting point for the development of such standard details, which should be reviewed by a knowledgeable design professional to ensure their appropriateness for the cases at hand. The references listed in the annotated bibliography provide additional sources of information.

STRUCTURAL/NONSTRUCTURAL INTERACTION

Although the focus of this guide is on nonstructural performance, there are a variety of ways to design or modify the structural system of a building in an effort to limit nonstructural damage. For new construction, it may be useful for the owner, architect, and engineer to discuss the advantages and disadvantages of various structural systems at the very early stages of the project. It is important for the owner to understand the interaction between the structural system and the nonstructural components. Structural systems are often described in terms of their lateral stiffness or flexibility. For instance, a concrete shear wall building is generally stiffer than a steel frame structure of comparable size. The design team might choose a flexible frame system, which may appear more economical because such systems can often be designed for lower earthquake forces by code than a shear wall system of comparable size. Buildings designed to have less drift, or horizontal sway, such as shear wall buildings or buildings with a frame that is stiffer than the

code minimum, will experience less nonstructural damage. If the increment of cost to upgrade the structural framing system is small, it may be advantageous to exceed the minimum code requirements and select a structural system that will provide improved nonstructural performance. It may also be desirable to provide movement joints to allow for protection of windows and partitions during earthquakes. The design of these joints is also related to the flexibility or expected seismic drift in the building.

If a client wants to reduce the potential for nonstructural earthquake damage and expects to receive extra attention in the structural, architectural, mechanical, or electrical design of the many features that make up a modern building, then it is vital that the client and the design team discuss these issues at the outset in order to develop a clear picture of the project

objectives.

FEEES FOR PROFESSIONAL SERVICES

If the architect, engineer, or interior designer/space planner is called upon to perform a service not usually provided, the fee will logically be higher. In most cases the engineer's drawings, specifications, and calculations cover only the building structure. The architect, mechanical engineer, and interior designer specify the nonstructural components of the building, but they may not have the expertise to adequately address the subject of earthquake performance. Designing upgrade details for a wide variety of nonstructural components can be time consuming. If the consultant has to make field visits to observe the construction, this will also involve additional time and expense.

GLOSSARY

Base - The portion of a building embedded in or resting on the ground surface.

Base isolation - A method whereby a building superstructure is separated from its foundation using flexible bearings in order to reduce the earthquake forces. This method can also be used as an upgrade technique for some types of large and/or sensitive equipment.

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).

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.

Earthquake shaking - The vibratory movement of the earth's crust caused by seismic activity.

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. For example, flexible hose connections are advisable for all gas-fired equipment.

Force level - The intensity of earthquake forces.

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.

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.

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.

Lateral force resisting system - The elements of a structure that resist horizontal forces. These 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 an earthquake.

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.

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.

Pounding - The impact of two structures during an earthquake. Pounding frequently occurs when the seismic gap between two adjacent wings of a building, or two neighboring buildings separated only by a few inches, is insufficient to accommodate the relative lateral movement of both buildings.

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.

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.

Seismic - Of, relating to, or caused by an earthquake.

Seismic drift - The horizontal displacement of a building resulting from the application of lateral earthquake forces.

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 used to limit the range of lateral motion of spring-mounted mechanical equipment.

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.

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.

Vertical force resisting system - The elements of a structure that resist the gravity loads or self-weight.

REFERENCES

1. Staff of the Los Angeles Times. 1994. *4:31, Images of the 1994 Los Angeles Earthquake*. Los Angeles, Calif.: Los Angeles Times.
2. Ding, Day, Christopher Arnold, et al. 1990. "Loma Prieta Earthquake Reconnaissance Report: Architecture, Building Contents, and Building Systems." *Earthquake Spectra*, Supplement to Volume 6.
3. Reitherman, Robert, et al. 1994. "Nonstructural Components." In *Northridge Earthquake, January 17, 1994, Preliminary Reconnaissance Report*, edited by John Hall. Oakland, Calif.: Earthquake Engineering Research Institute, and in-press Final Report to be published in *Earthquake Spectra*.
4. Federal Emergency Management Agency. 1981. *An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake: Findings and Actions Taken*. Washington, D.C.: FEMA.
5. Steinbrugge, Karl V., and Eugene E. Schader. 1973. "Earthquake Damage and Related Statistics." In *San Fernando, California, Earthquake of February 9, 1971*, edited by Leonard Murphy. Vol. 1A, pp. 709-710 and 713. Washington D.C.: National Oceanic and Atmospheric Administration.
6. Wong, Kit M. 1993. *High Seismic Economic Risk Buildings: Research Report to the National Science Foundation*. Oakland, Calif.: Vickerman, Zachary, Miller.
7. Dobb, Linda, librarian, San Francisco State University. Personal communication.
8. Nigbor, Robert L. 1993. "Seismic Protection of Museum Contents," presented at the fall seminar of the Structural Engineers Association of Northern California. San Francisco: Structural Engineers Association of Northern California.
9. Building Seismic Safety Council. 1991. *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*. Washington, D.C.: FEMA. [1994 edition in progress].
10. Shakal, A., et al. 1994. *CSMIP Strong-Motion Records from the Northridge, California, Earthquake of 17 January 1994*. Report No. OSMS 94-07. Sacramento: California Department of Conservation, Office of Strong Motion Studies.
11. Darragh, R., et al. 1994. *Processed Data for Sylmar - 6-story County Hospital from the Northridge Earthquake of 17 January 1994*. Report OSMS 94-11C. Sacramento: California Department of Conservation, Office of Strong Motion Studies.
12. International Conference of Building Officials. 1994. *Uniform Building Code*. Whittier, Calif.: ICBO.
13. Huttenbach, Robert A. 1980. *Policy on Seismic Hazard Reduction*. Santa Barbara, Calif.: University of California, Santa Barbara, Office of the Chancellor.
14. Steinmetz, William H. 1979. "How a Campus Handles an Earthquake Disaster," presented at the 26th National Conference on Campus Safety. Ann Arbor: University of Michigan.

The following references were used in compiling the checklists, details, and installation notes and are not cited specifically in the text:

15. California Office of the State Architect and California Office of Emergency Services. 1990. *Identification and Reduction of Nonstructural Earthquake Hazards in California Schools*. Sacramento and Oakland: California OSA and OES.

16. Reitherman, Robert, and Steve Minor. 1989. *Technical Guidelines for Earthquake Protection of Nonstructural Items in Communications Facilities*. Oakland: California Office of Emergency Services Earthquake Program.

17. Wiss, Janney, Elstner Associates, Inc.

1994. *Information on Protecting Your Home and Business from Nonstructural Earthquake Damage*. Los Angeles: California Office of Emergency Services.

18. California Office of the State Architect. 1993. *Earthquake Bracing of Water Heaters for Single-Family Homes*. Sacramento: California OSA.

19. Reitherman, Robert. 1991. *Nonstructural Earthquake Protection Manual for Idaho Schools*. Boise: Idaho Bureau of Disaster Services.

20. *Checklist of Nonstructural Earthquake Hazards*. Sacramento: California Office of Emergency Services Earthquake Project.

ANNOTATED BIBLIOGRAPHY

This brief bibliography can direct those who require more detailed information to other bibliographies, such as those contained in the references below, and thus is not meant to be comprehensive. This bibliography includes technical publications and nontechnical publications, both listed in alphabetical order, and also information on several organizations or government agencies with a specific focus on earthquake engineering issues. These organizations may be able to help the reader identify more recent publications than those listed here.

Technical Publications

Applied Technology Council. 1992. *ATC-29: Proceedings of Seminar and Workshop on Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures*. Redwood City, Calif.: ATC.

○ These proceedings contain papers with performance data, analytical methods, and/or suggested details for many specific items, including elevated tanks, ceilings, fire sprinklers, HVAC ducts and equipment, and computer access floors. Most of these papers also contain extensive reference lists pertinent to each specific topic.

Ayres, J. M., T. Y. Sun, and F. R. Brown. 1973. "Nonstructural Damage to Buildings." In *The Great Alaska Earthquake of 1964: Engineering*. Washington D.C.: National Academy of Sciences.

Ayres, J. M., and T. Y. Sun. 1973. "Nonstructural Damage." In *The San Fernando, California, Earthquake of February*

9, 1971. Washington, D.C.: National Oceanic and Atmospheric Administration.

○ These were the first two comprehensive postearthquake damage analyses devoted to the topic of nonstructural components. The authors are mechanical engineers.

Building Seismic Safety Council. 1992. *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*. Part 1--Provisions (FEMA 222), Part 2--Commentary (FEMA 223). Washington, D.C.: FEMA.

○ The 1994 edition was in draft form at the time this document went to press.

Building Seismic Safety Council. 1992. *NEHRP Handbook for the Seismic Evaluation of Existing Buildings*. (FEMA 178). Washington, D.C.: FEMA.

Building Seismic Safety Council. 1992. *NEHRP Handbook for the Seismic Rehabilitation of Existing Buildings*. (FEMA 172). Washington, D.C.: FEMA.

○ Items 4, 5, and 6 are all part of a series of FEMA documents produced by the National Earthquake Hazards Reduction Program (NEHRP). These documents may be obtained without charge by writing to the address listed at the end of this bibliography.

Dowrick, D. J. 1977. *Earthquake Resistant Design: A Manual for Engineers and Architects*. New York: John Wiley & Sons.

○ A comprehensive text, including two chapters on nonstructural issues: "Earthquake Resistance

of Services," which concerns mechanical and electrical components, and "Architectural Detailing for Earthquake Resistance." The book has an international perspective with references to many different codes.

Earthquake Engineering Research Institute. 1984. *Nonstructural Issues of Seismic Design and Construction*. Publication No. 84-04. Oakland, Calif.: EERI.

○ This is a technical overview based on a workshop sponsored by the National Science Foundation. It includes several technical papers and a discussion of key issues, and it lists many additional references.

International Conference of Building Officials. 1994. *Uniform Building Code*, Volumes 1-3. Whittier, Calif.: ICBO.

○ See especially the "Earthquake Regulations." The UBC contains specific requirements for some items, such as steel storage racks. New editions of the UBC are issued every three years. The earthquake regulations are taken almost verbatim from the SEAOC "Blue Book," listed below, which also includes a useful commentary.

McGavin, Gary L. 1981. *Earthquake Protection of Essential Building Equipment: Design, Engineering, Installation*. New York: John Wiley & Sons.

○ A book-length treatment of the subject. Especially appropriate for large, complex projects, such as hospitals or power plants.

Office of the State Architect, Structural Safety Section. 1991. *Interpretation of Regulations #IR 23-7, Title 24 California Administrative*

Code: Anchorage of Non-Structural Building Components and Hospital Equipment. Sacramento: California OSA.

○ The regulations legally pertain only to essential nonstructural items in California hospitals, but the regulations can provide a guide as to anchorage engineering of especially essential items for other types of buildings. The Office of the State Architect has been centrally involved in earthquake code regulations since the 1933 Long Beach earthquake.

Schiff, Anshel J. 1980. *Pictures of Earthquake Damage to Power Systems and Cost-Effective Methods to Reduce Seismic Failures of Electric Power Equipment*. West Lafayette, Ind.: Purdue Research Foundation.

○ This is one of the few works in this subject area that is readable by the nontechnical audience. Engineering appendix and bibliography also included.

Structural Engineers Association of California. 1990. *Recommended Lateral Force Requirements and Commentary*. San Francisco: SEAOC.

○ Also known as the SEAOC "Blue Book." The "Requirements" are adopted almost verbatim into the Uniform Building Code, while the "Commentary" explains the assumptions, limitations, and caveats that must be understood for the regulations to be used intelligently. The Structural Engineers Association of California has been active in the development of seismic code regulations, standards of practice, research, and testing for several decades.

Structural Engineers Association of Northern California. 1993. *Fall Seminar: Non-Structural Components--Design and Detailing*. San

Francisco: SEAONC.

○ These seminar notes include nine papers on the design and detailing of cladding, interior systems, and mechanical systems. Several of these papers also include extensive reference lists.

U.S. Department of Defense. 1982. *Seismic Design for Buildings*. Tri-Service Manual TM 5-809-10. Washington, D.C.: Superintendent of Documents.

○ Commentary and calculation examples are provided; see especially Chapters 9, 10, and 11. Generally parallels the UBC but is written as a design aid rather than a code.

U.S. Department of Defense. 1986. *Seismic Design Guidelines for Essential Buildings*. Tri-Service Manual TM 5-809-10-1. Washington, D.C.: Superintendent of Documents.

○ Chapters 6 and 7 cover nonstructural components and nonbuilding structures, respectively. Includes several design examples. (Revised edition by Wiss, Janney, Elstner Associates, Inc., due out in 1995).

U.S. Department of Defense. 1986. *Seismic Design Guidelines for Upgrading Existing Buildings*, Tri-Service Manual TM 5-809-10-2. Washington, D.C.: Superintendent of Documents.

○ Portions of Chapter 6, Chapter 9, and the design examples in Appendix G are related to nonstructural items.

U.S. Department of Veterans Affairs, Office of Construction. 1976. *Study to Establish Seismic Protection Provisions for Furniture, Equipment,*

and Supplies for VA Hospitals. Washington, D.C.: VA.

○ This guide shows typical nonstructural damage inside a hospital and illustrated restraint techniques with cost estimates for a variety of types of hospital equipment and furnishings; it includes a brief engineering appendix. Relevant for buildings other than hospitals, especially if laboratories are present.

Yancey, C. W. C., and A. A. Camacho. 1978. *Seismic Design of Building Service Systems: The State of the Art*. National Bureau of Standards Technical Note 970. Washington, D.C.: NBS.

○ A literature survey and review of present practice, especially with regard to the specific mandatory regulations of building codes. The National Bureau of Standards, a federal bureau, has been involved with earthquake research and postearthquake damage reports.

Rihal, Satwant, Barry J. Goodno, Hiroshi Ito, and Robert Reitherman. 1993. "Nonstructural Elements." In *Design of Low-Rise Buildings Subjected to Lateral Forces*, edited by Ajaya Kumar Gupta and Peter James Moss. Ann Arbor: CRC Press.

○ A chapter in a book intended for architects, engineers, building officials, and university professors. Most of this chapter concerns earthquakes rather than wind, and additional references are listed.

Reitherman, Robert, and Steve Minor. 1989. *Technical Guidelines for Earthquake Protection of Nonstructural Items in Communications Facilities*. Oakland: California Office of Emergency Services Earthquake Program.

○ Intended for the facilities staffs who install

and maintain telecommunications equipment. Includes simplified design guide for the selection of anchor bolts, drawings of anchorage and bracing details, and installation guidance.

Technical Standards

The following list of publications includes many of the specific design, fabrication, and/or installation requirements for particular nonstructural items.

American Institute of Steel Construction (AISC). 1989. *Manual of Steel Construction : Allowable Stress Design*. Ninth Edition.

American Petroleum Institute (API). 1988. *Welded Steel Tanks for Oil Storage*. API Standard 650.

American Society of Mechanical Engineers (ASME). 1990. *Safety Code of Elevators and Escalators*. ASME A17.1.

American Society of Mechanical Engineers (ASME). Including addenda through 1993. *Code for Pressure Piping*. ASME B31.

American Society of Mechanical Engineers (ASME). Including addendum through 1993. *Boiler and Pressure Vessel Code*.

American Society For Testing and Materials (ASTM). 1991. *Standard Specification for the Manufacture, Performance and Testing of Metal Suspension Systems for Acoustical Tile and Lay-in Panel Ceilings*. ASTM C635.

American Society For Testing and Materials (ASTM). 1991. *Standard Practice for Installation of Metal Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels*. ASTM C636.

American Water Works Association (AWWA).

1984. *Welded Steel Tanks for Water Storage*. D100.

Ceilings and Interior Systems Construction Association (CISCA). 1991. *Recommendations for Direct-Hung Acoustical Tile and Lay-In Panel Ceilings, Seismic Zones 0-2*.

Ceilings and Interior Systems Construction Association (CISCA). 1990. *Recommendations for Direct-Hung Acoustical Tile and Lay-In Panel Ceilings, Seismic Zones 3-4*.

Institute of Electrical and Electronic Engineers (IEEE). 1975. *Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations*. IEEE Standard 344.

Manufacturers Standardization Society of the Valve and Fitting Industry (MSS). 1988. *Pipe Hangers and Supports : Materials, Design, and Manufacture*. SP-58.

National Fire Protection Association (NFPA). 1991. *Standard for the Installation of Sprinkler Systems*. NFPA-13.

Rack Manufacturers Institute (RMI). 1990. *Specification for the Design, Testing, and Utilization of Industrial Steel Storage Racks*.

Sheet Metal and Air Conditioning Contractors National Association (SMACNA). 1985. *HVAC Duct Construction Standards, Metal and Flexible*.

Sheet Metal and Air Conditioning Contractors National Association (SMACNA). 1980. *Rectangular Industrial Duct Construction Standards*.

Sheet Metal and Air Conditioning Contractors National Association (SMACNA), Sheet Metal Industry Fund of Los Angeles, and Plumbing Industry Council. 1992. *Guidelines for Seismic*

Restraint of Mechanical Systems and Plumbing Piping Systems.

Nontechnical References

California Office of the State Architect and California Office of Emergency Services. 1990. *Identification and Reduction of Nonstructural Earthquake Hazards in California Schools.* Sacramento and Oakland: California OSA and California OES

- Survey forms and drawings of bracing concepts for 27 nonstructural items.

FIMS, Inc., and VSP Associates. 1987. *Data Processing Facilities: Guidelines for Earthquake Hazard Mitigation.* Sacramento, Calif.: VSP, Inc.

- Intended for owners and operators of data processing facilities (DPF). Contains illustrative material on nonstructural hazards and upgrades for raised floors and mainframe computer systems, as well as components found in buildings in general. Not intended as a self-help guide, but provides DPF manager with a basis for discussing design criteria with an engineer.

Noson, Linda, Todd Perbix, and Padraic Burke. 1989. *Safer Schools: Earthquake Hazards, Nonstructural.* Olympia, Wash.: Washington Superintendent of Public Instruction.

- Includes background information on earthquakes in Washington, survey checklists, and 32 pages of illustrations of nonstructural hazard reduction measures.

Olshansky, Robert B. No date (c. 1992). *Reducing Earthquake Hazards in the Central U.S.: Nonstructural Hazards.* Memphis, Tenn.: Central United States Earthquake Consortium.

- Prepared for the U.S. Geological Survey by the University of Illinois at Urbana-Champaign, Department of Urban and Regional Planning. Illustrations and explanations of nonstructural damage.

Reid & Tarics Associates. 1982. *Seismic Restraint Handbook for Furniture, Equipment, and Supplies.* Washington, D.C.: Veterans Administration.

- In addition to detailed administration procedures applicable to VA hospitals, the handbook contains detailed forms for collecting nonstructural survey data and producing cost estimates or lists of required materials and labor. Includes 18 pages of restraint details. Originally intended for use by engineering staffs at VA medical facilities, without the use of outside contractors or additional design/analysis assistance.

Reitherman, Robert. 1989. *Nonstructural Earthquake Hazard Mitigation for Hospitals and Other Health Care Facilities.* FEMA Publication SM (Student Manual) 370. Washington, DC: FEMA.

- Six chapters devoted to the nonstructural topic, some of them generally applicable and others more specific to hospitals. This is a manual used for a two-day course devoted to earthquake hazard reduction and emergency preparedness for hospital facilities.

Organizations

1. Federal Emergency Management Agency (FEMA); California Office of Emergency Services (OES) Earthquake Program; Central United States Earthquake Consortium (CUSEC).

A wide variety of publications, brochures, checklists, videotapes, and slide sets related to earthquake preparedness and nonstructural hazard mitigation are available from many state and federal agencies. Some of the items are tailored to meet differing needs in particular areas of the United States. Some are tailored for specific types of facilities, such as hospitals, schools, day care centers, nursing homes, or single-family residences. Many are available free of charge.

FEMA has regional offices throughout the country, and most states have an office or department of emergency services that may have similar material. The list below includes only several key agencies.

Federal Emergency Management Agency
Mitigation Directorate
500 C Street, S.W.
Washington, D.C. 20472

State of California
Governor's Office of Emergency Services
Earthquake Program
2800 Meadowview Road
Sacramento, CA 95832
(Phone 916-262-1800; Fax 916-262-1840)

Central United States Earthquake Consortium
2630 East Holmes Road
Memphis, TN 38118
(Phone 901-345-0932; Fax 901-345-0998)

2. The National Center for Earthquake Engineering Research (NCEER) is associated with the State University of New York at

Buffalo. Founded in 1987, NCEER sponsors academic research in earthquake engineering, publishes a quarterly bulletin, and has an extensive list of technical reports available by mail. NCEER also has a bibliographic database called QUAKELINE that covers the literature of earthquake engineering and natural hazards mitigation. The database contained over 24,000 records as of January 1994; approximately 400 additions are made each month. The database is accessible on Internet, through both academic computing services and commercial providers.

National Center for Earthquake Engineering Research
State University of New York at Buffalo
Red Jacket Quadrangle, Box 610025
Buffalo, NY 14621-0025
(Phone 716-645-3391; Fax 716-645-3399;
QUAKELINE Info: Phone 716-645-3377)

3. The Earthquake Engineering Research Institute (EERI) was organized in 1949 as a nonprofit corporation with the objective of reducing the impact of earthquakes by means of seismic studies, inspection of earthquake damage, education, and technology transfer, including conferences and the publication of newsletters, reports, technical papers, and conference proceedings. EERI has members in 47 states and 51 foreign countries, including many practicing engineers, architects, and seismologists, as well as university professors and government personnel. *Earthquake Spectra*, a monthly publication of EERI, contains articles covering a wide range of topics related to earthquakes. EERI has an extensive publication list that also includes videotapes and annotated slide sets showing examples of damage during many past earthquakes.

Earthquake Engineering Research Institute
499 14th Street
Oakland, CA 94612-1902
(Phone 510-451-0905; Fax 510-451-5411)

4. The Earthquake Engineering Research Center (EERC) is associated with the University of California at Berkeley. In addition to the extensive shake table testing program, which has been going on for many years and which has produced hundreds of research reports, EERC has an extensive library of earthquake-related materials and a large collection of earthquake slides, and it publishes a newsletter. EERC reports and slide sets are available for sale.

The National Information Service for Earthquake Engineering (NISEE) distributes computer software for earthquake engineering and is associated with EERC. NISEE also maintains a computer database of information on earthquake engineering, accessible through Internet.

Earthquake Engineering Research Center
University of California, Berkeley
1301 South 46th Street
Richmond, CA 94804-4698
(Phone 510-231-9554)

5. The Applied Technology Council (ATC) is a nonprofit corporation serving the structural engineering profession. The majority of its publications are related to technical topics in seismic analysis and design, postearthquake damage evaluations, new technological advances in seismic design, and so on. The specific focus of the organization is to provide a link between academic research and professional practice. ATC sponsors several technical workshops each year.

Applied Technology Council
555 Twin Dolphin Drive, Suite 270
Redwood City, CA 94065
(Phone 415-595-1542; Fax 415-593-2320)

APPENDIX A

NONSTRUCTURAL INVENTORY FORM

Facility: _____ Assumed Intensity: _____

Priority	Nonstructural Item	Location	Quantity	Risk			ER	Estimated Upgrade Cost		Notes
				LS	PL	LF		Per Item	Subtotal	
Total										

LS (Life Safety) PL (Property Loss) LF (Loss of Function) ER (Engineering Required) L (Low) M (Moderate) H (High)

Inventory Form

Facility: XYZ Office Assumed Intensity: Severe

Priority	Nonstructural Item	Location	Quantity	Risk			ER	Estimated Upgrade Cost		Notes
				LS	PL	LF		Per Item	Subtotal	
2	Air conditioner	roof	1	H	H	M	X	\$500.00 (estimated)	\$500.00	Sits on springs; no seismic restraints
1	Suspended ceiling	throughout	5,000 sq. ft.	H	H	H	X	\$50.00 (per strut)	\$4,000.00	No diagonal wires
5	Water heater	utility room	1	M	M	M	X	\$200.00 (each)	\$200.00	Gas fired; no flexible pipe no anchorage
4	Tall shelving	storage room	40 lin. ft.	H	M	M	X	\$20.00 (per lin. ft.)	\$800.00	*Low priority, contents not essential; unanchored; 8 ft. high
6	Half-height partition	work stations	20 (6' each)	M	M	M		\$10.00 (per lin. ft.)	\$1,200.00	Stable layout (has returns)
3	Suspended lights	offices	50	H	M	M		\$50.00 (each)	\$2,500.00	Fixtures just rest loosely on ceiling grid
								Total	\$9,200.00	

LS (Life Safety) PL (Property Loss) FL (Loss of Function) ER (Engineering Required) L (Low) M (Moderate) H (High)

APPENDIX B

CHECKLIST OF NONSTRUCTURAL EARTHQUAKE HAZARDS

How to Use This Checklist

This checklist is intended to be used in surveying buildings to assess whether the nonstructural elements (electrical, mechanical, architectural, and furniture or contents) pose a danger to the building occupants or are likely to cause financial loss or interruption following an earthquake. The questions in this form have been stated in such a way that a "NO" answer indicates there may be a potential problem with the item. Write "Y" for Yes and "N" for No in the box provided. The list may be used in conjunction with the nonstructural inventory form provided in Appendix A. As an example, a line item in the inventory form should be created for each instance where a question in this form is answered "NO".

BUILDING UTILITY SYSTEMS

EMERGENCY POWER-GENERATING EQUIPMENT

Emergency power-generating equipment generally consists of the following components:

U1. Generator

- Is the emergency generator adequately secured, especially if mounted on motor vibration isolation springs?

U2. Batteries, battery rack [See Example U2]

- 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 rack from sliding or tipping?

U3. Diesel fuel tank [See Example U3]

- Is the tank securely attached to the supports?
- Are the tank supports braced in both directions?
- Is the bracing attached with anchor bolts to concrete walls or foundation pad?
- Is the foundation large enough to keep the tank from tipping over or sliding?
- Is the wall strong enough to support the tank?

U4. Fuel line, cooling water lines, exhaust flues

- Are these lines 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?

ELECTRICAL EQUIPMENT

The emergency power system includes both power-generating equipment and the electrical distribution system:

U5. Transformers

- Are transformers properly anchored to the floor or wall?

U6. Motor Control Center (MCC)

- Are the motor control centers properly anchored to the floor or wall?

U7. Electrical switchgear

- Is the switchgear properly anchored to the floor or wall?

U8. Electrical bus ducts and primary cable system [See Example U8]

- Are electrical cables or conduit able to distort at the connections with the equipment or where they cross seismic joints between buildings?
- Are the bus ducts or cable conduits laterally braced?

(Caution: Only qualified personnel should open access panels on electrical equipment).

FIRE DETECTION AND SUPPRESSION SYSTEM

The fire detection and suppression system may include any or all of the following components:

U9. Smoke detectors, fire alarm system, control system for automatic fire doors

- Are fire and smoke detectors properly mounted?
- Is the control equipment for the fire alarm system and automatic fire doors securely anchored?

U10. Fire extinguisher or fire hose cabinets [See Example U10]

- Are the fire extinguisher cabinets and/or hose cabinets securely mounted?
- Are the fire extinguishers secured with quick-release straps?

U11. Fire sprinklers and distribution lines

- Are the fire sprinkler piping components laterally braced?

- Is the ceiling braced so the ceilings won't break the sprinkler heads?

- Are the distribution lines able to accommodate movement where they cross seismic joints between buildings?

U12. Fire water pump

- Is the fire water pump anchored, or is it mounted on vibration isolation springs with additional seismic restraints?

U13. Emergency water tank or reservoir

- Is the water tank or reservoir securely attached to its supports?
- Are the tank supports braced in both directions?
- Are the supports or braces properly anchored to the foundation?

U14. Smoke control systems

- Are the fans properly braced and/or anchored?
- Are fan control centers securely anchored?

PROPANE TANKS

Propane tanks may be used for backup power, heating, or cooking. These systems include:

U15. Propane tank [See Example U15]

- Is the tank securely anchored to the supports?
- Are the tank supports braced in both directions?
- Are the supports or braces anchored to a concrete foundation pad?
- Is the foundation large enough to keep the tank from sliding or tipping over?

U16. Shut-off valve

- Does the system have an automatic, earthquake-triggered shut-off valve?
- If the shut-off is manual, is a wrench stored within easy reach?

U17. Gas or fuel supply pipe

- Are the supply pipes laterally braced?
- Do the pipes have flexible connections at the tank that are able to accommodate relative movement?

PLUMBING SYSTEM

The plumbing system may include:

U18. Gas-fired water heater or boiler

- Are the water heaters or boilers securely anchored to the floor or wall?
- Does the gas line have a flexible connection to the water heater that is able to accommodate movement?

U19. Residential water heater [See Examples U19a and U19b]

- Are the water heaters securely anchored to the floor or wall?
- Does the gas line or electrical conduit have a flexible connection to the water heater that is able to accommodate movement?

U20. Distribution pumps

- Are the distribution pumps anchored, or are they mounted on vibration isolation springs with additional seismic lateral restraints?

U21. Hot and cold water pipes, hot water return, wastewater pipes [See Example U21]

- Are the pipes laterally braced at reasonable intervals?
 - Do the pipes have flexible connections to boilers or tanks that are able to accommodate movement?
 - Are the distribution lines able to accommodate movement where they cross seismic joints between buildings?
 - Are pipe penetrations through structural walls or framing members large enough to allow for some seismic movement?
 - Are the pipes free of asbestos insulation that could be damaged by movement in an earthquake?
-

ELEVATORS, ESCALATORS

The transport equipment generally includes:

U22. Elevator cab

- Is the elevator cab properly attached to the guide rails?

U23. Cables, counterweights, and guide rails (for cable-traction systems)

- Are the cables installed in such a way that they are protected against misalignment during an earthquake?
- Are the counterweights properly attached to the guide rails?
- Are the guide rails securely attached to the building?

U24. Elevator motor and motor control cabinets

- Are the motor and motor control cabinets properly anchored?

U25. Elevator cab and hydraulic elevator equipment (hydraulic systems)

- Are the components of the hydraulic system properly anchored?

U26. Escalator

- Is the escalator control equipment securely anchored?

U27. People mover (moving walkway)

- Is the control equipment for the people mover properly anchored?

(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.)

HEATING, VENTILATING, AIR CONDITIONING (HVAC) SYSTEM

The HVAC system may include any or all of the following components, depending on the size of the facility:

U28. Boilers and furnaces

- Are boilers and furnaces securely anchored with adequately sized bolts?
- Are furnaces, and furnace or boiler bases, constructed without using unreinforced masonry?

U29. Chillers [See Examples U29a and U29b]

- Are chillers securely anchored, or are they mounted on vibration isolation springs with added seismic restraints?

U30. Heat pumps or heat exchangers

- Are pumps or heat exchangers anchored, or are they mounted on vibration isolation springs with added seismic restraints?

U31. Fans, blowers, filters

- Are fans, blowers, and filters securely anchored, or are they mounted on vibration isolation springs with added seismic restraints?

U32. Air compressors [See Example U32]

- Are air compressors anchored, or are they mounted on vibration isolation springs with added seismic restraints?

U33. Roof-mounted HVAC units

- Are the HVAC units securely anchored, or are they mounted on vibration-limiting springs with added seismic restraints?

U34. Wall-mounted room air conditioning units

- Are the air conditioning units securely mounted to the wall or shelf?

U35. Suspended room heaters or fans [See Example U35]

- Are the suspended room heaters, especially gas-fired ones, laterally braced, and are gas-fired heaters fitted with flexible gas connections?

U36. Distribution ducts [See Example U36]

- Are the distribution ducts laterally braced?
- Are the distribution ducts able to accommodate movement at locations where they cross seismic joints?

U37. Diffusers [See Example U37]

- 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 independent support, such as at least two hanger wires per diffuser?

MECHANICAL APPENDAGES

This category may include the following:

U38. Small stacks or residential chimneys [See Example U38]

- Is the brick chimney braced to the roof?
- Are stacks bolted to the supports or foundation by means of anchor bolts of adequate length and double nuts?

U39. Roof-mounted equipment, vents, or flues

- Is roof-mounted equipment properly anchored?

U40. Solar panels

- Are the solar panels securely anchored to the roof?
- Is the piping laterally braced?

ARCHITECTURAL ELEMENTS

BUILT-IN PARTITIONS

These may include elements of many different materials and construction types:

A1. Permanent block wall partitions (concrete masonry unit, brick, hollow clay tile)

- Are block wall partitions reinforced? (Most brick or hollow clay tile walls in pre-1933 California buildings are unreinforced. In other regions, unreinforced masonry elements may be found even in current construction.)

- Are concrete masonry unit (CMU) partitions detailed to allow sliding at the top?

A2. Partial- and full-height stud wall partitions [See Examples A2a and A2b]

- Are partial-height partitions braced to the structure above the ceiling line?
- If partitions function as lateral support for tall shelving or cabinets, are these partitions rigidly attached or braced to the structure above the ceiling line?

CEILINGS AND SOFFITS

A3. Ceilings (acoustic tile, gypsumboard, plaster) [See Example A3]

- Does the suspended ceiling have adequate diagonal bracing wires?
- Are decorative ceiling panels and/or latticework securely attached?
- For plaster ceilings, is the wire mesh or wood lath securely attached to the structural framing above?

A4. Soffits (stucco, gypsumboard, plaster)

- Are decorative finishes and/or latticework on beam soffits or beneath exterior eaves securely attached, particularly over exits?
- For stucco soffits, is the wire mesh or wood lath securely attached to the structural framing above?

LIGHTING

A5. Suspended overhead lighting, fixed or track lighting [See Examples A5a and A5b]

- 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 chandeliers or other hanging fixtures have safety cables to prevent them from impacting each other or a window?

- 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?

- Are spot lights or track lights securely attached to resist seismic shaking?

A6. Emergency lighting and exit lights

- Are emergency lights and exit lights mounted to protect them from falling off shelf supports?

DOORS AND EGRESS ROUTES

A7. Primary exit doors

- If 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?

A8. Automatic doors with optical or floor sensors, mechanized roll-up doors

- Do these doors have a manual override in case of a power outage after an earthquake?

A9. Stairways [See Example A9]

- Do steel stairs in multistory buildings have sliding supports at one end that can accommodate interstory displacements?

- Have any unreinforced masonry partitions in stairwells been removed, strengthened, or encapsulated?

A10. Building utilities and architectural finishes along egress routes (piping, ducts, ceilings, lights, partitions, etc.)

- Are piping, ducts, ceilings, lights, partitions, and other elements braced adequately to prevent falling obstructions along egress routes?

A11. Furniture and/or contents along egress routes (cabinets, shelving, etc.)

- Are furniture and/or contents along the egress routes sufficiently anchored to prevent objects from obstructing the egress route?
- Are unanchored furniture and/or contents kept far enough from the exits so they will not slide and obstruct the doors?

WINDOWS

Note: The term *safety glass* means tempered, laminated, or wired glass; glass covered with shatter-resistant film; or plastic panels.

A12. Glazing [See Example A12]

- Is it known whether the glazing was designed by an architect/engineer to accommodate lateral movement?
- Do large windows, especially storefront windows, have safety glass?

A13. Overhead glazing or skylights

- 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/engineer to accommodate the expected seismic distortion of the surrounding structure?

A14. Interior glass or glass block partitions

- Are the glazed partitions laterally braced to the structure?
-

PERMANENT ORNAMENTATION AND APPENDAGES : EXTERIOR OR INTERIOR

A15. Parapets, cornices, veneer or other decoration [See Examples A15a and A15b]

- Are parapets or cornices reinforced and adequately braced?
- Do other decorative elements have positive anchorage to the building?
- Does the veneer have positive anchorage to the building?

A16. Freestanding walls or fences (concrete, CMU, brick, or stone) [See Example A16]

- Is it known whether freestanding walls or fences were 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?
- Is it known whether CMU walls or fences were built with adequate foundations to prevent them from tipping over in an earthquake?

A17. Hanging appendages

- Are hanging appendages braced or secured with a safety cable?

A18. Exterior lighting

- Are exterior light fixtures properly supported or securely attached to the structure?

A19. Flagpoles

- Are flagpoles securely attached to the structure?

A20. Tall sculptures (over about 5 feet)

- Are heavy or sharply pointed sculptures anchored to prevent overturning during an earthquake?
- Do hanging sculptures have a safety cable to prevent them from swinging excessively or falling?

A21. Heavy signs or exterior billboards [See Example A21]

- Are exterior signs or billboards adequately braced and anchored?
Are interior signs securely attached with positive connections?

A22. Clay roof tiles

- Are clay roof tiles secured to the roof with one nail-and-wire connection per tile?
-

FURNITURE AND CONTENTS

COMMUNICATIONS EQUIPMENT

Communications and emergency communications systems may include:

C1. Radio and short-wave radio equipment

- Is radio equipment restrained to keep it from sliding off shelving or tabletops?

C2. Telephone, cellular phone, and fax equipment

- Is important equipment restrained to keep it from sliding off shelving or tabletops?
- Are telephones placed on desktops or counters far enough from the edge that they will not slide and fall off?

C3. Public address system

- Is the public address system restrained to prevent the equipment from sliding and falling off the shelving?

C4. Suspended speakers in conference room or auditorium

- Are sound system speakers in elevated locations anchored to the structure or hung with safety cables?

C5. Microwave equipment (antennae, receiver, transmitter, etc.)

- Is the microwave communications equipment securely braced and/or anchored?

C6. Computer networks, data storage

- Is computer information vital to operations backed up and stored off-site?
- Is critical computer equipment securely anchored to supports?
- 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?

C7. Wall-mounted televisions or surveillance cameras

- Are wall-mounted televisions or surveillance cameras in elevated locations securely anchored to support shelves or brackets that are in turn adequately connected to the wall?

OFFICE AND COMPUTER EQUIPMENT

This category may include a broad range of equipment, such as:

C8. Large computer equipment, tape drives [See Example C8]

- Are computers, tape racks, and associated equipment that is about twice as tall as wide, anchored, tethered, and/or braced?
- Is heavy computer equipment anchored to the structural floor slab and braced independently of the computer access floors?

C9. Computer cabling

- Is computer cabling long enough to accommodate lateral movement within the building?

C10. Desktop computer equipment or printers [See Example C10]

- Are computer monitors anchored to desktops or computers?
- Are desktop 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?

C11. Computer access floors [See Notes with Example C8]

- Are computer access floors 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?

STORAGE OF RECORDS AND SUPPLIES

Storage for files, accounting records, and emergency supplies may include:

C12. Bookshelves and library stacks 5 feet or taller [See Examples C12a, C12b, C12c]

- Are bookshelves properly anchored with brackets to a solid wall or stud, or anchored to the floor?
- 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 books given extra protection to prevent falling and water damage?

C13. Tall vertical or lateral file cabinets [See Example C13]

- Do the file cabinet drawers or doors latch securely?
- Are tall file cabinets anchored with wall brackets to a solid wall or stud, 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 an exit?

C14. Tall storage racks or shelving

- Are tall storage racks or shelves securely anchored to the floor or walls?
- Are heavily loaded racks or shelves braced in both directions?
- For racks 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 racks, or are they stored in stable units (e.g., are they shelved in the original packing boxes, or are small items shrinkwrapped together)?

C15. Emergency supply cabinet (water, medicine, food, etc.)

- Is the cabinet in an accessible location that is not likely to be heavily damaged?
- Is the cabinet properly braced and anchored, and are the cabinet doors securely latched?

C16. Especially valuable and fragile merchandise

- Are valuable or fragile items protected against tipping over or falling off shelving or pedestals?

KITCHEN AND LAUNDRY EQUIPMENT

These facilities may include any or all of the following items: gas and/or electric stoves and ovens, built-in or countertop microwave ovens, garbage compactors, dishwashers, refrigerators and freezers, clothes washers and dryers, ironing and pressing equipment.

C17. Large kitchen or laundry equipment

- Are all of these items securely anchored to the floor, wall, or countertop?

C18. Gas and/or electric hook-up
[See Example C18]

- Are the gas or electric hook-up lines able to accommodate movements at the equipment interface and where they cross seismic joints between buildings?

C19. Drawer and cabinet latches (kitchen, laboratory, office, etc.) *[See Example C19]*

- 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?

C20. Freestanding wood stove (wood, pellet, or gas-fired) *[See Example C20]*

- Is the stove securely anchored to the hearth or floor framing in a manner that will not conduct heat to any combustible materials?
- Is the exhaust flue anchored to the stove, are the flue sections secured together, and is the flue anchored to the wall with some type of thermal radiation shielding?

HAZARDOUS MATERIALS

Hazardous materials may include:

C21. Compressed-gas bottles or cylinders (oxygen, carbon dioxide (CO₂), ammonia)
[See Example C21]

- Are gas cylinders tightly secured with one chain near the top and one near the bottom, or are they otherwise restrained?
- Are the chains or restraints securely anchored to a wall or counter with screws or bolts rather than clamps?

C22. Chemical, laboratory, or medical supplies *[See Example C22]*

- 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?
- 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?

C23. Cabinets for hazardous materials

- Are cabinets for hazardous materials securely attached to the floor or to a sturdy wall?

C24. Asbestos

- Has asbestos insulation been removed, or has it been encapsulated to reduce the possibility of damage in an earthquake?

FURNITURE, INTERIOR DECORATION

C25. Potted plants or indoor landscaping resting on shelves above the floor *[See Example C28]*

- Are heavy potted plants on file cabinets or tall shelves restrained to prevent falling?

C26. Valuable and fragile artwork or decorative vases *[See Example C26]*

- Are valuable or fragile items protected against tipping over and/or falling off shelves or pedestals?

C27. Freestanding half-height movable partitions *[See Example C27]*

- Are freestanding partitions braced or arranged in stable layouts?

C28. Miscellaneous furnishings *[See Example C28]*

- Are unanchored furnishings located where they cannot slide or overturn to block corridors or doors?

C29. Lockers, vending machines

- Are personal or storage lockers and vending machines anchored and braced, or are they clear of exits?

APPENDIX C

NONSTRUCTURAL RISK RATINGS

Explanation of Risk Ratings

The risk ratings that appear in this Appendix are based on the following assumptions:

Life Safety (LS) Risk: Risk of being injured by the item. 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 capability. These disruptions of service are covered under Function 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.

Loss of Function (LF) 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.

Unanchored, unbraced items are assumed. The risk ratings are based on the assumption that the item has been installed without seismic bracing, anchorage, 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.

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-rise 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; 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.

A building of ordinary occupancy is assumed. Some nonstructural items in special facilities would be rated differently. For example, shelving in an ordinary occupancy building is assumed here, 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 Loss of Function in a communications center.

NONSTRUCTURAL RISK RATINGS

		SH	LS	PL	LF	ER	PG
UTILITY SYSTEMS							
EMERGENCY POWER-GENERATING EQUIPMENT							
U1	Generator	Light	L	L	M	yes	
		Mod	L	M	H		
		Severe	L	H	H		
U2	Batteries and battery rack	Light	L	L	L	yes	30
		Mod	L	H	M		
		Severe	L	H	H		
U3	Diesel fuel tank	Light	L	L	L	yes	31
		Mod	H	H	L		
		Severe	H	H	M		
U4	Fuel line	Light	L	L	L		
		Mod	H	H	L		
		Severe	H	H	M		
ELECTRICAL EQUIPMENT							
U5	Transformers	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	M	M	M		
U6	Motor control center (MCC)	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	M	M	M		

SH= Shaking intensity
ER= Engineering required
PG= Upgrade detail page number

Type of Risk
LS= Life safety
PL= Property loss
LF= Loss of function

Risk Rating
L= Low
M= Moderate
H= High

		SH	LS	PL	LF	ER	PG
U7	Electrical switchgear	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	M	M	M		
U8	Electrical bus ducts and primary cable system	Light	L	L	L	yes	32
		Mod	L	M	M		
		Severe	M	M	M		
FIRE DETECTION AND SUPPRESSION SYSTEM							
U9	Smoke detectors, fire alarm system, control for automatic fire doors	Light	L	L	L		
		Mod	L	L	L		
		Severe	L	L	L		
U10	Fire extinguisher or fire hose cabinets	Light	L	L	L		33
		Mod	M	H	L		
		Severe	M	H	L		
U11	Fire sprinklers and distribution lines	Light	L	M	M	yes	
		Mod	L	H	H		
		Severe	M	H	H		
U12	Fire water pump	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	M	M	L		
U13	Emergency water tank or reservoir	Light	L	L	L	yes	
		Mod	M	H	L		
		Severe	H	H	L		

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		SH	LS	PL	LF	ER	PG
U14	Smoke control systems	Light	L	L	L	yes	
		Mod	L	M	L		
		Severe	L	M	L		
PROPANE TANKS							
U15	Propane tank	Light	L	L	L	yes	34
		Mod	H	H	M		
		Severe	H	H	M		
U16	Shut-off valve	Light	L	L	L		
		Mod	H	H	M		
		Severe	H	H	M		
U17	Gas or fuel supply pipe	Light	L	L	L		
		Mod	H	H	M		
		Severe	H	H	M		
PLUMBING SYSTEM							
U18	Gas-fired water heater or boiler	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	M	M	M		
U19	Residential water heater	Light	L	L	L		35, 36
		Mod	M	H	L		
		Severe	M	H	L		
U20	Distribution pumps	Light	L	L	L	yes	
		Mod	L	M	L		
		Severe	L	M	M		

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		SH	LS	PL	LF	ER	PG
U21	Hot and cold water pipes, hot water return, wastewater pipes	Light	L	L	L	yes	37
		Mod	M	M	M		
		Severe	M	M	M		
ELEVATORS, ESCALATORS							
U22	Elevator cab	Light	L	L	L	yes	
		Mod	L	M	M		
		Severe	M	M	M		
U23	Cables, counterweights and guide rails (for cable-traction system)	Light	L	L	L	yes	
		Mod	H	M	M		
		Severe	H	M	M		
U24	Elevator motor and motor control cabinets	Light	L	L	L	yes	
		Mod	L	M	M		
		Severe	L	H	M		
U25	Elevator cab and hydraulic elevator equipment (hydraulic systems)	Light	L	L	L	yes	
		Mod	L	M	M		
		Severe	M	M	M		
U26	Escalator	Light	L	L	L	yes	
		Mod	L	M	L		
		Severe	L	M	L		
U27	People mover (moving walkway)	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	L	M	L		

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		SH	LS	PL	LF	ER	PG
HEATING, VENTILATING, AIR CONDITIONING (HVAC) SYSTEM							
U28	Boilers and furnaces	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	M	M	M		
U29	Chillers	Light	L	L	L	yes	38, 39
		Mod	L	L	L		
		Severe	L	M	M		
U30	Heat pumps or heat exchangers	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	L	M	M		
U31	Fans, blowers, filters	Light	L	L	L	yes	
		Mod	L	M	L		
		Severe	L	M	M		
U32	Air compressors	Light	L	L	L	yes	40
		Mod	L	M	L		
		Severe	L	M	M		
U33	Roof-mounted HVAC units	Light	L	M	L	yes	
		Mod	L	M	L		
		Severe	M	H	M		
U34	Wall-mounted room air conditioning units	Light	L	L	L		
		Mod	H	M	L		
		Severe	H	M	L		
U35	Suspended room heaters or fans	Light	L	L	L	yes	41
		Mod	H	H	L		
		Severe	H	H	L		

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		SH	LS	PL	LF	ER	PG
U36	Distribution ducts	Light	L	L	L	yes	42
		Mod	L	L	L		
		Severe	M	M	L		
U37	Diffusers	Light	L	L	L		43
		Mod	H	H	L		
		Severe	H	H	L		
MECHANICAL APPENDAGES							
U38	Small stacks or residential chimneys	Light	L	L	L	yes	44
		Mod	M	M	L		
		Severe	H	M	M		
U39	Roof-mounted equipment, vents or flues	Light	L	L	L	yes	
		Mod	L	M	L		
		Severe	M	M	M		
U40	Solar panels	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	M	M	L		

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		SH	LS	PL	LF	ER	PG
ARCHITECTURAL ELEMENTS							
PARTITIONS AND CEILINGS							
A1	Permanent block wall partitions (CMU, brick, hollow clay tile)	Light	L	L	L	yes	
		Mod	H	H	H		
		Severe	H	H	H		
A2	Partial- and full-height stud wall partitions	Light	L	L	L	yes	45, 46
		Mod	M	M	H		
		Severe	M	H	H		
A3	Ceilings (acoustic tile, gypsumboard, plaster)	Light	L	L	L	yes	47
		Mod	M	M	M		
		Severe	H	H	H		
A4	Soffits (stucco, gypsumboard, plaster)	Light	L	L	L		
		Mod	M	M	M		
		Severe	H	H	H		
LIGHTING							
A5	Suspended overhead lighting, fixed or track lighting	Light	L	L	L		48, 49
		Mod	H	L	L		
		Severe	H	M	M		
A6	Emergency lighting and exit lights	Light	L	L	L		
		Mod	M	L	L		
		Severe	H	M	L		

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		SH	LS	PL	LF	ER	PG
DOORS AND EGRESS ROUTES							
A7	Primary exit doors	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	M	M	M		
A8	Automatic doors with optical or floor sensors, mechanized roll-up doors	Light	L	L	L	yes	
		Mod	L	M	L		
		Severe	M	M	M		
A9	Stairways	Light	L	L	L	yes	50
		Mod	H	M	L		
		Severe	H	M	H		
A10	Building utilities and architectural finishes along egress routes (ceilings, lights, partitions, etc.)	Light	L	L	L	yes	
		Mod	H	M	L		
		Severe	H	M	L		
A11	Furniture and/or contents along egress routes (cabinets, shelving, etc.)	Light	L	L	L		
		Mod	H	M	L		
		Severe	H	M	L		
WINDOWS							
A12	Glazing	Light	L	L	L	yes	51
		Mod	M	M	L		
		Severe	H	M	M		
A13	Overhead glazing or skylights	Light	L	L	L	yes	
		Mod	H	M	L		
		Severe	H	M	M		

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		SH	LS	PL	LF	ER	PG
A14	Interior glass or glass block partitions	Light	L	L	L	yes	
		Mod	M	M	L		
		Severe	H	H	M		
PERMANENT ORNAMENTATION AND APPENDAGES : INTERIOR OR EXTERIOR							
A15	Parapets, cornices, veneer or other decoration	Light	M	M	L	yes	52, 53
		Mod	H	H	L		
		Severe	H	H	L		
A16	Freestanding walls or fences (concrete, CMU, brick, or stone)	Light	L	L	L	yes	54
		Mod	L	L	L		
		Severe	H	H	M		
A17	Hanging appendages	Light	L	L	L	yes	
		Mod	H	H	L		
		Severe	H	H	M		
A18	Exterior lighting	Light	L	L	L		
		Mod	M	L	L		
		Severe	M	M	M		
A19	Flagpoles	Light	L	L	L	yes	
		Mod	L	L	L		
		Severe	M	M	L		
A20	Tall sculptures (over 5 feet)	Light	L	L	L	yes	
		Mod	M	M	L		
		Severe	H	H	L		

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		SH	LS	PL	LF	ER	PG
A21	Heavy signs or exterior billboards	Light	L	L	L	yes	55
		Mod	H	H	L		
		Severe	H	H	L		
A22	Clay roof tiles	Light	L	L	L	yes	
		Mod	L	M	L		
		Severe	M	H	M		
FURNITURE AND CONTENTS							
COMMUNICATIONS EQUIPMENT							
C1	Radio and short-wave radio equipment	Light	L	L	L		
		Mod	L	H	H		
		Severe	L	H	H		
C2	Telephone, cellular phone and fax equipment	Light	L	L	L		
		Mod	L	H	M		
		Severe	L	H	M		
C3	Public address system	Light	L	L	L		
		Mod	L	H	L		
		Severe	L	H	L		
C4	Suspended speakers in conference room or auditorium	Light	L	L	L	yes	
		Mod	M	M	L		
		Severe	H	H	L		
C5	Microwave equipment (antennae, receiver, transmitter, etc.)	Light	L	L	L	yes	
		Mod	L	M	L		
		Severe	M	H	M		

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		SH	LS	PL	LF	ER	PG
C6	Computer networks, data storage	Light	L	L	L		
		Mod	L	M	H		
		Severe	L	H	H		
C7	Wall-mounted televisions or surveillance cameras	Light	L	L	L	yes	
		Mod	H	H	L		
		Severe	H	H	L		
OFFICE AND COMPUTER EQUIPMENT							
C8	Large computer equipment, tape drives	Light	L	L	L	yes	56
		Mod	L	M	M		
		Severe	M	H	M		
C9	Computer cabling	Light	L	L	L		
		Mod	L	L	L		
		Severe	L	L	L		
C10	Desktop computers or office equipment	Light	L	L	L		57
		Mod	L	H	M		
		Severe	L	H	M		
C11	Computer access floors	Light	L	L	L	yes	56
		Mod	L	L	M		
		Severe	L	M	M		
STORAGE OF RECORDS AND SUPPLIES							
C12	Book shelves, library stacks (over 5 feet)	Light	L	L	L	yes	58, 59, 60
		Mod	H	M	M		
		Severe	H	M	M		

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C13	Tall vertical or lateral file cabinets	Light	L	L	L	yes	61
		Mod	M	M	M		
		Severe	H	M	M		
C14	Tall storage racks or shelving	Light	L	L	L		
		Mod	H	M	M		
		Severe	M	M	L		
C15	Emergency supply cabinet (water, medicine, food, etc.)	Light	L	L	L		
		Mod	L	L	L		
		Severe	M	M	M		
C16	Especially valuable and fragile merchandise	Light	L	M	L		
		Mod	L	H	L		
		Severe	L	H	L		
KITCHEN AND LAUNDRY EQUIPMENT							
C17	Large kitchen or laundry equipment	Light	L	L	L		
		Mod	M	M	L		
		Severe	H	M	M		
C18	Gas and/or electric hook-up	Light	L	L	L		62
		Mod	M	H	H		
		Severe	H	H	H		
C19	Drawer and cabinet latches (kitchen, laboratory, office, etc)	Light	L	L	L		63
		Mod	L	L	L		
		Severe	L	M	M		

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C20	Freestanding wood stove (wood, pellet, or gas-fired)	Light	L	L	L		64
		Mod	L	L	L		
		Severe	M	M	M		
HAZARDOUS MATERIALS							
C21	Compressed-gas bottles or cylinders (oxygen, CO ₂ , ammonia, etc.)	Light	L	L	L		65
		Mod	M	M	L		
		Severe	H	M	M		
C22	Chemical, laboratory, or medical supplies	Light	L	L	L	yes	66
		Mod	H	M	L		
		Severe	H	M	M		
C23	Cabinets for hazardous materials	Light	L	L	L	yes	
		Mod	H	M	H		
		Severe	H	M	H		
C24	Asbestos	Light	L	M	M		
		Mod	L	H	H		
		Severe	L	H	H		
FURNITURE, INTERIOR DECORATION							
C25	Potted plants or indoor landscaping resting on shelves above the floor	Light	L	L	L		69
		Mod	L	L	L		
		Severe	M	L	L		
C26	Valuable and fragile artwork or decorative vases	Light	L	L	L		67
		Mod	L	H	L		
		Severe	L	H	L		

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C27	Freestanding half-height movable partitions	Light	L	L	L		68
		Mod	L	L	L		
		Severe	M	M	M		
C28	Miscellaneous furnishings	Light	L	L	L		69
		Mod	L	M	L		
		Severe	L	M	L		
C29	Lockers, vending machines	Light	L	L	L		
		Mod	H	M	L		
		Severe	H	M	L		

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