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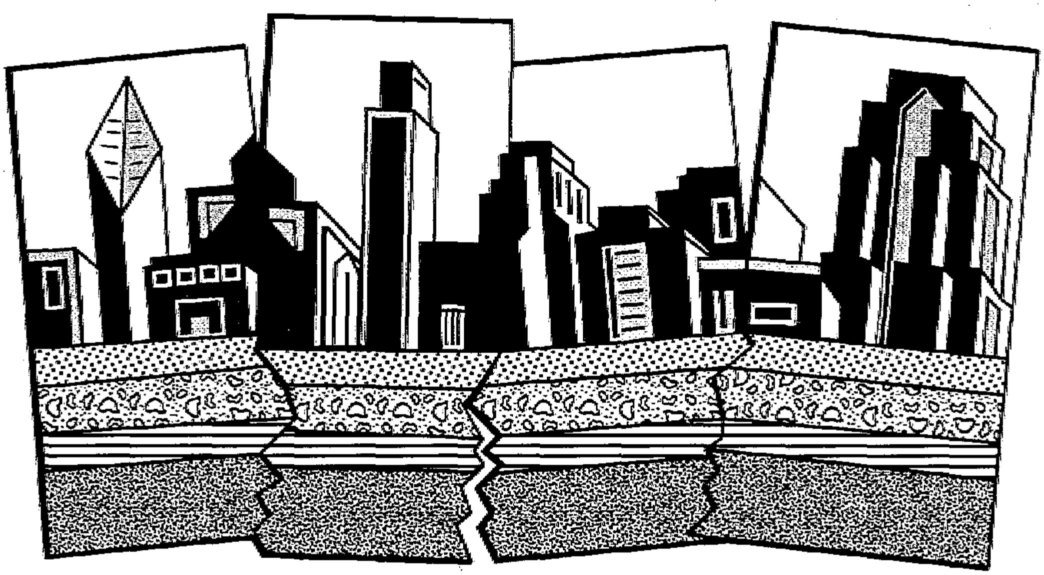
Supersedes 1985 Edition

# Reducing the Risks of Nonstructural Earthquake Damage



## A PRACTICAL GUIDE

Issued by FEMA in furtherance of the Decade for Natural Disaster Reduction

# Reducing the Risks of Nonstructural Earthquake Damage

# A Practical Guide

**Third Edition**

**FEMA 74/September 1994**
**Supersedes 1985 Edition**

Originally developed by Robert Reitherman of Scientific Service, Inc., for the Southern California Earthquake Preparedness Project (SCEPP)

Third Edition by
**WISS, JANNEY, ELSTNER ASSOCIATES, INC.**
For the Federal Emergency Management Agency (FEMA)
Under the National Earthquake Technical Assistance Contract (NETAC) EMW-92-C-3852

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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

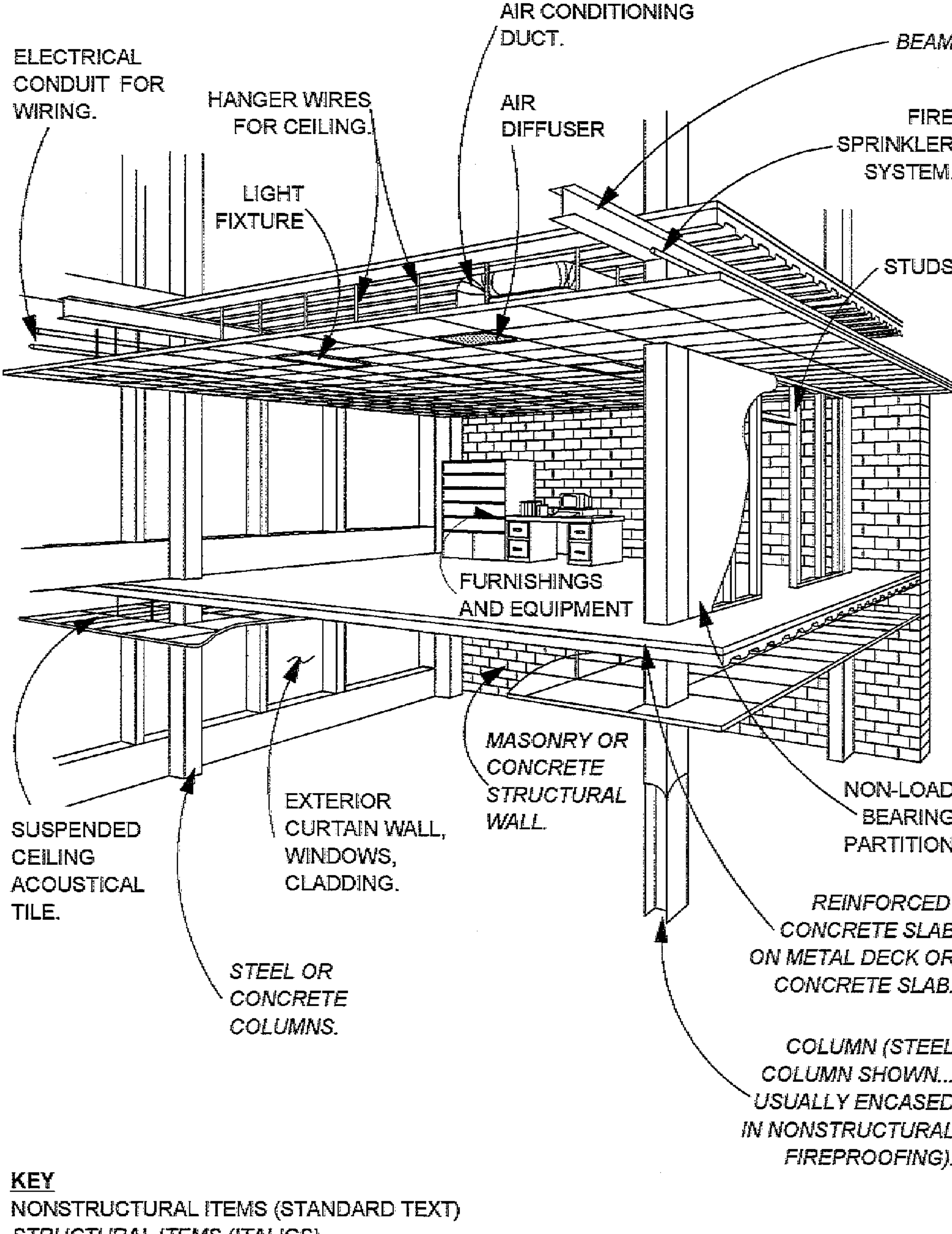



**Figure 1 - Nonstructural and Structural Components of a Typical Building**

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].

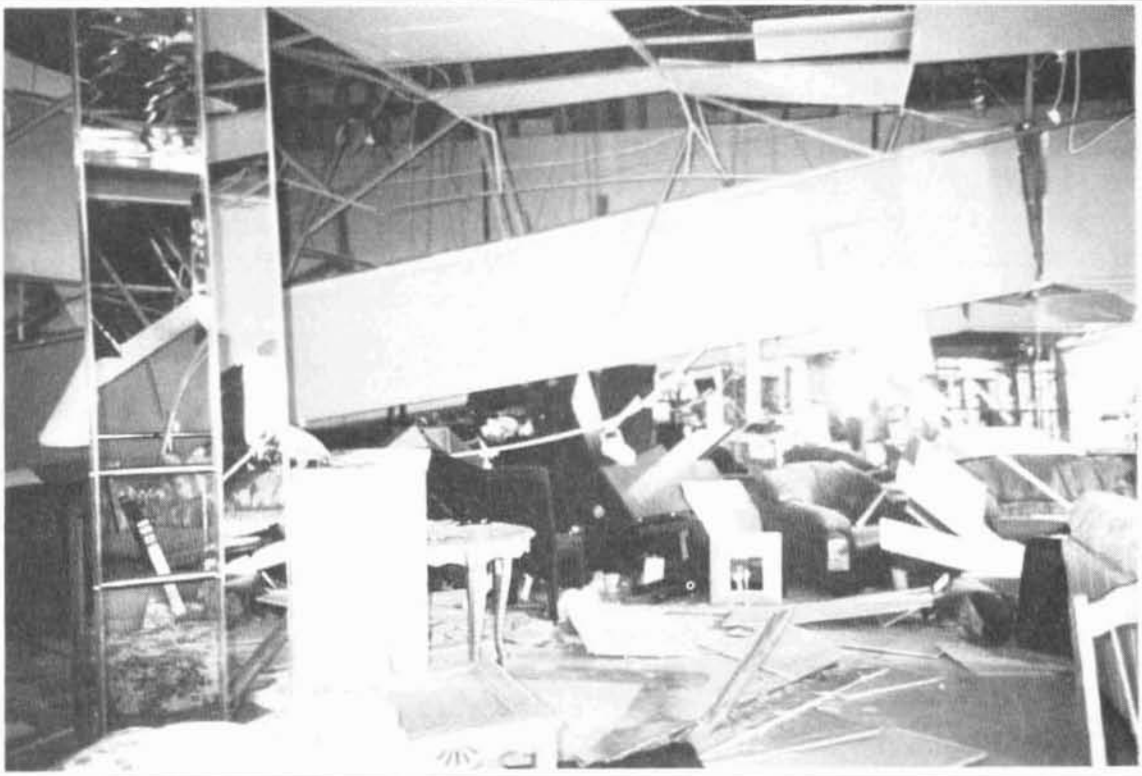
- One hospital patient on a life-support system died during the 1994 Northridge earthquake because of failure of the hospital's electrical supply [3].

- 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 McKevitt

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.

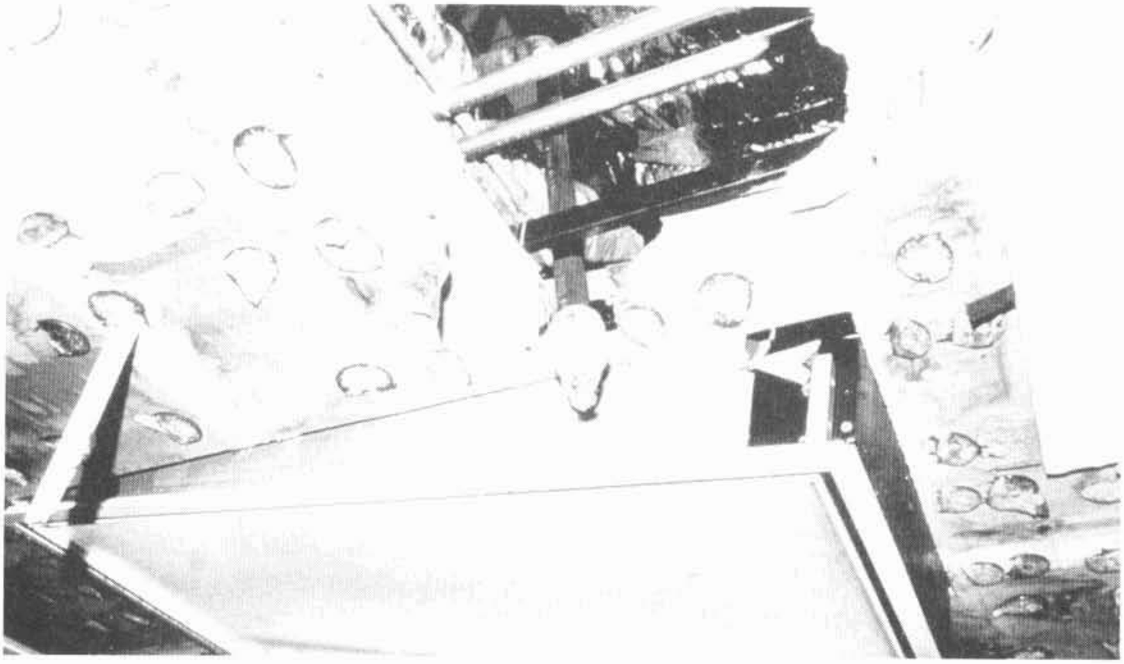
The following are examples of nonstructural damage that resulted in interruptions to postearthquake emergency operations or to business.

- 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

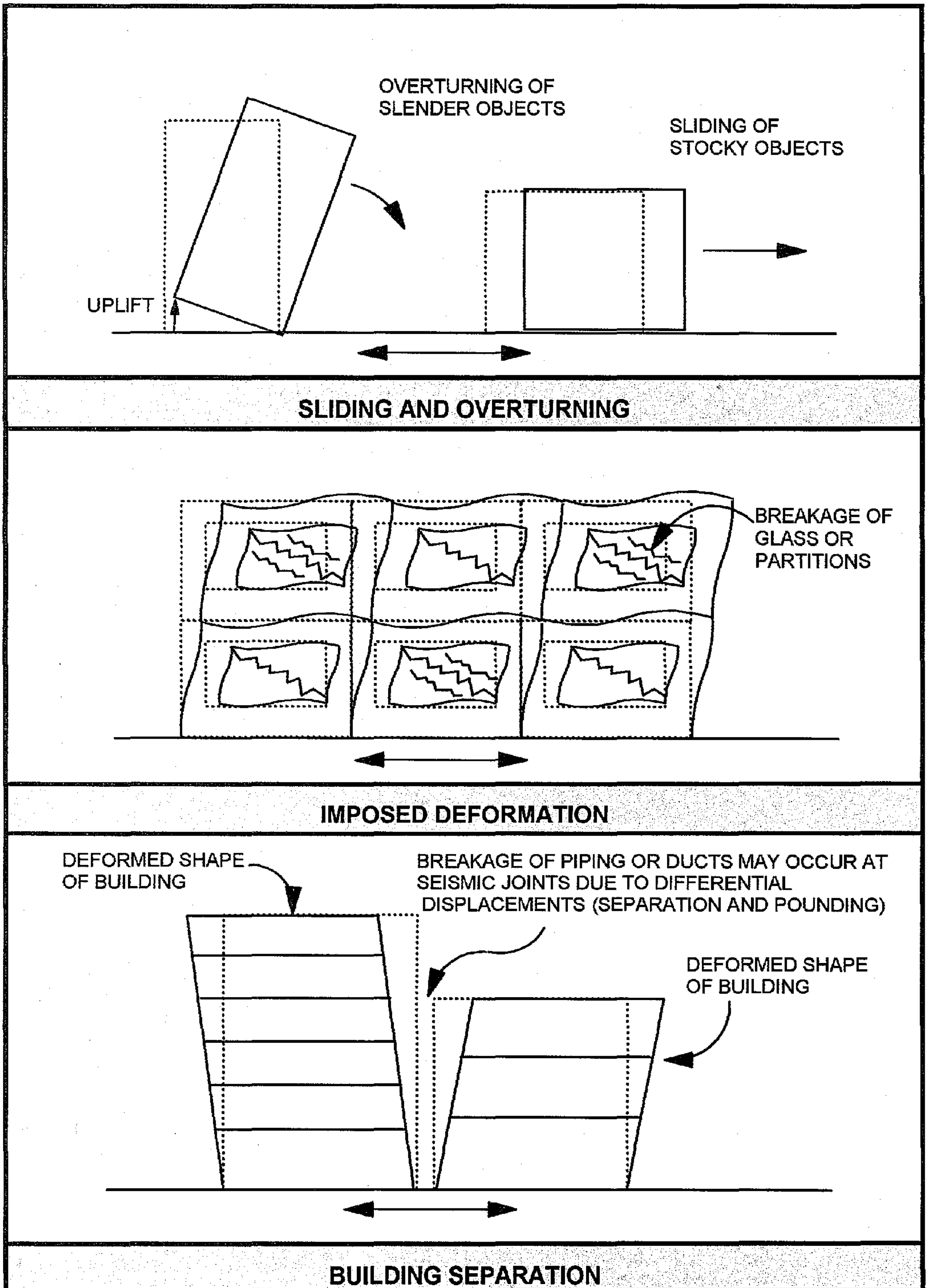



**Figure 6 - Effects of Earthquakes on Nonstructural Components**

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