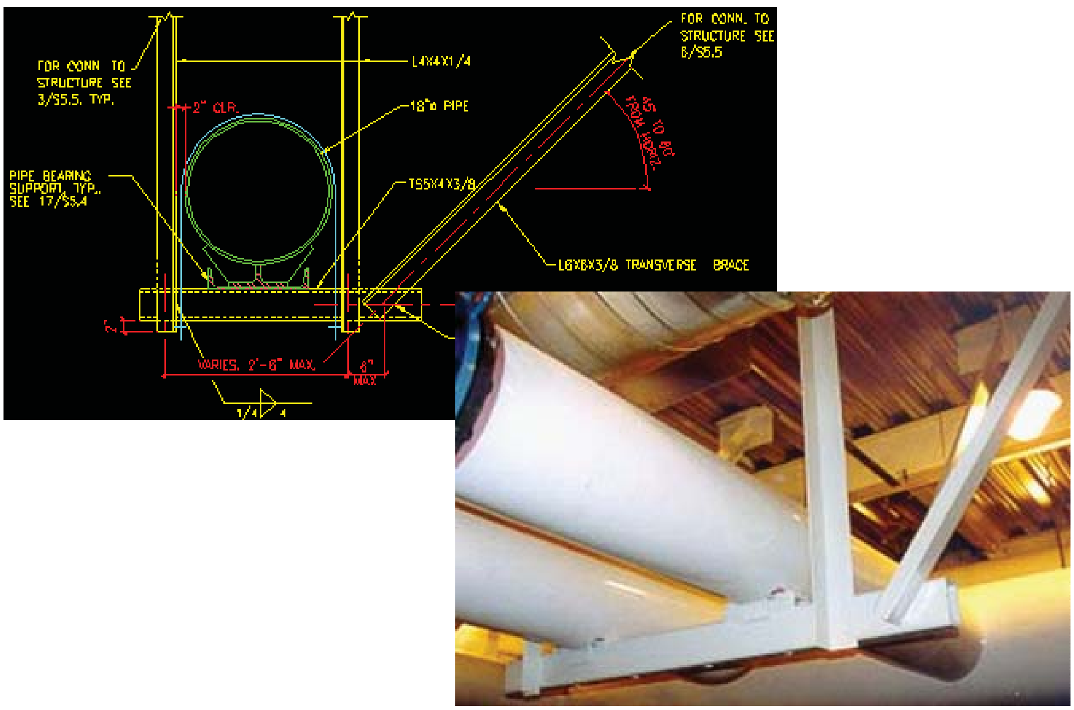
ATC 69

Reducing the Risks of Nonstructural Earthquake Damage

State-of-the-Art and Practice Report



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State-of-the-Art and Practice Report

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Preface

In September of 2006, under its ongoing "Seismic and Multi-Hazard Technical Guidance Development and Support" contract (HSFEHQ-04-D-0621) with the Federal Emergency Management Agency (FEMA), the Applied Technology Council (ATC) was awarded a task entitled "Update of FEMA 74, Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide," designated the ATC-69 Project. The primary objective of this project is to update the third edition of the FEMA 74 report, *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide*, issued by FEMA in 1994.

FEMA 74 explains the sources of earthquake damage that can occur in nonstructural components, and provides information on effective methods of reducing risk associated with nonstructural earthquake damage. It is intended for use by a lay audience, including building owners, facility managers, maintenance personnel, store or office managers, corporate/agency department heads, and homeowners. The reference material contained within the third edition of FEMA 74 is now approaching 20 years old. A considerable amount of new information now exists as a result of ongoing National Earthquake Hazard Reduction Program (NEHRP) activities, local and state government programs, private sector initiatives, and academic work focused on reducing the potential for nonstructural earthquake damage.

This State of the Art and Practice Report presents the results of research conducted on the current state of knowledge and practice with regard to bracing and anchorage of nonstructural components and contents. It serves as background information for the update of FEMA 74, and provides context for expanding future guidance on reducing the risk of nonstructural earthquake damage, considering different classes of components, different audiences or stakeholder groups, and higher performance objectives.

ATC gratefully acknowledges the ATC-69 Project Management Committee, including Maryann Phipps, Robert Bachman, James Carlson, Eduardo Fierro, Richard Kirchner, and Cynthia Perry, for their efforts in researching and developing the material contained in this report. The affiliations of these individuals are provided in the list of project participants.

ATC also gratefully acknowledges Cathleen Carlisle (FEMA Project Monitor) and Barry Welliver (Subject Matter Expert) for their input and

guidance in the preparation of this report, Peter N. Mork for ATC report production services, Thomas R. McLane as ATC Project Manager, and Steven Kuan as ATC Board Contact on this project.

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Chapter 1

Introduction

This report summarizes the current state of knowledge and practice regarding the seismic performance of nonstructural components of buildings. It addresses architectural, mechanical, electrical, and plumbing components, which are typically considered to be part of the building and the responsibility of the building owner. It also addresses building contents, such as furniture and movable partitions, which are typically the responsibility of the building occupant.

Information contained in this report is the result of interviews with architects, engineers, building officials, equipment manufacturers and contractors practicing in seismically active regions across the United States, and an extensive literature search of available information on nonstructural seismic design practice and earthquake damage to nonstructural components. Nonstructural damage cited in this report involves direct earthquake damage to nonstructural components. Damage caused by unintended interaction between nonstructural components and the structural system is outside the scope of this study.

The purpose of this report is to: (1) assess current knowledge and practice regarding nonstructural earthquake damage and its prevention; (2) recommend steps that can be taken to improve seismic performance of nonstructural components and contents; and (3) identify practical needs and available resources that could be used as a basis for updating FEMA 74, *Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide, Third Edition*, published in 1994.

This report is organized as follows:

Chapter 1 Introduction

Chapter 2 Global Context for Nonstructural Issues - An overview of nonstructural problems in terms of overall international seismic risk.

Chapter 3 Nonstructural Damage Data Collected from Past Earthquakes – A discussion of challenges associated with the collection of data on nonstructural earthquake damage, and a discussion of the performance of nonstructural components during past earthquakes.

Chapter 4	Code Requirements for Nonstructural Components and Contents – A chronicle of the historic foundation from which current code provisions have evolved, a description of 2006 International Building Code requirements, and a discussion of other code-related issues.
Chapter 5	Current Practice for Seismic Design and Installation of Nonstructural Components in the United States – A summary of information gathered by the project team regarding current design, plan review, construction and inspection practices.
Chapter 6	Guidance Documents Relevant to Seismic Design and Installation of Nonstructural Components – A compendium of handbooks and guidelines that are available to assist with nonstructural hazard mitigation.
Chapter 7	Nonproprietary Details and Other Resources for Nonstructural Components - A bibliography of reference materials and resources that provide standard or generic details for the seismic anchorage or restraint of nonstructural components and contents.
Chapter 8	Proprietary Details and Products for the Protection of Nonstructural Components – A reference list of some of the many types of proprietary details, devices, and systems that are currently available for the seismic anchorage or restraint of nonstructural components and contents.
Chapter 9	Recent and Ongoing Research and Development on Nonstructural Issues – An overview of selected recent and ongoing research in this area.
Chapter 10	Future Needs – Recommendations for FEMA 74 and beyond.
Appendices	Reference tables containing expanded lists of nonstructural earthquake damage and resource materials summarized in this report.

Chapter 2

Global Context for Nonstructural Issues

Many have suggested that global seismic risk is on the rise as a result of increased global population. Tragically, earthquakes in many countries can still be expected to result in significant loss of life. This is particularly true for urban populations in developing countries, where codes addressing seismic issues have not been adopted or implemented, and the risk of wholesale structural collapse remains high. For these communities, the primary concern is related to preventing catastrophic structural collapse.

In developed countries, or areas where codes addressing seismic issues have been implemented, improved seismic design and construction practice has helped to reduce the possibility of catastrophic structural collapse. Over time, as structural systems and technologies improve, and older buildings are demolished or upgraded, an increasing number of structures can be expected to survive major earthquakes without significant structural damage or collapse. Eventually, the concern for earthquake risk is expected to shift to where the majority of the focus is on damage to nonstructural systems and contents.

Since 1970, only two people per year on average have died in the United States due to building collapse, even though this period includes a number of large, damaging earthquakes. Average economic loss during this same period has been about $2 billion per year. A FEMA study based on theoretical simulations suggests that future economic losses due to earthquakes could average $4.5 billion per year (Kircher, 2003).

The structural system of an engineered building in the United States typically represents between 10% and 20% of the overall construction cost. Depending on the type of construction, type of occupancy, and relative cost of mechanical, electrical and plumbing (MEP) systems and contents, this percentage can change. It can be somewhat higher for standard office buildings and somewhat lower for critical-care medical buildings and high technology manufacturing facilities, but the overall trend remains the same. A larger portion of the capital investment for constructing most buildings is dedicated to the nonstructural systems and the building contents.

The relative importance of nonstructural issues is on the rise, and the earthquake engineering community is faced with an increasing awareness of the enormous magnitude of potential losses associated with nonstructural damage. Long after the seismic performance of structural systems has been improved, the myriad of increasingly complex and costly nonstructural systems and contents in modern buildings will continue to present new challenges to the overall seismic performance of buildings.

Performance-Based Earthquake Engineering (PBEE), and the future of seismic design, will be fueled in part by the need to improve the seismic performance of nonstructural systems. Post-earthquake functionality and operability will not be delivered until effective strategies are devised to minimize nonstructural damage.

Chapter 3

Nonstructural Damage Data Collected from Past Earthquakes

3.1 General

Every earthquake that resulted in building damage has also resulted in damage to nonstructural components and building contents. Bottles on shelves have tipped, books in libraries have fallen, plaster and paint have cracked, and unreinforced masonry parapets have collapsed, even in small magnitude events. Nearly every earthquake report ever written has mentioned some type of nonstructural damage.

The Modified Mercalli Scale (MMI) of 1931 defines intensity on a scale of I to XII. Intensity levels from I through VII are defined in terms of the performance of nonstructural items, such as "small unstable objects displaced," "pendulum clocks stop," "windows, dishes, glassware broken," "books off shelves," "bells ring," "weak chimneys broken at roof line," "cornices and architectural ornaments fall," (Richter, 1957). Nevertheless, generating statistics regarding the extent of losses due to nonstructural damage remains elusive because data have not been collected in a way that allows for statistical analyses.

3.2 Problems with Collection of Nonstructural Earthquake Damage Data

The Earthquake Engineering Research Institute (EERI) and other professional organizations have published hundreds of accounts of earthquake damage, and have consistently reported on major international earthquakes since the 1960s. While nearly every report includes some information and photo documentation of nonstructural damage, most do not have sufficient information to generate statistical data regarding deaths and injuries, direct economic losses and repair costs, or downtime that can be attributed to failures of nonstructural components and contents.

Part of the problem with data collection is that the earthquake engineering community has divided building components into two groups: (1) the components of the structural system; and (2) all nonstructural components and systems plus the building contents. These groups are not consistent with ownership or insurance interests. Building components are typically owned, leased, and insured on the basis of two different groups: (1) the structural system plus all nonstructural systems, which are typically the responsibility of the building owner; and (2) building contents, which are typically the responsibility of the building tenant or occupant.

In a building with minor structural damage and major nonstructural damage, only the earthquake engineering community is interested in apportioning these losses between structural damage, nonstructural damage, and content damage. A building owner may file a claim for earthquake damage, but the claim usually lumps structural and nonstructural damage together. A building may have experienced economic losses associated with content damage and downtime, but in a building occupied by multiple tenants, this information is not likely to exist in any one complete and consistent source. In the absence of a financial or other stakeholder need to collect nonstructural loss data in the proper format, the data become very hard to find.

Most detailed earthquake reconnaissance efforts have been devoted to gathering data following catastrophic earthquake events. In these situations, it is often hard to get a handle on total losses. Reconnaissance teams often focus on spectacular and photogenic failures, such as collapsed buildings and heavily damaged structures. When nonstructural damage is investigated, teams are typically directed to locations with collapsed ceiling grids or broken water pipes, and not to the many locations where these components may not have failed. Damaged contents are often cleaned up before reconnaissance teams arrive. Damaged infrastructure, such as water piping, electrical, and mechanical distribution systems may be repaired soon after the event, but cracked gypsum board walls may be painted months or years later, as part of routine maintenance.

Detailed earthquake reconnaissance efforts are also time consuming and expensive. Reitherman (1998) discusses the types of data needed, difficulties in gathering these data, and costs involved in collecting such data. Although EERI Reconnaissance Team labor was provided free of charge after the 1994 Northridge Earthquake, the cost of gathering and reporting nonstructural damage data, as it was performed, was estimated to have been $275,000. To perform data collection to a higher (recommended) level of quality and completeness, the estimated cost would have been $750,000. For an earthquake four times the size of the Northridge earthquake, which is within the credible limits of damage for California earthquakes, the estimated cost would have been approximately $1.5 million.

While several researchers have developed their own methods of collecting data, there are no current standards for the collection, organization and presentation of damage data, making it hard to compare across data sets or draw meaningful conclusions from a given data set. Within one such data set, the Nonstructural Damage Database, MCEER-99-0014 (Kao and Soong, 1999), there are 1,264 unique descriptions for the category "equipment." Within another data set, the ATC-38 database on the performance of structures near strong-motion recordings (ATC, 2000), some nonstructural components are subdivided by type, while others are not. In "A Taxonomy of Building Components for Performance-Based Earthquake Engineering," Porter (2005) has attempted to address some of these issues, and a standardized taxonomy to characterize nonstructural items has been proposed.

Bachman (2004) suggests that we have reached a point where nonstructural component and building content losses in recent events in developed countries represent 50% of total earthquake losses, but it is hard to find sufficient data to substantiate this view. Projections of damage from the 1994 Northridge Earthquake, for example, are based largely on a simulation of damage using HAZUS and ShakeMap, rather than on actual damage data. According to Kircher (2003), "comprehensive data on building damage do not exist for the Northridge Earthquake, and comprehensive nonstructural damage data are even harder to come by."

As a result, even EERI reports that have a special chapter on nonstructural damage, most notably the report on the 1994 Northridge Earthquake (Reitherman et al., 1995), have only limited information useful for generating meaningful statistics on overall losses from damage to nonstructural components and contents. For example, it is usually not possible to know how many lineal feet of sprinkler piping failed during a particular earthquake, as a percentage of the total lineal feet of sprinkler piping in an affected area. Information is not available on the specifics of which sprinkler components were damaged, the cost to repair damaged sprinkler piping, the number of injuries, and to what extent business interruption could be attributed to broken sprinkler lines.

3.3 Available Nonstructural Earthquake Damage Data

Appendix A, Table A-1, summarizes data from a sampling of major earthquakes in the United States and abroad. Much of this information was obtained from EERI Reconnaissance Reports. Organized by earthquake in reverse chronological order, the table lists the name and date of the earthquake, source of the information, and a brief description of available information on nonstructural damage. Many reports cited in Table A-1 include illustrative photos along with anecdotal evidence of damage to nonstructural components and contents. Statistical data are often scant, and conclusions about the overall impact of nonstructural damage cannot be drawn from the available reports, other than to say that it is clearly very significant.

Almost every type of architectural, mechanical, electrical, and plumbing component has been damaged in some earthquake, somewhere. Direct damage to nonstructural items has been compounded many times by the effects of leaking water or other fluids, the release of asbestos, toxic gases, chemicals, or other hazardous materials. Nonstructural components and contents that have been repeatedly reported as damaged include the following:

- Architectural components: partitions; suspended ceilings; storefronts; glazing; cladding and veneers; unreinforced masonry parapets, chimneys, and fences; and architectural ornaments.
- Mechanical, Electrical, Plumbing (MEP) components: small bore piping such as sprinkler distribution lines; large bore piping; pressure piping; connections of piping to equipment; ductwork; suspended lighting; roof mounted equipment; spring isolated equipment; elevators; water heaters; and vertical tanks.
- Contents: tall shelving; book cases; inventory stored on shelving such as retail merchandise, liquor bottles, library books, and medical records; computers and desktop equipment; wall and ceiling mounted TVs and monitors; file cabinets; industrial chemicals or hazardous materials; and museum artifacts and collectibles. Also classified as “contents,” larger items such as industrial storage racks and specialty building service equipment (e.g., medical equipment including CT scanners, operating room lights, and refrigerators) are also frequently reported as damaged.

Porter (2002) cites a number of damage surveys performed over the years, some of which included nonstructural damage. He notes that not all of these data are readily available in the public sector. The ATC-38 Project database is one such data set from the 1994 Northridge Earthquake that is publicly available. Another readily available database is the MCEER-99-0014 Nonstructural Damage Database, which includes 2909 entries for nonstructural damage taken from reports covering 52 international earthquakes between 1964 and 1999.

While the MCEER database is the most extensive database of nonstructural damage information found, it has limitations. There are only five categories covering all types of equipment, and seven categories covering all building types. A category for "damage ratio" is included, but only 371 (or 13%) of the 2909 entries have any data in this category, and the information provided is limited. Sample database entries on nonstructural damage include: for ceilings, "50% of tiles fell;" for sprinkler lines leaking, "throughout;" for generators, "1/3" (meaning that 1 of 3 emergency generators was damaged).

3.4 Ongoing Problems with the Performance of Nonstructural Components

As more recent data in Table A-1 show, problems with inadequate performance of nonstructural components continues to occur. In spite of past efforts to improve bracing and anchorage of nonstructural components and contents, particularly in California hospitals and schools, costly failures are still possible. The Olive View Hospital, which suffered extensive structural damage following the 1971 San Fernando Earthquake, was demolished and rebuilt using a stronger and more rigid structural system. It was evacuated again following the 1994 Northridge Earthquake due to nonstructural damage to ceilings, sprinkler piping, and chilled water piping, and the resultant water damage throughout the facility (Reitherman et al., 1995).

This is largely the result of the way building codes have been written, interpreted, and applied in practice. Historically, despite the presence of code provisions regulating seismic design of nonstructural components, the design and installation of architectural, mechanical, electrical and plumbing systems has traditionally been done without consideration of seismic forces or checks for compatibility of deformations. The continued poor performance of these components has prompted changes in the building codes, and an increasing number of items are subject to minimum seismic design requirements, but the implementation and enforcement of these design provisions has been inconsistent.

Problems with the performance of nonstructural components can be expected to continue. New types of nonstructural components and contents are continually being invented. As technology is relied upon more heavily in homes, offices, hospitals, airports, and schools, there are increasing numbers of objects to address, and new potential economic and safety risks. Many homes now have heavy wall-mounted televisions, public places have suspended cameras and monitors, and plenum spaces above office ceilings are becoming increasingly congested with additional overhead items. Tall buildings are becoming taller in many metropolitan areas, and potential falling hazards associated with glazing, cladding, and veneers are compounded. The list of nonstructural components and contents will continue to grow, as will the complexity of restraining many new and interconnected nonstructural systems.

3.5 Nonstructural Components that Interact with Structural Systems

Nonstructural earthquake damage cited in this report involves direct damage to nonstructural components only. While most nonstructural components do not affect the seismic performance of structural systems, it is important to point out that some do. Rigid nonstructural components that are not isolated from the structural system can have an unintended influence on the structural system, often precipitating failure or collapse. Damage to structural systems caused by unintended interaction with nonstructural components is outside the scope of this project, and this type of damage has been excluded from the information contained in Appendix A, Table A-1.

One example of this type of interaction is a common cause of structural failure observed in concrete buildings. A short column effect can be created by rigid nonstructural components that interact with structural columns, reducing the effective height over which the columns can deform. Short columns are most often caused by masonry infill walls adjacent to concrete columns, but failures have also been caused by rigid handrails, precast panels, masonry planters, or heavy steel window mullions.

While not a focus of this report, potential interaction between structural and nonstructural components is an important issue, and is addressed in current structural and nonstructural component design requirements. Designers are required to check for compatibility of deformations between the structural system and nonstructural components in order to avoid any unintended interactions and adverse effects on the performance of the building.

Chapter 4

Code Requirements for Nonstructural Components and Contents

4.1 Building Code Requirements

Codes regulate building construction and use in order to protect the health, safety and welfare of building occupants. In the United States, model codes are developed by codes and standards organizations, and adopted by local jurisdictions. A number of federal agencies, including the U.S. Department of Defense, the National Park Service, the Department of State, and the Forest Service, use private-sector model codes for projects funded by the federal government.

Prior to 2000, there were three organizations producing three model building codes in the United States. These were the International Conference of Building Officials (ICBO), which produced the *Uniform Building Code* (UBC), the Southern Building Code Congress International (SBCCI), which produced the *Standard Building Code*, and the Building Officials and Code Administrators International, Inc. (BOCA), which produced the *National Building Code*. Because the organizations that developed these codes were located in different regions of the country, they focused on criteria for natural hazards that were most important in their region. The UBC focused on requirements for seismic hazard, and was the model code adopted in the Western United States, Alaska, and Hawaii. Seismic requirements for nonstructural components have been included in the UBC for over 70 years.

In 1972, the American National Standards Institute (ANSI) published ANSI A58.1-1972, *Minimum Design Loads for Buildings and Other Structures*. The basis of seismic requirements for nonstructural components contained in ANSI A58.1-1972 was the 1970 UBC. In 1982, ANSI A58.1 was updated on the basis of seismic requirements contained in the 1979 UBC. In 1973, SBCCI and BOCA adopted ANSI 58.1-1972 by reference, and in 1985, both adopted ANSI A58.1-1982. As a result, seismic requirements in the United States prior to 1993 were based on the *Uniform Building Code* (although the versions were not the same everywhere).

In 1993, BOCA adopted seismic requirements based on the 1991 edition of the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* (BSSC, 1991), and SBCCI did the same in 1994. In 1996, BOCA referenced ASCE 7-95 *Minimum Design Loads for Buildings and Other Structures* (ASCE, 1996), and SBCCI did so in 1997. The seismic requirements in ASCE 7-95 were based on the 1994 *NEHRP Recommended Provisions* (BSSC, 1994).

In the mid-1990s, the three model code organizations formed the International Code Council (ICC) to develop one model code for use throughout the United States. This code was to be called the *International Building Code* (IBC), and was scheduled for initial publication in 2000. The seismic requirements for the IBC were to be based primarily on the 1997 *NEHRP Recommended Provisions* (BSSC, 1997).

In anticipation of what would be the 2000 IBC, a substantial revision of the seismic requirements was included in the publication of the 1997 UBC. For nonstructural components specifically, seismic requirements were a blend of requirements found in the 1994 *NEHRP Recommended Provisions*, and what was anticipated for the 1997 *NEHRP Recommended Provisions*.

Following publication of the IBC in 2000, local jurisdictions gradually began phasing out the BOCA, SBCCI, and UBC documents. In 2006, the IBC fully referenced ASCE/SEI 7-05 *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2006) for its seismic requirements, which are based on the 2003 *NEHRP Recommended Provisions* (BSSC, 2004). Thus, the key resource documents for seismic design in the United States have been the *Uniform Building Code*, the *NEHRP Recommended Provisions*, the *International Building Code*, and ASCE/SEI 7.

The following chronology of seismic requirements for nonstructural components is taken from selected editions of the UBC and IBC model codes. It summarizes the historic foundation from which current model code provisions have evolved. This discussion is focused on model codes in the United States. Appendix B, Table B-1, lists U.S. codes, along with selected codes in use in other countries, which contain seismic provisions for nonstructural components and contents.

1937 UBC, Section 2312: The formula for lateral force on elements of structures and nonstructural components was

$$F = CW$$

where C was a coefficient equal to 0.05 for walls, towers and tanks, and 0.25 for exterior and interior ornamentation and appendages, and W was the weight of the component under consideration.

1961 UBC, Section 2312: The formula for lateral force on elements of structures and nonstructural components was

$$F_p = ZC_pW_p$$

where, in the highest seismic zone (Zone 3) Z was equal to 1, C_p was a coefficient with a typical tabulated value of 0.2, and W_p was the weight of the component under consideration. Thus, the design force for the seismic restraint of a nonstructural component in a high seismic zone was 20 percent of its weight.

1976 UBC Section 2312(g): The formula for lateral force on elements of structures and rigid nonstructural components was

$$F_p = ZIC_pW_p$$

where, in the highest zone (Zone 4) Z was equal to 1, C_p was 0.3 for most rigid items, and the value of the importance factor, I, ranged from 1.0 to 1.5. Thus, the design force the seismic restraint of a nonstructural component, in a typical building, in a high seismic zone, was 30 percent of its weight.

1988 UBC Section 2312(g): The formula for lateral force on elements of structures and nonstructural components was

$$F_p = ZIC_pW_p$$

where, in the highest zone (Zone 4) Z was equal to 0.4, C_p was 0.75 for most rigid items and 1.5 for most nonrigid items, and the value of I ranged from 1.0 to 1.25. Thus, the design force the seismic restraint of a nonstructural component, in typical building, in a high seismic zone, remained at 30 percent of its weight. Explicit requirements for the dynamic response of nonrigid items was addressed through the increased C_p factor, and a 2/3 factor could be applied to reduce the design force for items supported at grade.

1994 UBC Section 2312(g): The 1994 UBC formula was similar to the 1998 UBC formula, although the maximum value of the importance factor, I, was returned to 1.5, as in earlier editions of the code.

Despite the presence of seismic requirements for nonstructural components in model codes since 1937, the practice of designing for the seismic restraint of nonstructural components has evolved slowly over time. First, there has been a lag between the creation of a model code provisions and adoption by local jurisdictions. Second, after adoption by a local jurisdiction, implementation of nonstructural code provisions has taken many years to become common practice. Code provisions for the design of cladding, parapet walls, and earthquake bracing of overhead sprinkler piping were among the first nonstructural provisions to be widely implemented. Enforcement and implementation of code requirements for other nonstructural components and contents have been increasing with time.

The 1989 Loma Prieta Earthquake caused an unprecedented amount of nonstructural damage, but the adequacy of the model code provisions for nonstructural components was not seriously challenged until after the 1994 Northridge Earthquake. The Northridge Earthquake caused closure of the newly reconstructed Olive View Hospital. Maximum accelerations of 0.82g at the base and 1.7g at the roof were recorded, yet the structural system performed without significant damage. Compromised fire sprinkler and chilled water piping, however, led to evacuation of the building. Additional nonstructural damage to electrical and mechanical equipment was documented.

Focused efforts by concerned structural engineers led to the revised model code provisions contained in the 1997 edition of the UBC. Notably, the formula for lateral force on elements of structures and nonstructural components was refined to reflect amplification of seismic forces over the height of a building.

1997 UBC Section 1632: The formula for lateral force on elements of structures and nonstructural components is

$$F_p = \frac{a_p C_a I_p \left(1 + 3h_x / h_r\right)}{R_p} W_p$$

where a_p is a component amplification factor ranging up to 2.5, but typically equal to1.0 for rigid items; C_a is a seismic coefficient related to soil profile and seismic zone, with a value up to 0.88 on soft soil sites in the near-field, and equal to 0.4 for competent soil sites in areas of high seismicity outside near field; I_p is unchanged from previous codes; and R_p is a component response modification factor ranging from 1.5 to 4.0, with a typical value of 3.0 assigned to most ductile components and attachments. Maximum and minimum limits on design force are also provided. Thus, for a typical rigid component, in an area of high seismicity, outside the near-field, the design force remained at approximately 30 percent of its weight when located at the base of the building, and increased to 60 percent of its weight when located at the roof. For a flexible component located at the roof, the design force would be 180 percent of its weight. Unlike in prior editions of the code, these forces are “strength” level rather than “allowable” level forces. Allowable level forces can be obtained by dividing strength level forces by 1.4.

The 1997 UBC also contained language excluding specific items from the requirements for explicit seismic design. According to this edition of the code, the attachments of the following items did not need to be detailed on construction plans: floor-mounted components under 400 pounds; vibration-isolated equipment weighing less than 20 pounds; wall-mounted or suspended equipment weighing less than 20 pounds; and furniture.

In essential and hazardous buildings, the 1997 UBC also required consideration of the effects of relative motion of the points of attachment to the structure using maximum calculated estimates of drift.

2006 IBC (ASCE/SEI 7-05 Section 13.1): ASCE/SEI 7-05 is adopted by reference in the 2006 IBC. It contains design requirements for both force- and displacement-controlled nonstructural components. The formula for lateral force on elements of structures and nonstructural components is

$$F_p = \frac{0.4 a_p S_{DS} \left(1 + 2z/h\right)}{\left(R_p / I_p\right)} W_p$$

where a_p is unchanged from the previous editions of the UBC; S_{DS} is the spectral acceleration at short periods; R_p is a component modification factor that varies from 1 to 12; I_p is a component importance factor (rather than a building importance factor as in previous editions of the UBC), and is equal to 1.0 for typical components, or 1.5 if a component must remain operational after an earthquake or contains hazardous materials; z is the height in the structure at the point of attachment; and h is the height of the roof. Maximum and minimum limits on design forces are very similar to those found in the 1997 UBC.

The formula for lateral displacement on nonstructural components is

$D_p = \delta_{xA} - \delta_{yA}$.

where δ_{xA} and δ_{yA} are the deflections of a building at levels x and y determined on the basis of an elastic analysis.

Tables of design coefficients a_p and R_p have been expanded to more thoroughly address the scope of architectural, mechanical and electrical components encountered. The following items are specifically exempt from the ASCE/SEI 7-05 seismic design requirements for nonstructural components:

1. Most components in Seismic Design Categories B and C (i.e., normal occupancies in areas of moderate seismicity).
2. Mechanical and electrical components in Seismic Design Categories D, E and F, where I_p is equal to 1, and both of the following conditions apply:
    a. flexible connections between the components and associated ductwork, piping and conduit are provided, and
    b. components are mounted at 4 feet or less above a floor level and weigh 400 pounds or less.
3. Mechanical and electrical components in Seismic Design Categories D, E and F, where I_p is equal to 1, and both of the following conditions apply:
    a. flexible connections between the components and associated ductwork, piping and conduit are provided; and
    b. the components weigh 20 pounds or less or, for distribution systems, weigh 5 pounds per foot or less.

Earlier provisions related to nonstructural components in the 2000 and 2003 IBC were concerned primarily with position retention, i.e., preventing components from becoming dislodged or overturned during an earthquake. ASCE/SEI 7-05 contains additional provisions related to post earthquake functionality that are applicable to components with hazardous contents and equipment that is required to remain operational following an earthquake. For such components, certification based on approved shake table testing or experience data must be submitted to the authority having jurisdiction.

4.2 Enforcement of Code Requirements

The effectiveness of model code requirements governing seismic design of nonstructural components depends on technically sound code provisions, proper application by designers, and code enforcement. Proper enforcement requires both comprehensive plan review and thorough construction inspection.

4.2.1 Plan Review

Comprehensive plan review includes: (1) a determination of which items require seismic design; and (2) examination of the details for compliance with code requirements. Determining which items require seismic bracing involves a review of the construction drawings and specifications for each discipline (e.g., architectural, electrical, mechanical, plumbing and other specialties). Few jurisdictions, if any, have resources devoted to such a comprehensive review of construction documents, and few jurisdictions have reviewers qualified to comprehensively evaluate compliance with all nonstructural code requirements.

An additional challenge in plan review arises from the many items that are commonly excluded from the construction drawings, but are identified in the project specifications to be procured from the contractor on a “design-build” basis. Unless these items are carefully tracked and submitted for review, building department plan review can be nonexistent. Few jurisdictions have mechanisms in place to track and support ongoing review of nonstructural seismic bracing designs developed during construction.

4.2.2 Construction Inspection

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

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

The 2006 IBC contains requirements for special inspection of designated seismic systems. For most buildings, a written statement of special inspection must be prepared by a registered design professional. In buildings assigned to Seismic Design Categories C, D, E or F, the statement of special inspection must include seismic requirements for selected HVAC components, piping systems and electrical equipment. These code requirements are expected to increase the construction oversight of nonstructural installations, and ultimately improve the seismic performance of nonstructural components.

4.3 Other Standards and Protocols

Many of the challenges related to design, plan review, and construction inspection are resolved when installation in accordance with nationally accepted standards becomes a construction standard of practice. For example, the IBC accepts seismic restraint of fire protection systems designed in accordance with National Fire Protection Association, *NFPA 13: Standard for the Installation of Sprinkler Systems*. As a result, verification of NPFA 13 compliance is a common occurrence in the field. Similar examples exist for other major nonstructural components. Installation of suspended ceilings in accordance with ASTM C635, ASTM C636 and the *Guidelines for Seismic Restraint for Direct-hung Suspended Ceiling Assemblies* (CISCA, 2004) is included in the IBC by reference. Selected additional industry standards are listed in Appendix B, Table B-1.

Qualification testing is an acceptable alternative to the analytical requirements of the code. The IBC accepts seismic qualification by testing based on nationally recognized testing procedures, such as the International Code Council Evaluation Service, ICC-ES AC 156 *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems*. Selected additional testing protocols are listed in Appendix B, Table B-1.

4.4 Requirements for Nonstructural Components in Existing Buildings

Modifications to existing buildings can trigger code requirements to improve the seismic restraint of existing nonstructural components. Such triggers include additions to existing buildings, changes in use, or alterations of a specified magnitude in terms of affected area or construction cost. For example, some jurisdictions require suspended ceilings to be brought into compliance with current seismic bracing requirements if modifications to the ceiling exceed a specified percentage of the ceiling area. In most cases, however, significant building improvements can be made without triggering improved seismic protection of existing nonstructural components.

A challenge associated with existing buildings is that new nonstructural components are regularly installed over the life of a building. This includes new furnishings, storage racks and specialty equipment, the replacement of aging equipment, installation of new piping, and updating of architectural components. Often these modifications fall outside the jurisdiction of the code, or are made without the benefit of a building permit. As a result, seismic protection of newly installed items becomes the responsibility of the installer, often without any oversight to ensure that adequate seismic protective measures are provided. Improper installations, such as piping installed across seismic joints without flexible connections, can easily occur and are highly vulnerable to damage in future earthquakes.

Another challenge associated with existing buildings is that seismic restraints included as part of an initial installation can be removed or compromised over time. This is commonly observed in items that are relocated during use, or require movement for servicing. Oversight is needed to ensure continued effectiveness of seismic protection measures for such components.

Chapter 34 of the 2006 *International Building Code* (ICC, 2006a), and the 2006 *International Existing Building Code* (ICC, 2006b) contain requirements for existing buildings. Systematic approaches to addressing the seismic restraint of nonstructural components and systems in existing buildings is also covered in several recently developed national standards. Among these are SEI/ASCE 31-03 *Seismic Evaluation of Existing Buildings*, and ASCE/SEI 41-06 *Seismic Rehabilitation of Existing Buildings*. Additional standards are listed in Appendix B, Table B-1.

4.5 Requirements for Contents

Building contents (e.g., furniture, movable partitions, and storage shelving) are typically considered separate from the building and are usually the responsibility of the building occupant. Many such items are specifically exempted from seismic provisions in model building codes (e.g., furniture, equipment weighing less than 400 pounds, and suspended items weighing less than 20 pounds). Regulated by the code or not, contents can pose an additional risk to safety and continuity of operations after an earthquake. The seismic protection of contents is dependent upon an understanding of potential seismic risk followed by action to mitigate that risk on the part of business owners, homeowners, and tenants. Building code provisions, guidance documents, or other resources listed in Appendix B can be effectively applied to the design and installation of seismic protection measures for building contents.

4.6 Validation and Refinement of Code Requirements for Nonstructural Components

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

Chapter 5

Current Practice for Seismic Design and Installation of Nonstructural Components in the United States

5.1 General

In current U.S. practice, limited attention is given to design and installation of seismically resistant nonstructural components. Exceptions include: (1) facilities such as hospitals, emergency operations centers, fire and police stations, located in areas of high seismicity and subject to strict state or federal regulations on post-earthquake operability; (2) California public schools; and (3) buildings with unusually valuable, hazardous, or essential contents such as museums, laboratories, or critical manufacturing facilities.

The manner in which seismic protection of nonstructural components is addressed varies widely from project to project. Even for similar projects, built in accordance with the same building code in the same seismic setting, approaches to design and installation of nonstructural components can range from comprehensive to incomplete. The range and scope of approaches is as varied as those that share responsibility for seismic protection. Responsible parties include: (1) owners; (2) design professionals including architects, mechanical engineers, electrical engineers, structural engineers and other specialty engineers who may be specifying equipment on a project; (3) general contractors; (4) subcontractors including plumbing subcontractors, mechanical subcontractors, electrical subcontractors, and the range of subcontractors associated with ceilings, interior partitions and exterior cladding; (5) material and equipment suppliers; (6) plan reviewers; and (7) construction inspectors. Each has a role to play in ensuring that important nonstructural components within a project are adequately protected. The action or inaction of any one responsible party can mean the difference between post-earthquake operability and the need to evacuate; or between protection of life safety and possible loss of life.

To date, the insurance industry and lending institutions have had a small to modest impact on the seismic design and installation of nonstructural components. The role that these institutions will eventually play in influencing seismic protection of nonstructural components is expected to increase when significant nonstructural losses are realized in future earthquakes.

5.2 Examples of Nonstructural Seismic Design Practice

Architects, engineers, building officials, equipment manufacturers, and contractors practicing in seismically active regions across the United States were interviewed to identify the "state of practice" related to the seismic protection of nonstructural components. Examples of nonstructural seismic design and installation practice are provided in the following sections.

5.2.1 Standard Occupancy Construction

Most design professionals in seismically active areas address the seismic protection of nonstructural components in standard occupancy buildings using a combination of standard details and performance specifications. In most areas outside of California and the Pacific Northwest, little or no specific attention is paid to the seismic protection of nonstructural components, other than fire sprinkler piping.

Seismic restraint of ceilings, partitions and other architectural items are often detailed on the architectural drawings. Anchorage of heavy floor-mounted or suspended equipment is shown on the drawings, or the specifications require the contractor to develop and install seismic restraint details on a "design-build" basis. Details on the drawings are prepared either by the specifying discipline or by the Structural Engineer of Record. Details and calculations prepared by an engineer hired by the contractor are sometimes part of a submittal process in which the Structural Engineer of Record will examine the details for conformance with the specified design requirements and for the loads imposed on the structure. In many cases, especially outside of California, the installation of nonstructural components is completed without the benefit of a submittal review or any project-specific engineering.

The details of nonstructural distribution systems are rarely included on the drawings. Rather, design-build requirements are typically included in the specifications. These requirements mandate compliance with referenced code provisions and standards for nonstructural components. In addition, they often require installation to be performed in accordance with one of several proprietary seismic restraint systems. In the case of fire sprinkler systems, compliance with NFPA requirements is uniformly mandated.

Rarely are nonstructural installations in standard occupancy buildings subject to comprehensive field review. While some building inspectors routinely check for the presence of code-required bracing for suspended ceilings and partitions, few inspect the anchorage of equipment, and even fewer examine the seismic bracing on piping and conduit. Inspection of fire sprinkler piping is typically handled by the fire marshal. Building contents, even those within the scope of the code, are often added to a building after inspections are complete and beneficial occupancy has been granted. Rarely are these items subject to inspection by a regulatory body.

It is also uncommon for design professionals to take responsibility for field verification of seismic bracing for nonstructural components. Structural Engineers are not typically on the jobsite during the phase of construction in which most nonstructural components are installed. If they are on site, most have explicitly excluded the design and oversight of nonstructural bracing from their contract. Architects, mechanical engineers and electrical engineers are generally not focused on this aspect of design, nor are they assigned the responsibility, and most do not have the requisite training to inspect for compliance with seismic requirements. As a result, responsibility for the restraint of nonstructural component often falls to the subcontractor responsible for the system or component installation.

5.2.2 California Hospital Construction

California hospitals provide one example of how a comprehensive and coordinated approach to design, plan review, and construction can be implemented. The California Office of Statewide Health Planning and Development (OSHPD) enforces building code provisions related to the anchorage of nonstructural components in California hospitals. Since 1973, OSHPD has been instrumental in improving the safety and reliability of hospital buildings. The initial focus of OSHPD's regulatory oversight was related to structural quality. Over time this focus has shifted to include comprehensive treatment of both structural and nonstructural performance.

Protection of nonstructural components in hospitals is based on a three-pronged approach: (1) clear and complete designs; (2) detailed plan review; and (3) thorough construction inspection. OSHPD requires details and calculations for all floor-mounted items over 400 pounds and for wall-mounted, suspended or vibration-isolated items over 20 pounds. The completeness and code compliance of the designs are reviewed by licensed Structural Engineers. All outstanding design issues are resolved during a backcheck process prior to issuance of a building permit. During construction, all installations are inspected by qualified inspectors, and post-installed concrete anchors are tested by independent testing laboratories. Deviations from the plans are monitored through a rigorous change order process requiring justification by the Structural Engineer of Record and acceptance by OSHPD. Similar standards are used for both new construction and renovation projects.

Portions of existing hospital buildings constructed prior to the rigorous enforcement of nonstructural standards have been the subject of recent attention. Since the passage of Senate Bill 1953 in 1994, California hospitals have been required to progressively improve their expected nonstructural performance by specific deadlines. By 2002, hospitals were required to anchor and brace communications systems, emergency power equipment, bulk medical gas, and fire alarm components. By 2013, architectural components, medical equipment, and mechanical, electrical and plumbing systems, including fire sprinkler bracing lines, must be anchored in critical care areas. By 2030, nonstructural components throughout the hospital must be anchored. These requirements, along with complementary structural upgrade requirements, are designed to increase the probability that hospitals will be able to provide uninterrupted service following major earthquakes. Hospitals that fail to comply with these requirements are subject to loss of their acute care license.

5.2.3 Private Sector Technology Construction

In certain building types, such as high technology fabrication facilities, research laboratories, and museums, the contents can be far more valuable than the building. In some circumstances, they can represent a potential hazard to building occupants and the general public. In these cases, special attention is required throughout design, manufacturing and construction, to ensure that critical components are protected.

One company's approach to the seismic protection of nonstructural components highlights several seismic hazard mitigation strategies. Intel, a large private sector semiconductor company, spent $6 billion on capital construction projects in 2006. Of that capital budget, about 5% was attributed to the cost of the building structure. The balance was attributed to the contents, equipment, process tools, and systems needed for specialized manufacturing processes.

Intel's basic approach to limiting nonstructural earthquake damage is to "do it right the first time." To this end, Intel's design and construction protocols include: (1) hiring integrated architectural/engineering teams expressly responsible for the design and construction oversight of seismic protection measures for nonstructural components and systems; (2) enforcing company-specific seismic standards that include a requirement to use an importance factor of 1.5 for the design of all seismic restraints for critical production facilities; (3) pre-engineering of support and bracing systems rather than having systems “field-engineered”; and (4) arranging for full-time, on-site inspectors from jurisdictions having authority over their construction projects.

5.2.4 Local Government Enforcement

When the 2003 IBC was adopted in St. Louis County, Missouri, enforcement of seismic requirements for nonstructural components was problematic. Design professionals, plan reviewers, contractors and building inspectors each had varying interpretations of the requirements. In response, the County established rules and regulations intended to establish a common set of standards for compliance with the code. A cornerstone of these standards is the use of a “Seismic Code Block” on the mechanical, electrical and plumbing drawings (Figure 5-1 and Figure 5-2).

12/1/05 Attachment "A" of St. Louis County Rules & Regulations
Anchorage & Sway Bracing Mechanical & Electrical System Components
SEISMIC CODE BLOCK ON 1ST SHEET OF MECHANICAL & PLUMBING PLANS
MECHANICAL & PLUMBING EQUIPMENT COMPONENTS
EARTHQUAKE LOAD RESISTANCE

Seismic Use Group ( ) **Seismic Design Category ( )**

LISTING OF EQUIPMENT AND SYSTEM COMPONENTS	ANCHORAGE TO FLOORS, ROOFS, ETC.		SWAY BRACING		LOCATION OF PROFESSIONALLY SEALED ANCHORAGE AND SWAY BRACING DETAILS			COMMENTS
					ON CONST. DOCUMENTS	SUBSEQUENT SUBMITTAL		
	Not Provided	Provided	Not Provided	Provided	*Drawing No. or Spec. Section*	Shop Drawings	Separate Permit & Plans	
FIRE PROTECTION, DETECTION & ALARM EQUIPMENT & SYSTEM COMPONENTS; * See Attachment "C" Table 200 (List items such as; fire sprinkler system equipment & system components, smoke control & evacuation equipment & system components)								
HAZARDOUS EQUIPMENT & SYSTEM COMPONENTS; * See Attachment "C" Table 200 (List items such as; gas piping, piping containing flammable, combustible liquids & gasses or toxic chemicals. Include items such as flammable & combustible tanks, vats & other industrial equipment containing hazardous or toxic liquids, gasses, chemicals, etc.)								
OTHER EQUIPMENT & SYSTEM COMPONENTS NEEDED FOR CONTINUED OPERATION OF SEISMIC USE GROUP III FACILITIES OR WHOSE FAILURE COULD IMPAIR THEIR CONTINUED OPERATION * See Attachment "C" Table 200 (List items)								
OTHER GENERAL EQUIPMENT & SYSTEM COMPONENTS (List items such as; boilers, furnaces/AHU's, tanks, heat exchangers and pressure vessels, suspended piping, water heaters, VAV boxes, HVAC ducts, drain waste & vent piping, pumps, etc.)								

Figure 5-1 St. Louis County Seismic Code Block, Attachment A.

12/1/05 Attachment "B" of St. Louis County Rules & Regulations
Anchorage & Sway Bracing Mechanical & Electrical System Components
SEISMIC CODE BLOCK ON 1ST SHEET OF ELECTRICAL PLANS
ELECTRICAL SYSTEM COMPONENTS
EARTHQUAKE LOAD RESISTANCE

Seismic Use Group ( ) Seismic Design Category ( )

LISTING OF EQUIPMENT AND SYSTEM COMPONENTS	ANCHORAGE TO FLOORS, ROOFS, ETC.		SWAY BRACING		LOCATION OF PROFESSIONALLY SEALED ANCHORAGE AND SWAY BRACING DETAILS			COMMENTS
					ON CONST. DOCUMENTS	SUBSEQUENT SUBMITTAL		
	Not Provided	Provided	Not Provided	Provided	Drawing No. or Spec. Section	Shop Drawings	Separate Permit & Plans	
FIRE PROTECTION, DETECTION & ALARM EQUIPMENT & SYSTEM COMPONENTS; * See Attachment "C" Table 200 (List items such as fire alarm panels, electric conductors powering fire protection equipment, etc.)								
EMERGENCY OR STANDBY EQUIP. AND SYSTEM COMPONENTS; * See Attachment "C" Table 200 (List items such as emergency generators, panel boards, single hanger and trapeze supported system components, bus-ducts, primary cable systems, motors control centers and devices, switch-gears, transformers, unit substations, cable tray, conduit, lighting fixtures, etc.)								
OTHER EQUIPMENT & SYSTEM COMPONENTS NEEDED FOR CONTINUED OPERATION OF SEISMIC USE GROUP III FACILITIES OR WHOSE FAILURE COULD IMPAIR THEIR CONTINUED OPERATION * See Attachment "C" Table 200 (List items)								
OTHER GENERAL EQUIPMENT & SYSTEM COMPONENTS (list items such as panel boards, single hanger & trapeze supported system components, communication systems, electrical bus ducts, primary cable systems, electrical motor control centers, motor control devices, switchgear, transformers, unit substations, cable tray, conduit, lighting fixtures, etc.)								

Figure 5-2 St. Louis County Seismic Code Block, Attachment B.

The Seismic Code Block requires the engineer(s) responsible for the design of mechanical, electrical and plumbing systems to identify the location of seismic restraint details on the plans, or to indicate that they will be furnished in a subsequent submittal, which will then be reviewed by the responsible engineer. This process forces accountability for design, and significantly enhances the enforcement of code requirements for seismic bracing of nonstructural components and systems. Installation inspection is facilitated by the availability of project-specific bracing details.

The Seismic Code Block approach also focuses the attention of the owner and the design team on the division of responsibilities pertaining to nonstructural components, and leads to greater coordination between disciplines. The St. Louis County approach can serve as a model for other jurisdictions throughout the country.

5.3 Equipment Specification

In standard occupancy construction, design of equipment anchorage, if provided, has focused on position retention and compliance with prescriptive seismic lateral force requirements. The performance of the equipment itself under seismic loading is another issue. Since equipment can become inoperable due to earthquake shaking even if it remains in place, buildings designed with the objective of functioning after an earthquake must consider the post-earthquake operability of critical equipment. Performance verification of equipment that must remain operational after an earthquake is obtained through qualification testing.

Manufacturers and vendors that provide equipment used in the nuclear industry have long been required to provide seismic performance qualification data for their equipment. Other occupancies for which seismically qualified equipment has been used include hospitals, schools, data centers, water treatment facilities, police stations, airport terminals, casinos, industrial facilities, and government buildings.

Some demand for seismically qualified equipment has come from the East Coast, and the Midwest near the New Madrid fault, in areas where the IBC has been adopted. To date, specification of mechanical, electrical and plumbing equipment qualified for seismic environments has been estimated at less than 5% of the total equipment specified in the United States. The eventual adoption of the 2006 IBC in the high seismic regions of California and the Pacific Northwest is expected to dramatically increase demand, since “special certification” of designated equipment is required for systems in Seismic Design Categories C, D, E and F.

Seismic qualification requirements in the IBC, coupled with the availability of a shake table testing protocol, ICC-ES AC 156 *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems*, has hastened the pace with which some manufacturers are qualifying the internal ruggedness of their equipment using shake table testing. While the cost of seismic qualification varies depending on many factors, the actual cost premium for seismically qualified equipment is often incidental. One estimate suggests the premium for seismically qualified equipment is on the order of about 1% of the cost of the equipment, or a minimum of about $8000 to $10,000 if the component has not previously been tested. In some cases the test can be “generic” with the effective cost spread over an entire product line.

5.4 Structural System Selection

The structural system of the building can influence seismic performance of nonstructural components and contents. Nonstructural earthquake damage is caused by inter-story drift, floor-acceleration, or both, and these quantities depend on the structural response of the building.

Structural systems that respond with reduced spectral floor accelerations and reduced inter-story drifts are most effective in achieving enhanced seismic performance. Unfortunately, obtaining reductions in both structural response quantities at the same time is difficult using conventional structural systems. A study comparing the seismic performance of nonstructural components in various building types (Mayes et al., 2005) showed that base isolated buildings had the best performance by a significant margin, and that systems with viscous dampers performed considerably better than braced frames and moment frames. For this reason, base isolation systems have been used in many buildings where post-earthquake occupancy and protection of contents were of paramount importance.

The ATC 58 Project, "Development of Next-Generation Performance-based Seismic Design Procedures for New and Existing Buildings," has among its goals the quantification of earthquake losses in terms of casualties, repair costs and downtime. The project includes comprehensive treatment of nonstructural components and contents, providing the ability to explicitly compare nonstructural performance for different structural systems. Such comparisons are expected to clarify the relationship between structural system selection and nonstructural performance, and provide valuable guidance on system selection to achieve desired performance objectives.

Chapter 6

Guidance Documents Relevant to Seismic Design and Installation of Nonstructural Components

In addition to codes, standards and protocols, there are a number of evaluation, design, and installation guidance documents relevant to improving nonstructural seismic design and installation practice. Many have been developed with funding from federal agencies, such as the Federal Emergency Management Agency (FEMA) and the Department of Interior Bureau of Reclamation. Guidance has also been developed by engineering research organizations such as the Applied Technology Council (ATC), and professional or trade groups such as the Sheet Metal and Air Conditioning National Association (SMACNA), the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), the Vibration Isolation and Seismic Control Manufacturers Association (VISCMA) and the Rack Manufacturer's Institute, Inc. (RMI).

Available guidelines contain useful information and sample details targeting different audiences. Some address new facilities, while others address the evaluation and upgrade of existing facilities. Many cover building seismic issues in general, but have at least one chapter or section pertaining to nonstructural seismic design in particular. When compared side by side, there appears to be a high degree of overlap and redundancy, but each seems to serve a specific need.

A list of currently available guidance documents, including some still under development, is provided in Appendix B, Table B-2. These documents can be grouped into categories, and summarized as follows:

- General discussions of nonstructural issues intended for lay audiences including homeowners, building owners, facilities managers, and tenants. Examples include the 1983 edition, and the 1985 and 1994 FEMA-published editions of *FEMA 74, Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide, Third Edition*.
- General guidelines intended for lay audiences, but targeted to a particular type of facility such as schools, hospitals, commercial office buildings, multifamily residential buildings, retail facilities, hotels and motels.

Examples include the FEMA Incremental Seismic Rehabilitation Series (FEMA 395, 396, 397, 398, 399, and 400), which are intended for the owners, managers, and administrators of these facilities. Nonstructural issues are not the primary focus of these guides, but they each include a section that addresses nonstructural issues relevant to the facility in question.

- General guidelines intended for design professionals that explain seismic design issues explicitly, but without the technical detail required to perform any calculations. *FEMA 454, Designing for Earthquakes: A Manual for Architects* is an example of this type of guide, and includes a chapter on nonstructural issues.
- Technical guidelines intended for design professionals that provide seismic design, evaluation, or rehabilitation requirements for both new and existing buildings. Some of these guides are prestandards that have been used in the development of seismic evaluation and rehabilitation standards. Most of these are not specifically related to nonstructural seismic design, but include chapters or sections covering nonstructural issues. Examples include the FEMA 310 *Handbook for the Seismic Evaluation of Buildings - A Prestandard* (the precursor to SEI/ASCE 31-03), FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (the precursor to ASCE /SEI 41-06), and FEMA 547 *Techniques for the Seismic Rehabilitation of Existing Buildings*. In addition, there are a few guides that provide step-by-step explanations of the code provisions for nonstructural items, including the U.S. Army Corp of Engineers document, *Seismic Protection for Mechanical Equipment*.
- Detailed guidelines for builders and equipment installers that provide information regarding hardware, tools, and equipment that could be used to install generic anchorage details. These guides are specifically focused on nonstructural components. Examples include FEMA 412 *Installing Seismic Restraints for Mechanical Equipment*, FEMA 413 *Installing Seismic Restraints for Electrical Equipment,* FEMA 414 *Installing Seismic Restraints for Duct and Pipe*, FEMA 460 *Seismic Considerations for Steel Storage Racks Located in Areas Accessible to the Public*, and the Department of Interior Seismic Safety Program (DOISSP) *Nonstructural Hazards Mitigation Guidelines, Volumes 1 and 2*.

Chapter 7

Nonproprietary Details and Other Resources for Nonstructural Components

A number of available resources provide generic details that address a wide variety of nonstructural components and contents. These include many of the guidance documents listed in Appendix B, Table B-2. A list of resources that contain nonproprietary and generically applicable nonstructural anchorage and restraint details is provided in Appendix B, Table B-3.

Most nonproprietary details are intended to provide general information on typical assemblies, typical hardware, and typical connections between nonstructural components and the supporting structure. Schematic in nature, they generally do not include specific member sizes, dimensions, capacities, or load ratings. While some can be readily implemented in the field, others require the input of a design professional or specialty subcontractor familiar with the type of installation.

The 1994 edition of FEMA 74 includes many such generic, nonproprietary details, showing typical connections and hardware needed to protect ordinary furniture, equipment, and contents that would be typical of residential and small business occupancies. The details are classified as "Do-It-Yourself" or "Engineering Required." With some ingenuity and modest skills, many could adapt these details for home or small business use. For any large public agency or commercial enterprise with significant exposure to casualties, direct economic losses, or downtime associated with nonstructural earthquake damage, reliance on the generic details in FEMA 74 would not be recommended.

Resources such as FEMA 412 *Installing Seismic Restraints for Mechanical Equipment*, FEMA 413 *Installing Seismic Restraints for Electrical Equipment*, and FEMA 414 *Installing Seismic Restraints for Duct and Pipe* provide details for mechanical, electrical, and plumbing components that would be more typical of commercial occupancies. These guides are intended as aids for installers, presumably after connections have been designed or specified by design professionals or others.

Also included in Appendix B, Table B-3 are other resources such as checklists, sample specifications, and photographs pertaining to nonstructural seismic design and installation, which could be useful resources in the future update of FEMA 74.

Chapter 8

Proprietary Details and Products for the Protection of Nonstructural Components

Proprietary details, devices and systems used for the protection of nonstructural components and contents are becoming more readily available. Internet search phrases such as “seismic details,” “seismic protection,” “seismic safety products,” “equipment base isolation,” “seismic restraints,” “OSHPD details,” “earthquake bracing,” “seismic fragility,” “seismic dampers,” “nonstructural seismic,” and “nonstructural retrofit” identify countless resources. Some specialize in a particular market niche, while others offer a range of products; however, there does not appear to be any one resource that addresses the entire spectrum of nonstructural components. Currently, there are many vendors offering specialized devices and pre-approved details that have been evaluated for compliance with the IBC or have been accepted by authorities such as the California Office of Statewide Health Planning and Development (OSHPD).

A sampling of proprietary products and vendors is listed in Appendix B, Table B-4. The purpose of this sampling is to indicate that there are now many such products available, and many of them can be readily located on the internet. No attempt has been made to comprehensively list all vendors or proprietary products that are currently available, and identification in this report does not constitute an endorsement of a particular vendor or approval of a particular product.

Mason Industries (www.mason-ind.com) offers information about hundreds of products for use with MEP equipment, piping and ducts, and includes engineering specifications, data submittal sheets in pdf format, CAD details, load ratings, product selection charts, technical data, and installation notes. Although it appears that Mason’s primary focus is on providing noise and vibration control products, they have many products designed specifically for seismic environments.

International Seismic Application Technology (www.isatsb.com) provides hardware for seismic bracing of mechanical, electrical, plumbing, and piping systems. Their manual, *International Seismic Application Technology (ISAT) Applications and Design Manual*, is provided free upon request, but not visible online. Their website states that in addition to seismic bracing hardware that they manufacture and sell, they offer consulting services, educational seminars, budget estimates, specification review, value engineering, and installation oversight.

WorkSafe Technologies (www.worksafetech.com) focuses primarily on protection of contents typically found in office, data center, hospital, laboratory, and warehouse occupancies. Their website is organized by occupancy, with further subdivisions for specific contents found in each setting. As an example, under "Offices/Desktop Equipment," the following proprietary products are listed: Monitor Lasso™, Small Monitor SwivelStraps™, Large Monitor SwivelStraps™, QuakeMat™, and SeismaLok™. A major product line for data centers includes Iso-Base™ base-isolation devices for sensitive equipment, which are analogous to base-isolation devices used for buildings. Although load ratings and engineering data are not provided on the website, they state that WorkSafe products have been tested successfully in accordance with the Canadian Government Standards Testing at the University of British Columbia and have received Japan Quality Assurance (JQA) Certification for use in Japan. WorkSafe has offices in the United States, Canada, Japan, Mexico, New Zealand, Philippines, Taiwan, and Turkey, indicating that there is an international market for these products.

For architectural components, proprietary products are less common and more difficult to find. While there seems to be many different specialty products, there does not appear to be a vendor that specializes in seismic bracing for a wide variety of architectural components. The phrases "veneer anchor," "glazing seismic," and "partition bracing" can be used to locate resources, but generic phrases like "nonstructural seismic" or "architectural seismic" do not lead to useful results. The phrase "seismic ceilings" led to a "Seismic Ceiling Resource Center" on United States Gypsum (USG) website, but did not lead to Armstrong, a firm known to have recently performed seismic tests on their proprietary ceiling systems.

Widespread adoption of the 2006 International Building Code, and ongoing developments in performance-based earthquake engineering, are expected to stimulate the development of additional proprietary products and new vendors as more stringent code requirements are adopted and enforced, and there is greater awareness of the costs and disruption associated with nonstructural earthquake damage.

Chapter 9

Recent and Ongoing Research and Development on Nonstructural Issues

9.1 General

Research and development efforts on the seismic performance of nonstructural components and contents can be grouped into the following categories:

- Federally funded projects undertaken by organizations such as the Federal Emergency Management Agency (FEMA), National Science Foundation (NSF), and the Applied Technology Council (ATC)
- Research undertaken at the national earthquake engineering research centers, including the Pacific Earthquake Engineering Research Center (PEER), Multidisciplinary Center for Earthquake Engineering Research (MCEER), and Mid-America Earthquake Center (MAE)
- Private sector research in the United States
- International research

Recent and ongoing research and development efforts, and reports on recent testing of nonstructural components, are listed in Appendix B, Table B-5.

9.2 Federally Funded Projects and Initiatives

9.2.1 NSF-Funded ATC-29 Project

A significant body of information on seismic design, performance, and research pertaining to nonstructural components is contained in the series of reports from the ATC-29 Project, funded by the National Center for Earthquake Engineering Research and the National Science Foundation:

- ATC-29, *Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures* (ATC, 1992)
- ATC-29-1, *Seismic Design, Retrofit, and Performance of Nonstructural Components* (ATC, 1998), *and most recently*

- ATC-29-2, *Proceedings of Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities* (ATC, 2003).

The most recent report, ATC-29-2, prepared in cooperation with the Multidisciplinary Center for Earthquake Engineering Research, focused principally on nonstructural components and systems in facilities with critical functions. Invited papers were organized into the following themes related to the state of the art, state of the practice, and efforts needed to improve the performance of nonstructural components and contents:

- Current Practices and Emerging Codes

  Code provisions and seismic level forces for buildings, with an emphasis on hospitals; research required for implementation of performance-based design; seismic qualification using shake table tests and code requirements; recent and future developments for nonstructural items in the *NEHRP Recommended Provisions*; and current practice on installation of mechanical, electrical, piping, ductwork, and equipment.

- Seismic Design and Retrofit

  Economic considerations in the improvement of nonstructural systems; case studies of behavior and research of nonstructural items such as cladding, partitions, laboratory equipment, bookcases; retrofit of storage racks and metal stud partitions; and comparison of nonstructural risks before and after the nonstructural retrofit.

- Risk and Performance Evaluation

  Overview of nonstructural research at the three national earthquake engineering research centers; behavior of elevators, piping, suspended ceilings, cladding, and acceleration sensitive equipment; fragility analysis of nonstructural elements in critical facilities; and estimates of seismic demands such as floor accelerations.

- System Qualification and Testing

  Overview of shake table test characteristics for seismic qualification testing, and results of seismic qualification tests on selected nonstructural components and contents.

- Advanced Technologies

  Experimental studies with base isolation, energy absorbing devices, and semi-active devices.

9.2.2 FEMA-Funded ATC-58 Project

The Applied Technology Council is under contract with FEMA to conduct the ATC-58 Project, "Development of Next-Generation Performance-Based Seismic Design Guidelines." The overall purpose of this long-term, multi-phased program is to develop practical and effective performance-based seismic design guidelines, as outlined in the FEMA-445 *Next-Generation Performance-based Seismic Design Guidelines, Program Plan for New and Existing Buildings* (FEMA 2006).

The project began with the initiation of Phase 1 in 2001. Phase 2 included the development and publication of the FEMA 461 report, *Interim Protocols for Determining Seismic Performance Characteristics of Structural and Nonstructural Components* (FEMA, 2007), and the 35% draft *Guidelines for the Seismic Performance Assessment of Buildings* (ATC, 2007). The current Phase 3, scheduled to end in 2011, will result in the completion of the methodology for seismic performance assessment of new and existing buildings. A later Phase 4 will develop guidelines that will assist engineers in utilizing the performance assessment methodology to efficiently and effectively design new buildings and upgrade existing buildings.

The resulting methodology will be applicable to most common building types designed and constructed in the United States within the past 50 years. It will provide tools for estimating earthquake losses in terms of causalities, direct economic losses, and downtime as a result of damage to both structural and nonstructural components. Of particular value will be the ability to separate losses into their constituent parts, making it possible to determine the contribution of each item, or group of items, to total estimated losses, and to compare the impact of different structural and nonstructural mitigation strategies.

Completion of the performance assessment and design guidelines will eventually result in identification and development of the following nonstructural seismic performance and response information:

- nonstructural systems and components that are important to the performance of buildings, and damage states that are meaningful to each of these components and systems
- intensity measures that are useful and efficient for predicting damage to nonstructural components and systems
- demand parameters that are relevant for predicting damage to nonstructural components and systems

- standard procedures for quantifying the performance capability (fragility and loss functions) for nonstructural components and systems, including testing protocols
- fragility functions for nonstructural components and systems relative to the damage states identified
- loss functions for nonstructural components and systems

9.2.3 NSF-Funded NEES Grand Challenge

In 2007, the George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES) research program of the National Science Foundation awarded a $3.6 million Grand Challenge grant to the University of Nevada, Reno (UNR) to study the seismic performance of ceiling-piping-partition nonstructural systems. Currently in the early stages of planning and development, this Grand Challenge project will eventually integrate multidisciplinary system-level studies that will develop a simulation capability and implementation process for enhancing the seismic performance of the ceiling-piping-partition system. A comprehensive experimental program is proposed that will use the UNR and University at Buffalo NEES Equipment Sites to conduct full-scale subsystem and system-level experiments.

A numerical simulation program will be integrated with the experimental program to develop experimentally verified analytical models, establish system and subsystem fragility functions, and develop visualization tools that will provide engineering educators and practitioners with sketch-based modeling capabilities. Public policy investigations at the building and metropolitan levels are designed to support the implementation of the research results.

9.3 National Earthquake Engineering Research Center Activities

A variety of research projects involving both analytical and experimental work have been undertaken at the national earthquake engineering research centers, particularly at the Pacific Earthquake Engineering Research Center (PEER), in Berkeley, California and at the Multidisciplinary Center for Earthquake Engineering Research (MCEER), in Buffalo, New York. Examples of recent research include the following:

- Experimental and Analytical Studies on the Seismic Response of Freestanding and Anchored Laboratory Equipment, Report PEER 2005/07.

- PEER Testbed Study on a Laboratory Building: Exercising Seismic Performance Assessment, Report PEER 2005/12.
- Simulation of Strong Ground Motions for Seismic Fragility Evaluation of Nonstructural Components in Hospitals, MCEER-05-0005.

9.4 Private Sector Research in the United States

There are an increasing number of proprietary systems, devices, equipment and products available to address the seismic performance of nonstructural items. The development and testing of these products is typically funded by private manufacturers, although some of these tests are conducted at the national earthquake engineering research centers. Several examples include:

- MCEER testing of Ridg-U-Rak's patented unidirectional base isolation scheme for pallet racks.
- PEER testing of electrical substation equipment for PG&E.
- Shake table testing of electrical components by Square D.

9.5 International Research

Included in Appendix B, Table B-5, are examples of international research, indicating that there is ongoing research on nonstructural issues outside of the United States. One of these is a report on the testing of tabletop equipment situated on an inclined plane, which was performed at the University of Chile. A comprehensive search of international literature is beyond the scope of this report.

Chapter 10

Future Needs

10.1 Overview

At present, it appears there are two different challenges in the effort to reduce future losses associated with nonstructural earthquake damage. While these represent two points on a continuum, the solutions may end up being quite different. One is to find cost effective ways to reduce nonstructural losses in ordinary residential and commercial structures. The other is to meet the needs of critical facilities to maintain post-earthquake operations.

The challenge for ordinary buildings will be to find cost effective solutions that do not require custom designs for every nonstructural component. It is imperative that someone (e.g., the lead design professional, designated design professional or specialist) be responsible for overseeing the design and installation of these items. While the building code is increasingly comprehensive in its treatment of nonstructural items, the development of many generic, pre-evaluated and pre-approved details that can be used repetitively, under a variety of circumstances, without the need for calculations and project-specific details for each pipe and every bookcase on every project should be encouraged.

The challenge for critical facilities has largely been addressed in the nuclear industry, where every nonstructural component that is capable of posing a safety hazard or impacting operations requires pre-installation seismic qualification testing, seismic design calculations and details, rigorous design review, construction inspection, and in-place testing. The challenge is to find ways to scale these efforts down to something that is less costly, and will still achieve the desired result, which is facilities that are capable of operating after a major earthquake. The experience of hospital and school construction in California is an example of a systematic approach that can be adapted for use in a wide range of occupancy types and locations.

The introduction of performance-based earthquake engineering methods is likely to provide a quantifiable impetus for improving the treatment of nonstructural components and contents. There are, however, many issues with human factors engineering that are a major concern in critical facilities. Attempts to anchor or tether specialized equipment that must be used on a daily basis, or periodically moved for maintenance, pose ongoing operational challenges.

10.2 Recommendations

In order to further the reduction of risks associated with earthquake damage to nonstructural components and contents, the following actions are recommended:

1. **Update FEMA 74.** FEMA 74 is a useful introduction to the subject for anyone unfamiliar with nonstructural hazard mitigation. This includes anyone who owns or occupies a building, as well as design professionals, who might not be experienced with seismic design and protection of nonstructural components and contents. A revised version of FEMA 74 should emphasize that the most costly damage in future earthquakes in the United States may well be caused by nonstructural damage; thus effective earthquake mitigation should consider the cost/benefit of addressing nonstructural issues. It should also emphasize that this is not only a cost issue, and that many of these items represent life safety hazards if not addressed. As reliance on high technology equipment increases, the risk increases. The graphics and photos in a new edition should be improved to facilitate easy application and to take advantage of developments over the past decade.

2. **Expand FEMA 74.** Many users of FEMA 74 have identified the availability of details as the most widely used and valuable aspect of the document. The availability of details addressing a wider range of nonstructural components and a broader scope of installation conditions will support increased application of mitigation measures. Consideration should be given to aligning FEMA 74 with the nonstructural chapter in ASCE 41 to provide a comprehensive and coordinated suite of documents addressing the identification, assessment and mitigation of nonstructural hazards for use by design professionals.

3. **Supplement FEMA 74.** Additional guides should be developed that cover not only the technical aspects of seismic design for nonstructural components and contents, but that also address detailed discussion of the many other issues involved in their protection. Such issues might include writing clear design criteria and specifications; requirements for vendor certification of equipment; assignment of clear responsibilities for design, installation, and inspection of nonstructural details (including differences associated with ownership and responsibilities for contents versus ownership and responsibility for fixed building components); identification of elements or areas that are most critical to operations; and determining what backup systems are required. Discussion should cover how to maintain portability of lab or hospital equipment; how to avoid tripping hazards; how to make tethers easy to operate and remind

personnel to use them; how to anchor delicate equipment without penetrating the housing; and how to implement a plan that will address new equipment or furnishings on a continuing basis. This effort should include development of seminars based on this material to provide training for nonstructural specialists, and increase awareness of the many issues related to post-earthquake operations.

4. **Establish accountability for seismic design and installation of nonstructural components by defining responsibilities.** This effort could include the development and use of a "seismic code block" such as the one in use in St. Louis County, Missouri. The table is required on every set of drawings submitted for permit and requires identification of the relevant seismic details for each nonstructural component listed, and designation of the party accountable for design, shop drawings, and permits. This provides a public record of accountability, and serves as an important reminder to the architect or engineer of record to assign these responsibilities, and for the responsible parties to fulfill these duties. Successful implementation will require promotion of appropriate code revisions, and adoption of these requirements in other local jurisdictions.

5. **Develop an outreach and education program for Architects, Mechanical Engineers, Electrical Engineers and Structural Engineers.** Each design professional receives considerable training in the design of components within their area of expertise. Yet none receives specialized training in seismic protection of nonstructural components. Such training should be focused on the dual purpose of demonstrating the details useful for protecting nonstructural components and the administrative approaches available for achieving reliable protection on a project-by-project basis. Courses should be designed to provide Continuing Education Units (CEUs) for those professions that require them. University courses on earthquake engineering should also address seismic protection of nonstructural components.

6. **Support training of plan reviewers, building officials and construction inspectors.** Training is needed to enhance the quality and completeness of plan review and construction inspection for nonstructural components. Training should include the development of standardized checklists based on code requirements, to ensure that all items regulated by the code are examined as part of the plan review and inspection process.

7. **Foster building code refinements and efforts to enhance code usability to promote comprehensive implementation on all projects.** If building code requirements are clear, technically-grounded, and well

understood, enforcement through plan review and inspection will be enhanced. In addition, this effort should include support for the development of acceptable practical guides as companion resources to building codes.

8. **Encourage the designation of nonstructural specialists with responsibility for oversight of the seismic design of nonstructural components and contents.** One of the key roadblocks to providing reliable protection of nonstructural components in new construction is that no one is designated with the responsibility for providing this protection. There is a critical need for the development of multidisciplinary specialists that have an understanding of seismic and structural engineering, as well as mechanical and electrical equipment, specialty equipment, piping systems, architectural features and finishes, contents, and human factors engineering. While this role could be played by the Structural Engineer of Record for a project, it could alternatively be delegated to a specialist with expertise in this area.

9. **Develop standard contract language for seismic protection of nonstructural components.** The development of standard contract language covering the responsibilities associated with the design, installation, and inspection of nonstructural components should be promoted. This language could be incorporated into standard American Institute of Architects (AIA) contracts, and other contracts, so that the lead design professional designates responsibility for these tasks.

10. **Develop standard specifications for seismic protection of nonstructural components and contents.** The development of standard specifications for the seismic protection of nonstructural components and contents should be promoted. This should include providing guidelines for documentation of properties including weight, center of gravity, dimensions, recommended anchorage details, and fragilities for nonstructural components and contents.

11. **Develop a standardized framework for the collection of nonstructural earthquake damage data, find a host organization to support the collection, and provide a web-based repository for new data.** Several efforts have been made to standardize the collection of nonstructural earthquake damage data, but there still is no consensus on how to proceed. Data gathering is costly, so it is important to clearly identify what information should be gathered in order to inform efforts to reduce future losses. We need to identify the failures that are most likely to result in life safety hazards, expensive repair costs, and extensive business interruption. In order to generate damage statistics, data must also be gathered to describe the total quantity of each class of nonstructural component that was in the affected area. The taxonomy of nonstructural elements (Porter, 2005) is a start at identifying the vast list of nonstructural items, their possible locations, and their varying degrees of anchorage, although even this list does not fully address contents.

    Developing a useful electronic data input sheet, with drop down menus of items, would force users to utilize specified categories for documenting pre-earthquake characteristics and post-earthquake damage data in a standardized format. If an organization like the Earthquake Engineering Research Institute (EERI) hosted a website as a repository for standardized damage data, it would greatly facilitate the gathering and dissemination of this information. Also, a nonstructural damage specialist should be included as part of each post-earthquake reconnaissance team (EERI or other). Consideration should be given to gathering additional data through the USGS website feature "Did you feel it?"

12. **Develop a pilot project to collect nonstructural damage data for a small class of public buildings.** In order to start collection of nonstructural earthquake damage data in a systematic way, a small class of buildings, such as fire stations or public libraries, should be selected for a pilot project. Such a project would provide useful information in the next earthquake, and would also help focus data gathering efforts for nonstructural damage in future earthquakes. This effort could be initiated with the preparation of data collection forms relevant for a selected facility type, along with a data collection plan covering this class of building in the next earthquake. Data forms should focus on a manageable list of items, and be designed to include information on whether bracing or anchorage is present, whether it was designed and installed properly, and estimates of demand parameters. Recorded observations should include whether damage was induced by

acceleration or drift, or whether the item was damaged by interaction with other elements. Forms should also include adequate information to determine total quantities of nonstructural components, so that statistical data can be developed.

13. **Study ways to mitigate secondary damage from water or steam.** Secondary damage caused by leaks from compromised fluid piping, including broken sprinkler heads, is a major source of costly repairs, loss of contents, and business interruption. Testing to validate current standard approaches to pipe bracing, and exploration of alternate means of protection, should be accelerated. There are some flexible sprinkler systems currently on the market. Additional testing of such products, and other innovative solutions, should be encouraged in order to reduce the likelihood of piping failures and subsequent water damage. Study should consider wider use of pressurized shut-off valves and compartmentalization to limit damage.

14. **Support the development of testing and performance data for engineering design of nonstructural components to bolster the database available for performance-based engineering.** The ATC-58 project promises the ability to quantify losses due to structural and nonstructural components. However, limitations on available fragility data will limit application of the methodology to the full spectrum of nonstructural components and contents. Shake table testing and other sources should be used to create a robust database of nonstructural component damage and performance data.

15. **Promote development of generic nonstructural anchorage details and connections available online.** Although published guidelines have their place, an online resource for current details, keyed to a consistent taxonomy, would expand the usefulness of such a guide. The site could provide links to many proprietary and nonproprietary products, specifications, and CAD details, as well as information on testing and pre-approvals performed by a host of international agencies.

16. **Develop standardized ANSI and ISO hazard symbols and a color scheme for earthquake related hardware.** In the same way that we associate red items with fire suppression equipment, four interlocking circles with biohazards, or the yellow and black trefoil with radiation, the development of a symbol and color coding that will universally be recognized as seismic related should be encouraged. If millions of employees in thousands of facilities are expected to implement seismic protection of nonstructural components and contents, they will need training, visual reminders, signage, and color coding as signals and

reminders that a seismic mitigation plan is in place, and that seismic installations are important.

17. **Support training of building engineers, stationary engineers and facility managers.** After a building has been constructed, nonstructural components are routinely added or replaced. Training of building engineers, stationary engineers, and facility managers is needed to ensure that the components are installed and maintained with consideration of earthquake performance. Development of additional documents like FEMA 74, and companion outreach efforts tailored to the needs of individuals not specially trained in nonstructural hazard mitigation, should be promoted.

Appendix A

Log of Reported Nonstructural Earthquake Damage

Table A-1, Log of Reported Nonstructural Earthquake Damage, is a listing of major earthquakes, in reverse chronological order, citing damage and reconnaissance reports, and summarizing the extent of reported nonstructural earthquake damage.

Table A-1 Log of Reported Nonstructural Earthquake Damage

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
Niigata Chuetsu-Oki, Japan, Earthquake of July 16, 2007	7/16/2007	Preliminary Report on the Niigata Chuetsu-Oki, Japan, Earthquake of July 16, 2007	10/9/2007	Report includes preliminary information regarding damage at the nuclear power plant in Kariwa. There was fire in an electrical transformer and radiation leaks caused by spilling of water from the spent fuel pools, failure of joints in exhaust pipes, and falling of drums containing low-radiation nuclear waste. At Reactor 1, EW ground motion recorded at the plant was 680 cm/sec^2. The report notes that the reactor was designed for 272 cm/sec^2 in that direction and an "importance factor" of 3 was used in the design. No summary of nonstructural damage provided.
October 15th, 2006 Earthquakes on the Island of Hawaii	10/15/2006	2006 Kiholo Bay, Hawaii Earthquake RMS	2006	Damage photos and anecdotal evidence provided; no significant statistical data provided.
October 15th, 2006 Earthquakes on the Island of Hawaii	10/15/2006	Preliminary Observations on the Hawaii Earthquakes of October 15, 2006	2006	Reported damage to healthcare and emergency response facilities: Healthcare and emergency response facilities had significant damage to their nonstructural systems, principally T-bar lighting and ceiling systems and fire sprinkler systems (Page 10, 11, and Figure 16). The Kona Community Hospital, a 94-bed acute care, psychiatric, and long-term care facility, reported fallen ceilings, light fixtures, and other nonstructural damage. Failures were attributed to a lack of adequate seismic bracing for nonstructural components. Following the earthquake, patients were evacuated and temporarily housed at the Sheraton Keau Hou Bay Resort and Spa Convention Center, or transferred to the Hilo Medical Center, or other medical facilities. The Hale Ho'ola Hamakua facility includes 48 long-term care/skilled nursing facility beds, two acute care beds, and emergency and health center services. It consists of several large one- and two-story steel-framed buildings with concrete masonry unit (CMU) and concrete walls. The facility was opened in 1995 to replace the original Honoka'a Hospital that opened in 1951. The main two-story building sustained significant nonstructural damage to the exterior cladding and soffits, and to the interior ceiling and wall systems, mainly as a result of broken sprinkler lines and broken water piping.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
October 15th, 2006 Earthquakes on the Island of Hawaii	10/15/2006	Preliminary Observations on the Hawaii Earthquakes of October 15, 2006	2006	Reported damage to healthcare and emergency response facilities, continued: Following the earthquake, 49 patients at Hale Ho'ola Hamakua were evacuated and housed in tents until accommodations were made in the facility's original building. Although the building is of recent construction, the ceiling systems were not laterally braced, did not have compression struts to prevent vertical movement, and were not isolated by means of a gap from the surrounding walls. Reportedly, the design of the building made it difficult to install diagonal bracing wires because of the distance between the ceiling and the high-pitched roof. Damage suggests that the ceilings were forced laterally against the walls, causing a buckling and failure of the T-bar grid that allowed ceiling tiles, and in some cases fluorescent light fixtures, to fall to the floor. The interaction of the ceiling system and the fire sprinkler system, which was only nominally braced, broke a number of sprinkler heads, resulting in flooding of the building. Water piping in the walls also broke, and contributed to the flooding. In addition, a heavy cement plaster on metal lath exterior cladding and soffit system failed, blocking building exits and creating a falling hazard.
October 15th, 2006 Earthquakes on the Island of Hawaii	10/15/2006	Preliminary Observations on the Hawaii Earthquakes of October 15, 2006	2006	Reported damage to schools and libraries: Waikoloa Elementary, Honoka'a Elementary, and Kohala Elementary schools sustained the most damage. Virtually no structural damage was reported at these schools. Waikoloa Elementary, less than ten years old, suffered considerable nonstructural damage. Many classrooms were closed because of an extensive amount of fallen ceilings, light fixtures, and other nonstructural items. The Honoka'a Elementary, an older school dating to the 1950s, sustained moderate structural damage to concrete masonry block (CMU) walls that support the roof girders. Kohala Elementary sustained damage to a two-story classroom building with wall cracking and ceiling damage. All schools on the island were able to open one week after the earthquake, sometimes utilizing alternative rooms.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
October 15th, 2006 Earthquakes on the Island of Hawaii	10/15/2006	"Reconnaissance Following the October 15th, 2006 Earthquakes on the Island of Hawaii," Ian N. Robertson, Peter G. Nicholson, Horst G. Brandes, University of Hawaii College of Engineering department of Civil and Environmental Engineering Research Report UHM/CEE/06-07	10/26/2006	Includes reported nonstructural damage to healthcare facilities, emergency response facilities, schools, and libraries, as identified in preliminary observation reports. Damage to exterior stucco soffits at the Hale Ho'ola medical center is shown (Page 18). Considerable nonstructural damage to the elementary school in Waikaloa is shown (Page 20). Many classrooms remained closed as of the date of the report due to fallen ceilings, light fixtures and other nonstructural items.
October 15th, 2006 Earthquakes on the Island of Hawaii	10/15/2006	"Reconnaissance Following the October 15th, 2006 Earthquakes on the Island of Hawaii," Ian N. Robertson, Peter G. Nicholson, Horst G. Brandes, University of Hawaii College of Engineering department of Civil and Environmental Engineering Research Report UHM/CEE/06-07	10/26/2006	Reconnaissance continued: At the Manoa Valley Inn in Manoa, Oahu, a rock-masonry chimney collapsed. At Iolani Palace in downtown Honolulu, Oahu, cracking occurred in the interior stucco ceiling and wall finishes. The Nihon Restaurant had diagonal cracking of the infill walls occurred due to the lack of an isolation gap between the infill and the structure. No statistics or numbers are provided.
2004 Niigata Ken Chuetsu, Japan, Earthquake	10/23/2004	Earthquake Spectra, Volume 22, Special Issue 1, 2004 Niigata Ken Chuetsu, Japan, Earthquake Reconnaissance Report, March 2006	2006	Photos and anecdotal evidence provided; no significant statistical damage data provided. Figure 11 shows a 2-story modern reinforced concrete building, appearing relatively undamaged, except for broken glass presumably caused by first-floor inter-story drift. Figure 12 shows a 10-story dormitory for an electronics company north of Ojiya, which sustained visible facade cracking, and perhaps structural damage. Adjacent to this dormitory was a high-tech electronics fabrication plant that reportedly sustained significant business interruption due to nonstructural damage, but this information was not confirmed as of the time of the report. This appears to be a reference to Sanyo (see article from Businessweek, below).

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
2004 Niigata Ken Chuetsu, Japan	10/23/2004	Businessweek (online - May 2005)	2005	"In October an earthquake measuring 6.8 on the Richter scale struck Japan's Niigata prefecture. The temblor damaged machinery at Sanyo Electric Co.'s semiconductor plant, and forced the facility to close for months - costing the company, which wasn't insured against quakes, $690 million in repairs and lost income."
September 28, 2004 Parkfield Earthquake	9/28/2004	"Preliminary Report on September 28, 2004 Parkfield Earthquake," Rakesh K. Goel, and Charles B. Chadwell, Department of Civil & Environmental Engineering, California Polytechnic State University, San Luis Obispo, California		Damage photos and anecdotal evidence provided; no significant statistical data provided.
2003 Bam, Iran, Earthquake	12/26/2003	Preliminary Observations on the Bam, Iran, Earthquake of December 26, 2003	2004	Damage photos and anecdotal evidence provided; no significant statistical data provided.
2003 Bam, Iran, Earthquake	12/26/2003	Earthquake Spectra, Volume 21, Special Issue 1, 2003 Bam, Iran, Earthquake, December 2005	2005	Damage photos and anecdotal evidence provided; no significant statistical data provided.
San Simeon Earthquake of December 22, 2003	12/22/2003	Findings and Recommendations from the San Simeon Earthquake of December 22, 2003 California Seismic Safety Commission CSSC No. 04-02	5/5/2004	Nonstructural damage not reported.
San Simeon Earthquake of December 22, 2003	12/22/2003			Nonstructural damage reportedly in excess of 50% of total losses (information unconfirmed; source unknown).

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
Tokachi-Oki, Japan, Earthquake of September 26, 2003	9/26/2003	"Preliminary Information on the 2003 Tokachi-oki Earthquake," Yohsuke Kawamata and Scott Ashford, Department of Structural Engineering, University of California, San Diego	2003	Damage photos and anecdotal evidence provided; no significant statistical data provided.
Tokachi-Oki, Japan, Earthquake of September 26, 2003	9/26/2003	Preliminary Observations on the Tokachi-Oki, Japan, Earthquake of September 26, 2003	2003	Damage photos and anecdotal evidence provided; no significant statistical data provided.
Boumerdes, Algeria, Earthquake of May 21, 2003	5/21/2003	The Boumerdes, Algeria, Earthquake of May 21, 2003, EERI Learning from Earthquakes Reconnaissance Report, October 2003	2003	Damage to industrial equipment reported; no statistical data provided.
May 1, 2003, Bingöl, Turkey, Earthquake	5/1/2003	Preliminary Observations on the May 1, 2003, Bingöl, Turkey, Earthquake	2003	Nonstructural damage not reported.
May 1, 2003, Bingöl, Turkey, Earthquake	5/1/2003	A Preliminary Engineering Report on the Bingöl Earthquake of May 1, 2003, Polat Gülkan, Sinan Akkar and Ufuk Yazgan, Middle East Technical University Department of Civil Engineering and Disaster Management Research Center		Nonstructural damage not reported.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
May 1, 2003, Bingöl, Turkey, Earthquake	5/1/2003	May 01, 2003 Bingöl (Turkey) Earthquake; M. Erdik, M. Demircioğlu, K. Beyen, K. Şeşetyan, N. Aydõnoğlu, M. Gul, B. Siyahi, G. Önem, C. Tüzün, A. Salkõn, and Y. Kaya, Department of Earthquake Engineering, Kandilli Observatory and Earthquake Research Instõtute, Bogazici University, İstanbul		Nonstructural damage not reported.
Colima, Mexico, Earthquake of January 21, 2003	1/21/2003	Quick Report To EERI, SMIS, CENAPRED and GIIS Regarding The Earthquake In Colima, Mexico, January 21, 2003	1/30/2003	Damage photos and anecdotal evidence provided; no significant statistical data provided.
Colima, Mexico, Earthquake of January 21, 2003	1/21/2003	Preliminary Observations on the Tecomán, Colima, Mexico, Earthquake of January 21, 2003	2003	Damage photos and anecdotal evidence provided; no significant statistical data provided.
Tecomán, México Earthquake January 21, 2003	1/21/2003	The Tecomán, México Earthquake January 21, 2003. An EERI and SMIS Learning from Earthquakes Reconnaissance Report	2006	Cracking of unreinforced masonry walls, roof tiles collapsed, no statistics at all
November 3, 2002 Denali Fault, Alaska Earthquake	11/3/2002	Preliminary Observations on the November 3, 2002 Denali Fault, Alaska, Earthquake		Damage photos and anecdotal evidence provided; no significant statistical data provided.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
2002 Molise, Italy, Earthquake (October 31 and November 1, 2002)	10/31/2002	Preliminary Observations on the October 31-November 1, 2002 Molise, Italy, Earthquake Sequence	2003	Damage photos and anecdotal evidence provided; no significant statistical data provided.
2002 Molise, Italy, Earthquake (October 31 and November 1, 2002)	10/31/2002	Earthquake Spectra, Volume 20, Special Issue I, 2002 Molise, Italy, Earthquake Reconnaissance Report, July 2004	2004	Damage photos and anecdotal evidence provided; no significant statistical data provided.
Southern Peru, Earthquake of June 23, 2001	6/23/2001	Earthquake Spectra, Volume 19, Supplement A, Southern Peru, Earthquake of 23 June 2001 Reconnaissance Report, January 2003	2003	Chapter 8: Reports heavy damage to industrial equipment, but also failure of light poles, ceilings, electrical equipment, fire suppression piping, and damage to artifacts and frescoes in historic cathedral in Arequipa.
February 28, 2001 Nisqually Earthquake	2/28/2001	"Guidelines, Specifications, and Seismic Performance Characterization of Nonstructural Building Components and Equipment," A. Filiatrault, C. Christopoulus, and C. Stearns, PEER Report 2002/05	2002	Chapter 2, entitled "Performance of Building Components During the February 28, 2001, Nisqually Earthquake" includes many photos and a statement that, "A large portion of the estimated $2 billion dollar loss resulting from the Nisqually earthquake was associated with damage to nonstructural components." Statistical data not provided.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
February 28, 2001 Nisqually Earthquake	2/28/2001	"Reconnaissance Report of the February 28, 2001 Nisqually (Seattle-Olympia) Earthquake," A. Filiatrault, C. Uang, B. Folz, C. Christopoulos, and K. Gatto, March 2001	2001	Includes a brief description of failed ceilings, failed lights, overturned furniture, and cracked plaster. Windows in the control tower at SEA-TAC Airport failed, store front glazing failed, bookshelves fell. Even though building structures generally performed well during the earthquake, the performance of non-structural components reduced the overall performance of many building systems. No statistical data or numbers provided. [Report was sponsored by the Pacific Earthquake Engineering Research (PEER) Center and the Consortium of Universities for Earthquake Engineering (CUREE), and Department of Structural Engineering, University of California, San Diego]
February 28, 2001 Nisqually Earthquake	2/28/2001	The Nisqually Earthquake of 28 February 2001 Preliminary Reconnaissance Report, Nisqually Earthquake Clearinghouse Group, University of Washington, Seattle, Washington, March 2001	2001	Reported nonstructural damage similar to other reports; no statistical data or numbers provided.
February 28, 2001 Nisqually Earthquake	2/28/2001			Nonstructural damage reportedly in excess of 50% of total losses (information not confirmed, source unknown).
Napa Earthquake of September 3, 2000	9/3/2000	EERI Special Earthquake Report, Learning from Earthquakes, The Napa Earthquake of September 3, 2000, November 2000	2000	Queen of the Valley Hospital, Napa: 25% of all suspended ceiling tiles dropped to the floor; ceiling damage most prevalent near the walls; no light fixtures fell; no sprinkler heads were damaged; a chiller on the roof fell off the vibration mounts. Statistical data on damage for other nonstructural components not provided.
Chi-Chi, Taiwan, Earthquake of September 21, 1999	9/21/1999	Earthquake Spectra, Volume 17, Supplement A, Chi-Chi, Taiwan, Earthquake of September 21, 1999, Reconnaissance Report, April 2001	2001	Chapters 7 and 9: Many residential buildings were reportedly given red tags because of nonstructural damage to the concrete curtain walls and the brick partition and infill walls. Over 100,000 people were displaced. Statistical data not provided.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
Kocaeli, Turkey, Earthquake of August 18, 1999	8/18/1999	Earthquake Spectra, Volume 16, Supplement A, Kocaeli, Turkey, Earthquake of August 18, 1999, Reconnaissance Report, December 2000	2000	Chapters 14 and 16: Skylights reportedly popped out; storage racks used for steel plates collapsed; expansion joints opened; and light fixtures fell. One substation transformer displaced horizontally, requiring repair. Piping failures reported in some facilities. Stacked and stored material, however, was not displaced.
Kobe, Japan Earthquake, January 17, 1995	1/17/1995	Nonstructural Damage Database, MCEER-99-0014	5/7/1999	The MCEER Database (1999) includes many line items documenting specific references to nonstructural damage from this earthquake. No comprehensive summary or statistical data provided.
1994 Northridge, CA Earthquake	1/17/1994	Earthquake Spectra, Supplement C to Volume 11, Northridge Earthquake of January 17, 1994 Reconnaissance Report, Volume 1, April 1995	1995	Chapter 11: Includes many examples of little or no structural damage, but buildings were reportedly out of operation due to nonstructural damage. Damage to low-rise storefronts was more prominent than high-rise curtain walls. Suspended ceilings with diagonal braces had less damage than older pre-1980 ceilings, even if they were not fully code-compliant. Architectural, mechanical and electrical systems were not coordinated and interfered with each other. Extensive disruption to essential functions was caused by nonstructural damage. Water leakage was a major cause, as piping failures of a few pipes caused large disruption. Leakage found early was controlled, but in other cases damage was extensive after hours of leakage. One reported death due to water dripping on a properly functioning emergency power system. Failure of emergency power systems was prevalent. Criteria for post earthquake inspection of nonstructural hazards (ATC-20) were not properly followed. Buildings with dangerous nonstructural damage, such as glass and roof tiles, were green tagged instead of yellow tagged.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
1994 Northridge, CA Earthquake	1/17/1994	Earthquake Spectra, Supplement C to Volume 11, Northridge Earthquake of January 17, 1994 Reconnaissance Report, Volume 1, April 1995	1995	Northridge Earthquake continued: Typical recommendations for museum pieces appeared to work well. Of 500,000 objects in museums, only 150 suffered damage. Raised computer floors performed relatively well. Ceilings were dislodged in 40% of the facilities surveyed. Seismic switches worked in some cases and not in others. Reported elevator damage was as follows: 17 rail damage, 11 counterweight derail, 9 rail damage and/or counterweight derail, 9 unspecified damage, 2 motor damage, and 2 miscellaneous, for a total of 50 damaged elevators; 8-pound rails were more prone to failure than 15-pound rails.
1994 Northridge, CA Earthquake	1/17/1994	"It Makes Dollars and Sense to Improve Nonstructural System Performance," C. Kircher, ATC-29-2	10/24/2003	Kircher states: "Results show that earthquake losses are dominated by nonstructural (and contents) damage. For example, of the approximate $6.3 billion of direct economic loss to non-residential buildings that occurred due to the 1994 Northridge earthquake, only about $1.1 billion is due to structural damage." Data on overall nonstructural damage from this earthquake is not provided.
1994 Northridge, CA Earthquake	1/17/1994	"Elevator Earthquake Damage – January 17, 1994," McTiernan, W.E., Elevator, Tramway, and Amusement Ride Unit of the California Division of Occupational Safety and Health, San Francisco, CA.	1994	Cites damage to elevators and escalators; 688 cases of derailment of elevator counterweights reported. Describes one instance where escalator truss fell.
Klamath Falls Earthquake of September 20, 1993	9/20/1993	The Klamath Falls Earthquake of September 20, 1993, Special Earthquake Report		Reports extensive failure of parapets; terracotta also failed; statistical data not provided.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
Guam Earthquake of August 8, 1993	8/8/1993	Earthquake Spectra, Supplement B to Volume 11, Guam Earthquake of August 8, 1993 Reconnaissance Report, April 1995	1995	Chapter 5: Includes reported damage to concrete block partitions, heavy furniture and televisions, and failure of spring-mounted equipment in hotel buildings.
Hokkaido-Nansei-Oki Earthquake and Tsunami of July 12, 1993	7/12/1993	Earthquake Spectra, Supplement A to Volume 11, Hokkaido-Nansei-Oki Earthquake and Tsunami of July 12, 1993 Reconnaissance Report, April 1995	1995	Chapter 7 and 8: Includes some reported cladding damage; report of well-behaved battery racks; no major nonstructural issues reported.
Landers and Big Bear Earthquakes of June 28 and 29, 1992	6/28/1992	Landers and Big Bear Earthquakes of June 28 and 29, 1992	1992	Reported failures of hung ceilings, light fixtures, and items in grocery stores; statistical data not provided.
Landers and Big Bear Earthquakes of June 28 and 29, 1992	6/28/1992	The Landers Big Bear Earthquakes, Newsletter 1 Opinions	1992	Nonstructural damage not reported.
Landers and Big Bear Earthquakes of June 28 and 29, 1992	6/28/1992	Earthquake-Damaged Big Bear Solar Observatory Reopened	1993	Observatory equipment and telescope were badly damaged.
Landers and Big Bear Earthquakes of June 28 and 29, 1992	6/28/1992	The Landers Big Bear Earthquakes Newsletter 2 Casualty Data		Includes reports of injuries that were most likely due to failures of nonstructural components.
Erzincan, Turkey, Earthquake of March 13, 1992	3/13/1992	Earthquake Spectra, Supplement to Volume 9, Erzincan, Turkey, Earthquake of March13, 1992 Reconnaissance Report, July 1993	1993	Chapters 5 and 6: Structural damage was reportedly extensive; little reported on nonstructural damage; some mention of equipment failure.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
Costa Rica Earthquake of April 22, 1991	4/22/1991	Earthquake Spectra , Supplement B to Volume 7, Costa Rica Earthquake of April 22, 1991 Reconnaissance Report, October 1991	1991	Chapters 4 and 5: A light steel building collapsed when heavy paper rolls damaged the columns. In the Limon Hospital, reported nonstructural damage included large areas of dislodged T-bar ceiling system; some failure of the fluorescent light hangers and ceiling fans; overturned bookcases and furniture; and widespread fracture and loss of asbestos panel roofing. Anchorage problems, and internal mechanical damage, were reported for some boilers.
Philippines Earthquake of July 16, 1990	7/16/1990	Earthquake Spectra, Supplement A to Volume 7, Philippines Earthquake of July 16, 1990 Reconnaissance Report, October 1991	1991	Chapters 5, 6 and 10: Many museum objects were not subject to catastrophic failure; however, much of the pottery in the collections was destroyed. Most of the collections consisted of wood carvings and baskets. These objects survived the earthquake because of their inherent robustness. Statistical data not provided.
Loma Prieta, California, Earthquake of October 17, 1989	10/17/1989	Earthquake Spectra, Supplement to Volume 6, Loma Prieta, California, Earthquake of October 17, 1989 Reconnaissance Report, May 1990	1990	Chapter 9: There are 428 hospitals and health care facilities under the jurisdiction of OSHPD. Of these, 282 had seismic safety devices reset. Fifty of these had damage that required repair (Table 9.5). Limited information reported on repair times indicates that 3 units took from three to five days to repair, 11 units took seven days to repair, and 1 unit took five weeks to repair.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
Loma Prieta, California, Earthquake of October 17, 1989	10/17/1989	Earthquake Spectra, Supplement to Volume 6, Loma Prieta, California, Earthquake of October 17, 1989 Reconnaissance Report, May 1990	1990	Loma Prieta Chapter 9, continued: $50 million in cumulative losses reported for PG&E: 1. Damage to exterior unreinforced masonry-brick veneer and facade systems, especially in upper stories, that resulted in extreme life-hazard to pedestrians below. 2. Modern precast concrete cladding panels and connections in multistoried commercial buildings appeared to have performed satisfactorily, without noticeable damage or collapse. 3. Broken windows and storefront glazing resulted in many hazardous conditions on sidewalks; also caused temporary loss of operability of businesses. 4. Damage to interior gypsum board and hollow-clay tile partitions caused by drift of building structural systems. 5. Damage to suspended-ceiling systems in many medium-rise buildings caused by drift of building structural systems. Suspended ceiling damage was typical of that observed during previous earthquakes. Damage occurred mainly at ceiling perimeters, and at interior building corners.
Loma Prieta, California, Earthquake of October 17, 1989	10/17/1989	Loma Prieta October 17, 1989 Preliminary Reconnaissance Report, Part 1		Nonstructural damage not reported.
Loma Prieta, California, Earthquake of October 17, 1989	10/17/1989	Loma Prieta October 17, 1989 Preliminary Reconnaissance Report, Part 2		Nonstructural damage of $50 million reported in some facilities. Ceiling, partition and piping damage was extensive. Damage to store front glazing was also extensive. Sales floors suffered extensive damage. Theaters suffered heavy ceiling damage.
Whittier Narrows, California, Earthquake of October 1, 1987	10/1/1987	Earthquake Spectra, Volume 4, Issue 2, The Whittier Narrows, California, Earthquake of October 1, 1987 Reconnaissance Report, May 1988	1988	Chapter 5: The traditional suggested method for anchoring water heaters using plumbers tape (perforated steel straps) proved to be inadequate. Water heaters moved, and rigid pipe connections were broken. Many semi-flexible tubing connections also failed. In addition, poor installation practices resulted in failures that allowed water heaters to fall over.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
Whittier Narrows, California, Earthquake of October 1, 1987	10/1/1987	Earthquake Spectra, Volume 4, Issue 2, The Whittier Narrows, California, Earthquake of October 1, 1987, Reconnaissance Report, May 1988	1988	Chapter 3: Reported nonstructural damage to buildings at California State University, Los Angeles (CSULA): 1. Extensive damage to partition walls, acoustical ceiling tiles, light fixtures, wall mounted television sets, floor tiles/coverings, and sound baffles attached to ceiling conduits. 2. Damage to pipe lines and chillers mounted in the upper floors of buildings. 3. Damage to mechanical equipment and utilities, resulting in gas and water leaks. 4. Extensive damage to library stacks and books. 5. Flash fire in a top floor chemistry lab (Physical Sciences Building). 6. Hazardous and toxic combinations of liquid chemicals in the chemistry labs due to fallen and broken bottles. 7. Release of hazardous levels of existing friable asbestos contamination into the air (Salazar Hall and Physical Sciences Building). 8. Damaged and temporarily inoperable elevators in various buildings. 9. Damage to desk-top personal computers in computer labs and offices, due to objects falling from the ceilings. 10. A student fatality caused by a 5000-pound precast concrete rail-panel falling from a height of 25 feet.
San Salvador Earthquake of October 10, 1986	10/10/1986	Earthquake Spectra, Volume 3, Number 3, An EERI Learning from Earthquakes Publication, The San Salvador Earthquake of October 10, 1986, August 1987	1987	Chapters 7, 10, 11, and 12: Includes reports of overturned batteries and ceramic breakage at electrical substations. Loss of operations was reportedly a major contributor to the losses for this Earthquake, but numbers or statistics are not provided.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
Mexico Earthquake of September 19, 1985	9/19/1985	Earthquake Spectra, Volume 5, Number 1, An EERI Learning from Earthquakes Publication, The Mexico Earthquake of September 19, 1985, February 1989	1989	Chapter 13: Reports on poor performance of heavy cladding on subject buildings. Statistical data not provided.
Chile Earthquake of March 3, 1985	3/3/1985	Earthquake Spectra, Volume 2, Number 2, An EERI Learning from Earthquakes Publication, The Chile Earthquake of March 3, 1985, February 1986	1986	Chapter 4, 5, 6 and 9: Includes reports of some window glass breakage, and collapsed ceilings. In industrial facilities, piping failures were reported at equipment, and at intersections between large and small pipes; 10% of tanks founded on sand reportedly failed. In hospitals, nonstructural damage was extensive.
Morgan Hill, California, Earthquake of April 24, 1984	4/24/1984	Earthquake Spectra, Volume 1, Number 3, An EERI Learning from Earthquakes Publication, The Morgan Hill, California, Earthquake of April 24, 1984, May 1985	1985	Chapter 4, 5, 6 and 8: Reported nonstructural damage at selected facilities included: Wiltron facility - significant damage to the structure and contents, San Martin Winery - shifting of equipment, IBM Santa Teresa - some damage to ceilings and fallen light fixtures that damaged consoles; Alexian Hospital in San Jose - overturning of 1 piece of equipment; Jackson Elementary School in Morgan Hill - ceilings fell; Morgan Hill Elementary School - small amount of ceiling damage in the multi-use room, Raymond Gwinn Elementary School in San Martin - bookshelves overturned, artwork fell. Damage at hospitals and public school disclosed that adopted regulations appear to be adequate; however, field control of installed items must be improved. Also building owners and their staff must become aware of the importance of properly anchoring fixed shelving, equipment, and other contents installed by the owners. Interior damage in many homes appeared to be disproportionate to the magnitude of the earthquake and the general lack of structural damage. Large dressers and bookcases fell over, contents of shelves in kitchens and other storage areas spilled onto floors, pictures fell off walls, and a few windows were broken (Figures 14, 15, and 16). State officials estimated the dollar loss attributed to content damage

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
				was in excess of $2.5 million.
Borah Peak, Idaho, Earthquake of October 18, 1983	10/18/1983	Earthquake Spectra, Volume 2, Number 1, An EERI Learning from Earthquakes Publication, The Borah Peak, Idaho, Earthquake of October 18, 1983, November 1985		Chapters 10 and 11: Includes reports of fallen parapets, fallen veneer, and cracked chimneys. Two fatalities (children), reportedly due to falling debris at a storefront. $12.5 million in estimated damage.
1971 San Fernando Earthquake	2/9/1971	"Nonstructural Damage, The San Fernando, California Earthquake of February 9, 1971," Vol. 1B, Ayres, J. M., and Sun, T. Y., National Oceanic and Atmospheric Administration, Washington, D.C.	1973	Detailed report; overall statistical data not provided.
1971 San Fernando Earthquake	2/9/1971	Automatic Sprinklers and Earthquakes, Earthquake Fire Seminar, Anaheim California	1973	Detailed report of damage to sprinklers and fire protection equipment, and good overview of the performance of fire protection systems. Some statistics, including information about specific types of failures are provided. Of 973 sprinklered properties in the affected area, detailed surveys were made on 68 of these properties. The single most repetitive failure was reported to be C-type clamps without lock nuts or retaining straps, used with threaded U-type hangers.

Table A-1 Log of Reported Nonstructural Earthquake Damage (continued)

Earthquake	Date	Reference Title	Publication Date	Reported Nonstructural Damage
1971 San Fernando Earthquake	2/9/1971	Preliminary Findings from the Los Angeles Earthquake February 9, 1971, Earthquake Engineering Research Institute		New effort is needed to safeguard electrical and communication equipment and to protect essential equipment within buildings. Greater attention to safety measures in the use of glass for windows and doors is called for.
1964 Alaska Earthquake	3/27/1964	"Nonstructural Damage to Buildings, The Great Alaska Earthquake of 1964," Ayres, J. M., and Sun, T. Y., National Academy of Sciences, Washington, D.C.	1973	Detailed report; overall statistical data not provided.
1964 Alaska Earthquake	3/27/1964	Automatic Sprinklers and Earthquakes, Earthquake Fire Seminar, Anaheim California	1973	Automatic sprinkler systems were reportedly the only mechanical system with seismic resistant design; other systems were generally unbraced. In one new department store, sprinkler lines were distorted but otherwise undamaged (building was demolished due to structural damage).
1952 Kern County, California	7/21/1952	Automatic Sprinklers and Earthquakes, Earthquake Fire Seminar, Anaheim California	1973	Little reported damage to automatic sprinkler systems or properly braced elevated sprinkler gravity tanks.
1933 Long Beach, California	3/10/1933	Automatic Sprinklers and Earthquakes, Earthquake Fire Seminar, Anaheim California	1973	Report on investigation by Board of Fire Underwriters of the Pacific: Of 150 sprinklered properties investigated, 40% had no shutdowns or limited shutdowns; 40% had partial impairments; and the remaining 20% had total shutdowns. Of those that experienced shutdowns, 60% were restored to service within 72 hours. There were no fires in sprinklered properties following this earthquake. This prompted changes in seismic design of elevated sprinkler gravity tanks, anchoring of sprinkler pressure tanks, and mandatory provisions for seismic bracing of overhead sprinkler piping and flexible couplings in sprinkler risers.
1925 Santa Barbara Earthquake	1/1/1925			Reportedly, one fatality due to a falling bookcase occurred at University of California, Santa Barbara (information unconfirmed, source unknown).

Appendix B

List of Resources Related to Nonstructural Components

Appendix B is a list of available resources related to nonstructural components, including codes and standards, testing protocols, guidance documents, nonproprietary details, photos, sample specifications, proprietary details, products, and research efforts. Information is organized into the following tables:

Table B-1 Codes and Standards Related to Nonstructural Components

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
ACI 318-08	Building Code Requirements for Reinforced Concrete and Commentary	2008	Appendix D	Appendix on requirements for anchorage in concrete; published by the American Concrete Institute, Detroit, Michigan.
ACI 355.2-07	Qualification of Post-Installed Mechanical Anchors in Concrete	2007		Published by the American Concrete Institute, Detroit, Michigan.
ASCE/SEI 7-05	Minimum Design Loads for Buildings and Other Structures	2005	Chapter 13	Chapter specifying seismic design requirements for nonstructural components; published by the American Society of Civil Engineers, Reston, Virginia.
SEI/ASCE 31-03	Seismic Evaluation of Existing Buildings	2003	Sections 3.9, 4.2.7, 4.8, and Table 4-9	Successor document to FEMA 310 *Handbook for the Seismic Evaluation of Buildings – A Prestandard*. Relevant sections describe evaluation procedures for existing nonstructural components. Includes comprehensive checklists of potential nonstructural hazards. Published by the American Society of Civil Engineers, Reston, Virginia.
ASCE/SEI 41-06	Seismic Rehabilitation of Existing Buildings	2007	Chapter 11	Successor document to FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*. Relevant chapter describes design procedures for the rehabilitation of existing nonstructural components, and a table identifying nonstructural component types and their applicability to different performance objectives. Published by the American Society of Civil Engineers, Reston, Virginia.
ASCE/SEI 43-05	Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities	2005		Provides design criteria for structures, systems, and components in nuclear facilities, with the goal of ensuring that these facilities can withstand the effects of earthquake ground shaking at the desired level of performance. Published by the American Society of Civil Engineers, Reston, Virginia.
ASHRAE SPC 171P	Method of Test of Seismic Restraint Devices for HVAC&R Equipment	2006		Establishes methods of testing and documenting the working shear and tensile strength of seismic restraint devices that are integral with vibration isolators or resilient devices. Published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

Table B-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
ASTM E580/ E580M-06	Standard Practice for Application of Ceiling Suspension Systems for Acoustical Tile and Lay-In Panels in Areas Requiring Seismic Restraint	2006		Standard for Zone 2; could also be used for Zones 3 and 4. Published by ASTM International, West Conshohocken, Pennsylvania.
Bulletin 2004-014-BU (Vancouver)	Seismic Restraint of Nonstructural Components	2004		Addresses suspended ceilings and non-load bearing partitions. Published by the City of Vancouver, British Columbia.
CSA S832-06 (Canada)	Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings	2006		Operational and functional components (OFCs) is a Canadian term for nonstructural components. The second edition of a document first published in 2001. Describes how to identify and evaluate hazards caused by nonstructural components, and provides strategies to mitigate damage. Intended to be applicable to most buildings types, either new or existing, and intended for building owners, inspectors, facility managers, engineers, architects and others whose focus is to provide safety, serviceability and durability of nonstructural components when subjected to earthquakes. Published by the Canadian Standard Association, Mississauga, Ontario.
E.030 (Peru)	National Construction Code, Technical Standard for Buildings, E.030 Earthquake-Resistant Design	2003		Design requirements for buildings in Peru. Drift provisions changed in 1997, and are now among the most stringent in the world. Drift must be computed without an R factor, and allowable drift is limited to .007h for reinforced concrete, and .01h for steel structures. Standard school construction must be confined concrete, and masonry infill must be isolated from the concrete frame. Schools built since 1997 meeting these criteria have suffered virtually no damage in recent large earthquakes in Peru. Published by El Servicio Nacional de Normalización, Capacitación e Investigación para la Industria de la Construcción (SENCICO), Lima, Perú.

Table B-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
EN 1998-1:2004(E) (Europe)	Eurocode 8: Design of Structures For Earthquake Resistance (English version, Final Draft)	2004	Part 1, Sections 4.3.5, 4.3.6	Includes general rules, seismic actions, and rules for buildings. Relevant sections cover design of nonstructural elements and additional measures for masonry infilled frames. Non-structural elements mentioned include parapets, gables, antennae, mechanical appendages and equipment, curtain walls, partitions, and railings. Nonstructural elements that might cause risks to persons, affect the main structure, or disrupt services of critical facilities must be verified to resist seismic design actions. Designs for nonstructural elements of great importance are based on realistic models of the structure and on appropriate response spectra derived from the response of the supporting structural elements. Lateral force calculations include consideration of period ratio, importance factor, and behavior factor. Published by the European Committee for Standardization (CEN).
IBC 2006	2006 International Building Code	2006		National model building code, latest edition; scheduled for adoption in most jurisdictions across the United States. Specifically references ASCE 7-05 for design of nonstructural components. Published by the International Code Council, Washington, D.C.
IBC 2003	2003 International Building Code	2003		National model building code; adopted in some areas of the United States. Published by the International Code Council, Washington, D.C.
ICC-ES AC-156	Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems.	2004		Published by the International Code Council Evaluation Service, Whittier, California.
NFPA 13	Standard for the Installation of Sprinkler Systems, 2007 Edition	2007		Published by the National Fire Protection Association, Quincy, Massachusetts.

Table B-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
NCh 433.Of96 (Chile)	Chilean Norm NCh 433.Of96, Earthquake Resistant Design of Buildings	1996		Chilean code for buildings. Includes the following drift criteria: (1) drift must be computed without an R factor; and (2) must be less than 0.002h for buildings with precast shear walls with dry joints; less than 0.003h for shear wall building with rigidly attached masonry infill; less than .0075h for unbraced frames with isolated infill; and less than .015h for other structures. Includes a scale factor Q/Q_{min} that allows a reduction of the computed drift for longer period structures where the design base shear Q is less than a minimum base shear Q_{min}. Stringent drift criteria (more stringent than U.S. codes) have resulted in an almost exclusive use of shear wall systems in buildings. As a result, drift-related nonstructural damage is significantly reduced. Published by the Instituto Nacional de Normalizacion (INN-Chile), Santiago, Chile.
NCh 2369.Of2003 (Chile)	Chilean Norm NCh2369, Earthquake Resistant Design of Industrial Structures and Facilities	2003		Chilean code for industrial buildings. Includes recommendations and design rules for mechanical equipment that could be applicable to other types of buildings. Currently only available in Spanish. Published by the Instituto Nacional de Normalizacion (INN-Chile), Santiago, Chile.
UBC 1961	Uniform Building Code, 1961 Edition	1961		First appearance of separate provisions for nonstructural components in the UBC; maximum lateral force of 0.2g in Zone 3.
UBC 1976	Uniform Building Code, 1976 Edition	1976		Nonstructural provisions updated in response to 1971 San Fernando Earthquake; maximum force increased to 0.3g in Zone 4.
UBC 1988	Uniform Building Code, 1988 Edition	1988		Update of nonstructural provisions to consider response of non-rigid items and items at grade; maximum force remained 0.3g in Zone 4 for rigid items.
UBC 1997	Uniform Building Code, 1997 Edition	1997		Nonstructural seismic requirements are a blend of requirements from the 1994 and 1997 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*.
USACE TI 809-04	Tri-Service Manual, Seismic Design for Buildings	1998	Chapter 10	Successor document to TM 5-809-10 and TM 5-809-10-1. Published by the US Army Corps of Engineers, Washington, D.C.

Table B-1 Codes and Standards Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
USACE TM 5-809-10	Tri-Service Manual, Seismic Design for Buildings	1996	Chapter 8, Appendix L	Provides a dynamic analysis procedure for design of nonstructural components that must remain functional after a major earthquake. Requires generation of floor response spectra and consideration of inter-story drift at the location of essential equipment. Appendix includes four design examples. Published by the US Army Corps of Engineers, Washington, D.C.
USACE TM 5-809-10-1	Tri-Service Manual, Seismic Design Guidelines for Essential Buildings	1986	Chapter 6	Provides methodology for design; defines essential nonstructural systems (Table 6-3); defines two levels of earthquake ground motion (EQ-I and EQ-II); requires equipment certification. Published by the US Army Corps of Engineers, Washington, D.C.
USACE TM-5-809-10-2	Tri-Service Manual, Seismic Design Guidelines for Upgrading Existing Buildings	1988	Chapter 9	Chapter focuses on improving performance of existing nonstructural installations. Includes a list of nonstructural systems with descriptions of potential damage and failure modes (Table 9-1). Published by the US Army Corps of Engineers, Washington, D.C.
VISCMA 102-07	Static Qualification Standards for Obtaining a VISCMA Compliant Seismic Component Rating	2007		Testing protocol for mechanical, electrical and plumbing equipment. Published by the Vibration Isolation and Seismic Control Manufacturers Association, Wayne, Pennsylvania.

Table B-2 Guidance Documents Related to Nonstructural Components

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
ASHRAE RP-812	A Practical Guide to Seismic Restraint	1999		Published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia.
ASHRAE /SMACNA	Seismic Restraint Applications CD-ROM	2002		Provides technical information for design and installation of seismic restraints for HVAC equipment, piping, and ducts. Includes representative bracing details, layout examples, and tables. Consists of portions of the following documents: SMACNA's Seismic Restraint Manual: Guidelines for Mechanical Systems; ASHRAE's Handbook - HVAC Applications (2003); and ASHRAE's A Practical Guide to Seismic Restraint. Produced by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. and the Sheet Metal and Air Conditioning Contractors' National Association.
CISCA 1991	Recommendations for Direct-Hung Acoustical and Lay-in Panel Ceilings, Seismic Zones 0-2	1991		Industry standards for ceilings in low seismic zones. Published by Ceilings and Interior Systems Construction Association, Deerfield, Illinois.
CISCA 1990	Recommendations for Direct-Hung Acoustical and Lay-in Panel Ceilings, Seismic Zones 3-4	1990		Industry standards for ceilings in high seismic zones. Published by Ceilings and Interior Systems Construction Association, Deerfield, Illinois.
DGS, DSA (California)	Guide and Checklist for Nonstructural Earthquake Hazards in California Schools			Identifies potential hazards associated with nonstructural components and provides recommendations to mitigate hazards. Includes typical details and a nonstructural earthquake hazards checklist. Published by the California State Department of General Services, Division of the State Architect, and the Governer's Office of Emergency Services, Sacramento, California.

Table B-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
DOISSP	Nonstructural Hazards Rehabilitation Guidelines; Vol. I; Guidelines Usage, Architectural, Mechanical, Electrical, Plumbing			Contains guidance gathered from various sources, both public and private sources. Includes both proprietary and non-proprietary details. Published by the Department of the Interior Bureau of Reclamation, Seismic Safety Program (DOISSP), Washington, D.C.
DOISSP	Nonstructural Hazards Rehabilitation Guidelines; Vol. II; Furnishings, Interior Equipment, Miscellaneous Components, Mobile Homes, Manufactured Homes, FEMA 273, FEMA 310, FEMA 178, & ASCE 31-xx Excerpts			Contains guidance gathered from various sources, both public and private sources. Includes both proprietary and non-proprietary details. Published by the Department of the Interior Bureau of Reclamation, Seismic Safety Program (DOISSP), Washington, D.C.
EERI 84-04	Nonstructural Issues of Seismic Design and Construction	1984		Results of workshop including invited papers on nonstructural issues. Published by the Earthquake Engineering Research Institute, Oakland, California.
FEMA	Instructor's Guide for Nonstructural Earthquake Mitigation for Hospitals and other Health Care facilities.	1988		Materials for course given by Emergency Management Institute, Emmitsburg, Maryland.
FEMA	Final Report, Nonstructural Earthquake Mitigation Guidance Manual.	2004		Based on FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, 2002. Includes flowcharts, step-by-step procedures and some details. Divides nonstructural components into four groups: contents, exterior building elements, interior building elements, and building utilities. Prepared by URS Group, Inc. for FEMA.
FEMA Region X	Earthquake Hazard Mitigation Handbook for Public Facilities	2002		Available at http://www.conservationtech.com/FEMA-WEB/FEMA-subweb-EQ/index.htm

Table B-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA 74	Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide. Third Edition	1994		Successor document to previous editions of FEMA 74, first published in 1985.
FEMA 74-FM	Earthquake Hazard Mitigation for Nonstructural Elements, Field Manual	2005		Includes three types of details: Non-Engineered, Prescriptive, and Engineered. Contains more details than FEMA 74, along with a field data sheet based on the FEMA 74 checklist.
FEMA 150	Seismic Considerations: Health Care Facilities	1990		Published by the Federal Emergency Management Agency, Washington, D.C.
FEMA 172	NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings	1992	Chapters 5, 6	Relevant chapters include details for electrical cabinets, chimneys, parapets, masonry partitions, raised access floors, and mechanical equipment.
FEMA 178	NEHRP Handbook for the Seismic Evaluation of Existing Buildings	1992	Section 10.5	Predecessor document to FEMA 310.
FEMA 232	Homebuilders' Guide to Earthquake-Resistant Design and Construction	2006		Includes details based on the 1994 edition of FEMA 74.
FEMA 273	NEHRP Guidelines for the Seismic Rehabilitation of Buildings	1997		Predecessor document to FEMA 356.

Table B-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA 310	Handbook for the Seismic Evaluation of Buildings - A Prestandard	1998	Sections 3.9, 4.2.7, 4.8, and Table 4-9	Predecessor document to SEI/ASCE 31-03. Relevant sections describe evaluation procedures for existing nonstructural components. Includes comprehensive checklists of potential nonstructural hazards.
FEMA 356	Prestandard and Commentary for the Seismic Rehabilitation of Buildings	2000	Chapter 11	Successor document to FEMA 273/274, and predecessor to ASCE/SEI 31-03. Relevant chapter describes design procedures for the rehabilitation of existing nonstructural components, and a table identifying nonstructural component types and their applicability to different performance objectives.
FEMA 389	Communicating with Owners and Managers of New Buildings on Earthquake Risk: A Primer for Design Professionals	2004		
FEMA 395	Incremental Seismic Rehabilitation of School Buildings (K-12): Providing Protection to People and Buildings	2003		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-21) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to school occupancies.
FEMA 396	Incremental Seismic Rehabilitation of Hospital Buildings: Providing Protection to People and Buildings	2003		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-23) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to hospital occupancies.
FEMA 397	Incremental Seismic Rehabilitation of Office Buildings: Providing Protection to People and Buildings	2003		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-24) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to office occupancies.

Table B-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA 398	Incremental Seismic Rehabilitation of Multifamily Apartment Buildings: Providing Protection to People and Buildings	2004		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-22) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to multifamily apartment occupancies.
FEMA 399	Incremental Seismic Rehabilitation of Retail Buildings: Providing Protection to People and Buildings	2004		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-22) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to retail occupancies.
FEMA 400	Incremental Seismic Rehabilitation of Hotel and Motel Buildings	2005		Includes a table of "Nonstructural Seismic Performance Improvements" (page C-23) that lists possible seismic performance improvements that could be undertaken on nonstructural components common to hotel and motel occupancies.
FEMA 412	Installing Seismic Restraints for Mechanical Equipment	2002		Includes numerous elaborate details and many recommendations for seismic restraint of mechanical equipment.
FEMA 413	Installing Seismic Restraints for Electrical Equipment	2004		Includes numerous elaborate details and many recommendations for seismic restraint of electrical equipment.
FEMA 414	Installing Seismic Restraints for Duct and Pipe	2004		Includes numerous elaborate details and many recommendations for seismic restraint of duct and piping components.
FEMA 424	Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds	2004		Includes pictures of nonstructural damage (pages 4-17 through 4-19, 4-23, 4-24, 4-30, 4-31); a list of types of nonstructural components (page 4-59); graphics for ceilings, shelves, and walls (pages 4-60 and 4-61).
FEMA 433	Using HAZUS-MH for Risk Assessment: How-To Guide	2004		

Table B-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA 445	Next-Generation Performance-Based Seismic Design Guidelines: Program Plan for New and Existing Buildings	2006	Section 4.2	Describes how performance-based seismic design guidelines will be developed under the ATC-58 Project. Section 4.2 refers specifically to the development of nonstructural performance products.
FEMA 450	NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Part 1 and 2: Provisions and Commentary	2004	Chapters 6, 6A, and Commentary	Provides criteria for the design and construction of structures to resist earthquake ground motions. Relevant chapters include prescriptive requirements for the design of architectural, mechanical, electrical and piping components.
FEMA 452	A How-To Guide to Mitigate Potential Terrorist Attacks Against Buildings	2005		
FEMA 454	Designing for Earthquakes: A Manual for Architects	2006	Section 6.6, Chapter 9	Discussion of code issues including nonstructural issues. Contains a collection of photos and generic details borrowed from various sources including: FEMA 74; details developed for the Lawrence Livermore National Lab; and the SMACNA Guidelines. Includes a discussion on the need for systems engineering, considering all parts of the building as a whole. Provides a checklist (Table 9-3) showing allocation of design responsibilities for nonstructural systems and components.

Table B-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
FEMA 460	Seismic Considerations for Steel Storage Racks Located in Areas Accessible to the Public	2005		Includes: a review of the performance of storage racks in past earthquakes; a history of the development of codes and standards used for storage rack design; current storage rack design practices; guidance on recommended performance goals and design requirements for storage racks; guidelines for implementation/responsibilities associated with the specification, procurement, and installation of pallet storage racks; suggested guidance for securing contents; recommendations for operations and use; suggested guidance for quality assurance programs; a discussion of current and past storage rack research and testing; suggestions for post-earthquake inspections; and proposed modifications to seismic design provisions and standards for racks.
FEMA 461	Interim Protocols for Determining Seismic Performance Characteristics of Structural and Nonstructural Components	2007		Provides an interim protocol for testing of building components to establish their performance capability in the form of fragility functions. Fragility functions are used to assess the seismic performance of individual components, systems incorporating these components, and buildings containing these systems and components that are subjected to earthquake shaking. Protocols are not intended for seismic performance qualification testing of nonstructural components required by the building code, although the loading protocols could be used for that purpose.
FEMA 577	Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings	2007		
FEMA 582	Design Guide for Improving Commercial Buildings Safety in Earthquakes, Floods, and High Winds	Future		

Table B-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
John Wiley & Sons, Inc.	Earthquakes, an Architect's Guide to Nonstructural Seismic Hazards	1990		Target audience is architects. Written by H.J. Lagorio. Published by John Wiley & Sons, Inc., New York, New York.
OCIPEP (Canada)	Seismic Hazard Assessment and Mitigation for Buildings' Functional and Operational Components: A Canadian Perspective	2002		Contains figures and photos from various sources, including FEMA 74. Includes damage photos from 1999 Chi Chi, Taiwan Earthquake: damage to rooftop equipment (page 19); collapse of free-standing non-structural wall (page 20); and damage to sprinkler systems. Prepared by the Department of Civil Engineering, University of Ottowa, for the Office of Critical Infrastructure Protection and Emergency Preparedness (OCIPEP), Ontario, Canada.
Oregon Emergency Management	Earthquake Preparedness and Mitigation Guidance for Oregon State Agency Offices and Warehouses	2004		Focuses on office and warehouse occupancies, with special attention to storage racks. Includes photos and guidance including shrink-wrap and netting to mitigate potential falling hazards. Provides some specific information on performance of furniture by specific vendors (Hayworth, Steelcase, and Artmet).
Pan American Health Organization	Principles of Disaster Mitigation in Health Facilities	2000	Chapter 3	Includes guidance on assessing and mitigating seismic vulnerabilities of nonstructural components. Published by the Pan American Health Organization, Regional Office of the World Health Organization, Washington, D.C.
Salt Lake City School District	Seismic Design Criteria of Nonstructural Systems For New School Facilities And Existing School Facilities	2001		Developed under a FEMA "Project Impact" Grant. Intended for use on new school design projects and seismic retrofit projects in the Salt Lake City School District. Establishes minimum design procedures, general detailing requirements, design approval procedures, and construction inspection procedures for nonstructural items. The design engineer or architect is responsible for development of project specific nonstructural details. Some requirements exceed the minimum standards given in the Uniform Building Code (UBC).

Table B-2 Guidance Documents Related to Nonstructural Components (continued)

Document Number/Source	Title	Publication Date	Relevant Sections	Comments
Seattle Public Schools	School Facilities Manual: Nonstructural Protection Guide. Safer Schools, Earthquake Hazards, Nonstructural. Second Edition	2000		Includes detailed inventory form and details not included in FEMA 74.
University of California, Berkeley	UC Berkeley: Q-Brace Quake Bracing Guidelines	2005		Guidelines developed for University of California, Berkeley campus facilities. Includes detailed solutions for contents identifying vendor supplied products or size of hardware to use.
USACERL TR-98/34	Seismic Mitigation for Equipment at Army Medical Centers	1998		Presents simple methods for reducing the seismic vulnerability of equipment at Army medical centers. Illustrations, observations, and recommendations are based on examples from Madigan Army Medical Center (MAMC). Concerns about particular well-anchored critical medical equipment are presented. Published by the U.S. Army Construction Engineering Research Laboratories.
USACE, Engineering and Support Center	Seismic Protection for Mechanical Equipment			Presentation on procedures to design seismic supports of equipment, piping, and ducts; includes force coefficients and methods to calculate forces. Also includes a list of references useful as guidelines for the design. Available from the U.S. Army Corps of Engineers at http://www.dtic.mil/ndia/2005triservice/track16/stut.pdf.
VISCMA	Understanding the 2000 IBC Code (Architectural Components and Equipment Restraint)	2005		Available on the Vibration Isolation and Seismic Control Manufacturers Association website at http://www.viscma.com/articles.htm
VISCMA	The Pitfalls of Combining Internal & External Equipment Isolation	2003		Explains problems associated with utilizing both internal and external isolation in equipment. Shows that performance is better if only external isolation is used. Available on the Vibration Isolation and Seismic Control Manufacturers Association website at http://www.viscma.com/articles.htm

Table B-3 Nonproprietary Details and Other Resources for Nonstructural Components

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
ASHRAE /SMACNA	Non-proprietary Details	Seismic Restraint Applications CD-ROM	2002		Provides technical information for design and installation of seismic restraints for HVAC equipment, piping, and ducts. Includes representative bracing details, layout examples, and tables. Consists of portions of the following documents: SMACNA's Seismic Restraint Manual: Guidelines for Mechanical Systems; ASHRAE's Handbook - HVAC Applications (2003); and ASHRAE's A Practical Guide to Seismic Restraint. Produced by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. and the Sheet Metal and Air Conditioning Contractors' National Association.
ATC-38	Damage Inventory Form	ATC-38 Postearthquake Building Performance Assessment Form and Surveyor Instructions	2001		10-page form and instructions that provides standardized damage percentages and standardized codes for ceilings and partitions. Available with the ATC-38 Project report, or on the EERI website at http://www.eeri.org/
Dartmouth College	Sample Specification	Dartmouth College Design & Construction Guidelines, Section 15240 Seismic Restraint and Vibration Control	2004		Specification for the installation of equipment at Dartmouth College. Available at http://www.dartmouth.edu/~opdc/pdfs/15240.pdf
DGS, DSA (California)	Guide and Checklist	Guide and Checklist for Nonstructural Earthquake Hazards in California Schools	2003		Identifies potential hazards associated with nonstructural components and provides recommendations to mitigate hazards. Includes typical details and a nonstructural earthquake hazards checklist. Published by the California State Department of General Services, Division of the State Architect, and the Governer's Office of Emergency Services, Sacramento, California.

Table B-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
DOISSP	Non-proprietary Details	Nonstructural Hazards Rehabilitation Guidelines; Vol. I; Guidelines Usage, Architectural, Mechanical, Electrical, Plumbing	2003		Contains guidance gathered from various sources, both public and private sources. Includes both proprietary and non-proprietary details. Published by the Department of the Interior Bureau of Reclamation, Seismic Safety Program (DOISSP), Washington, D.C.
DOISSP	Non-proprietary Details	Nonstructural Hazards Rehabilitation Guidelines; Vol. II; Furnishings, Interior Equipment, Miscellaneous Components, Mobile Homes, Manufactured Homes, FEMA 273, FEMA 310, FEMA 178, & ASCE 31-xx Excerpts	2003		Contains guidance gathered from various sources, both public and private sources. Includes both proprietary and non-proprietary details. Published by the Department of the Interior Bureau of Reclamation, Seismic Safety Program (DOISSP), Washington, D.C.
EERI	Damage Inventory Form	EERI Reconnaissance/ Clearinghouse Report Form - Architectural and Nonstructural Elements	2000		2-page form consisting of broad categories, several subcategories, and blank lines to report damage and gather damage statistics.
FEMA	Non-proprietary Details	Final Report, Nonstructural Earthquake Mitigation Guidance Manual	2004		Based on FEMA Region X Earthquake Hazard Mitigation Handbook for Public Facilities, 2002. Includes flowcharts, step-by-step procedures and some details. Divides nonstructural components into four groups: contents, exterior building elements, interior building elements, and building utilities. Prepared by URS Group, Inc. for FEMA.
FEMA Region X	Non-proprietary Details	Earthquake Hazard Mitigation Handbook for Public Facilities	2002		Available at http://www.conservationtech.com/FEMA-WEB/FEMA-subweb-EQ/index.htm

Table B-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
FEMA 74	Non-proprietary Details	Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide. Third Edition	1994		Successor document to previous editions of FEMA 74, first published in 1985.
FEMA 74 FM	Non-proprietary Details	FEMA 74 Field Manual	2005		Includes three types of details: Non-Engineered, Prescriptive, and Engineered. Contains more details than FEMA 74, along with a field data sheet based on the FEMA 74 checklist.
FEMA 172	Non-proprietary Details	NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings	1992	Chapters 5, 6	Relevant chapters include details for electrical cabinets, chimneys, parapets, masonry partitions, raised access floors, and mechanical equipment.
FEMA 412	Non-proprietary Details	Installing Seismic Restraints for Mechanical Equipment	2002		Includes numerous elaborate details and many recommendations for seismic restraint of mechanical equipment.
FEMA 413	Non-proprietary Details	Installing Seismic Restraints for Electrical Equipment	2004		Includes numerous elaborate details and many recommendations for seismic restraint of electrical equipment.
FEMA 414	Non-proprietary Details	Installing Seismic Restraints for Duct and Pipe	2004		Includes numerous elaborate details and many recommendations for seismic restraint of duct and piping components.
FEMA 424	Photos, Damage	Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds	2004		Includes pictures of nonstructural damage (pages 4-17 through 4-19, 4-23, 4-24, 4-30, 4-31); a list of types of nonstructural components (page 4-59); graphics for ceilings, shelves, and walls (pages 4-60 and 4-61).

Table B-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
FEMA 454	Non-proprietary Details	Designing for Earthquakes: A Manual for Architects	2006	Section 6.6, Chapter 9	Discussion of code issues including nonstructural issues. Contains a collection of photos and generic details borrowed from various sources including: FEMA 74; details developed for the Lawrence Livermore National Lab; and the SMACNA Guidelines. Includes a discussion on the need for systems engineering, considering all parts of the building as a whole. Provides a checklist (Table 9-3) showing allocation of design responsibilities for nonstructural systems and components.
Los Alamos National Laboratory	Sample Specification	Section 22 0548 Vibration and Seismic Controls for Plumbing, Piping, and Equipment	2006		Specification for the anchorage of equipment at Los Alamos National Lab. Available at http://engstandards.lanl.gov/conspec/pdf/22_0548R0.pdf
OCIPEP (Canada)	Photos, Damage	Seismic Hazard Assessment and Mitigation for Buildings' Functional and Operational Components: A Canadian Perspective	2002		Contains figures and photos from various sources, including FEMA 74. Includes damage photos from 1999 Chi Chi, Taiwan Earthquake: damage to rooftop equipment (page 19); collapse of free-standing non-structural wall (page 20); and damage to sprinkler systems. Prepared by the Department of Civil Engineering, University of Ottowa, for the Office of Critical Infrastructure Protection and Emergency Preparedness (OCIPEP), Ontario, Canada.
Oregon Emergency Management	Non-proprietary Details	Earthquake Preparedness and Mitigation Guidance for Oregon State Agency Offices and Warehouses	2004		Focuses on office and warehouse occupancies, with special attention to storage racks. Includes photos and guidance including shrink-wrap and netting to mitigate potential falling hazards. Provides some specific information on performance of furniture by specific vendors (Hayworth, Steelcase, and Artmet).

Table B-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
PEER 2003/05	Taxonomy and Nonstructural Damage Inventory Form	Response Assessment of Nonstructural Building Elements	2003		Proposes a taxonomy (classification) of nonstructural elements by functionality, modes of failure, acceleration-sensitive or drift-sensitive response parameter, and repercussions of damage. Provides damageability, cost, and loss data for 200 elements. Includes a Nonstructural Damage Inventory Form used following the Nisqually Earthquake.
PEER 2003/12	Non-proprietary Details	Implementation Manual for the Seismic Protection of Laboratory Contents: Format and Case Studies	2003		Presents case studies for University of California Berkeley campus labs. Suggests format for User's Manual that could be used to help occupants install do-it-yourself details for a particular facility.
PEER 2005/03	Taxonomy	A Taxonomy of Building Components for Performance-Based Earthquake Engineering	2005		Provides a detailed taxonomy (classification) of nonstructural components. Each component is assigned a unique identification number. The list differentiates between anchored and unanchored versions of the same item.
Sandia	Sample Specification	Special Specification Section 13085S - Seismic Protection			Sample specification for the anchorage of equipment at Sandia (16 pages). Includes lists of equipment, detailed requirements, specific instructions for some items, load limits, and member sizes.
Seattle Public Schools	Non-proprietary Details	School Facilities Manual: Nonstructural Protection Guide. Safer Schools, Earthquake Hazards, Nonstructural. Second Edition	2000		Includes detailed inventory form and details not included in FEMA 74.
Southern California Earthquake Center	Photos, Damage	Nonstructural Issues in Public Schools - "Stairs to Nowhere"	2000		Photos of damage in school facilities in Southern California. Available at http://www.scec.org/instanet/00news/images/mcgavin/sld001.htm

Table B-3 Nonproprietary Details and Other Resources for Nonstructural Components (continued)

Document Number/Source	Resource Type	Title	Publication Date	Relevant Sections	Comments
University of California, Berkeley	Non-proprietary Details	UC Berkeley: Q-Brace Quake Bracing Guidelines	2005		Guidelines developed for University of California, Berkeley campus facilities. Includes detailed solutions for contents identifying vendor supplied products or size of hardware to use.
USACERL TR-98/34	Photos, Mitigation	Seismic Mitigation for Equipment at Army Medical Centers	1998		Presents simple methods for reducing the seismic vulnerability of equipment at Army medical centers. Illustrations, observations, and recommendations are based on examples from Madigan Army Medical Center (MAMC). Concerns about particular well-anchored critical medical equipment are presented. Published by the U.S. Army Construction Engineering Research Laboratories.
VISCMA 101-07	Sample Specification	Seismic Restraint Specification Guidelines for Mechanical, Electrical And Plumbing Systems	2007		Sample specification for seismic restraint of mechanical, electrical and plumbing equipment. Published by the Vibration Isolation and Seismic Control Manufacturer's Association, Wayne, Pennsylvania.

Table B-4 Proprietary Details and Products for the Protection of Nonstructural Components (

Product Source/Vendor	Product or Service Description	Comments
Chatsworth Seismic Protection Products	Chatsworth Seismic Protection Products	Variety of seismic protection products. Available at http://www.twacomm.com/catalog/dept_id_644.htm
Flexhead	Flexible fire protection	Proprietary flexible connection for sprinklers heads. Available at http://www.flexhead.com/
Hilti	Concrete anchors and hardware	Information on product selection, different installation systems, and load data. Available at www.hilti.com
International Seismic Application Technology	International Seismic Application Technology (ISAT) Applications and Design Manual	Focuses exclusively on mechanical, electrical, plumbing equipment and piping. Includes load tables and details showing use of products. Available at www.isatsb.com
International Seismic Application Technology	2003 IBC Specification - Seismic Restraint of Suspended Utilities	Sample specification available at www.isatsb.com
Kinetics Noise Control	Kinetics noise control seismic restraint capabilities	Brochure presents restraint systems that serve to limit the movement of equipment during a seismic event. Available at http://www.kineticsnoise.com/hvac/pdf/seismic%20restraint%20capabilities.pdf
Loos & Co	Proprietary details approved by OSHPD for use in California hospitals	Includes collections of details, such as: Section 7, Sway Brace Components, Installation Instructions and Details. Available at www.earthquakebrace.com
Mason Industries	Details, Handbook, and online resources	Available at http://www.mason-ind.com/html/about.htm or http://209.200.80.33/html/seismic_engineering_index.htm
Metraflex	Thermal and seismic expansion joints for pipe	Available at http://www.metraflex.com/seismic_met.php
Pacific Seismic Products	ASCE 25-97 listed seismic actuated valves for residential, commercial and industrial applications	Gas shut off valves and other seismic actuated devices. Available at http://www.psp4gasoff.com/aboutpsp.htm
Ridg-U-Rak	Isolation system for storage racks	Isolation test of storage racks, both with and without transverse isolation. Movie of test available on website. Available at http://www.ridgurak.com

Table B-4 Proprietary Details and Products for the Protection of Nonstructural Components (continued)

Product Source/Vendor	Product or Service Description	Comments
Technotes Issue No. 21 RWDI Consulting Engineers and Scientists	Base isolation system for museum pieces or equipment	"Seismic Protection of Museum Artifacts using Base Isolation," Bujar Myslimaj, Ph.D., P.Eng., Senior Specialist, Scott Gamble B.Sc., P.Eng., Principal, Ray Sinclair, Ph.D., Principal. Available at http://go.rwdi.com/technotes/t21.pdf
Safety Central	Earthquake safety fasteners, furniture straps, and emergency preparedness supplies	Available at www.safetycentral.com
Secure Quick	Secure Quick Seismic Fastening System	Consists of steel cable, wall bracket, and cable fasteners for attaching furniture to wood stud walls. Also provided on website, "Why You Should Not Use Plastic Tabs Devices, Velcro, Hook and Loop, Nylon Straps or Metal Braces." Available at www.quakesecure.com
Secure-It	PC Security Hardware	Provides products to secure computer equipment. Intended as protection against theft, but security cables and hardware could also be adapted as seismic restraint for other desktop items. Available at http://www.secure-it.com/shop/index.php/cPath/21
Seismic Restraints NZ	Hardware and systems for contents: collectables, home, office, school, hospital, lab, and technology.	Available at www.seismicrestraints.co.nz
Seismic Solutions	Seismic restraint for ducts, pipes, cable trays, and equipment using cables	Services include structural design, labor and materials for installation. Available at http://www.seismicsolutionsinc.com/details.html
Simpson Strong-Tie	Provides load rated straps and ties	Includes link for DIY (Do-it-Yourself) projects that illustrate the use of various connectors and adhesives, which could help with some nonstructural installations. Available at http://www.strongtie.com/products/categories/diy.html
Strand Earthquake Consultants	Engineering and products for nonstructural seismic mitigation	Distributors for GeoSIG, Pacific Seismic Products, Metraflex, and WorkSafe Technologies.

Table B-4 Proprietary Details and Products for the Protection of Nonstructural Components (continued)

Product Source/Vendor	Product or Service Description	Comments
Taylor Devices, Inc.	Viscous dampers for equipment protection	Available at http://www.taylordevices.com/SeismicDampers.htm
The Preparedness Center	Earthquake safety fasteners, furniture straps, and emergency preparedness supplies	Available at www.preparedness.com
USG	"Seismic Ceiling Resource Center"	Includes a series of technical notes and guidelines related to ceilings, ceiling tracks, and shadow moldings. Available at www.usg.com and www.seismicceilings.com
Viking	Flexible connections for sprinkler heads	Available at http://www.vikingcorp.com/databook/sprinklers/spk_accessories/070605.pdf
WorkSafe Technologies	System for base-isolation of equipment	IsoBase™ Seismic Isolation Platform, available at http://www.worksafetech.com/
WorkSafe Technologies	Large variety of products for seismic protection of nonstructural components in offices, data centers, hospitals, laboratories, and warehouses.	Available at http://www.worksafetech.com/

Table B-5 Recent and Ongoing Research Related to Nonstructural Components (

Document Number/Source	Title	Author(s)	Publication Date	Comments
8NCEE-002034	Enhancing the Resilience of Acute Care Facilities: An Overview of MCEER Research	Filiatrault, A., et al.	2006	Paper at 8th National Conference on Earthquake Engineering, San Francisco, California.
13WCEE-00295	Overturning Criteria for Non-Anchored Non-Symmetric Rigid Bodies	Boroschek, R.L., and Romo, D.	2004	Theoretical discussion of the effect of non-symmetric bodies subjected to overturning. Paper at 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada.
ATC-29	Proceedings of a Seminar on Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures		1992	Includes information on seismic design, performance, and research pertaining to nonstructural components. Funded by the National Center for Earthquake Engineering Research and the National Science Foundation.
ATC-29-1	Proceedings of a Seminar on Seismic Design, Retrofit, and Performance of Nonstructural Components		1998	Includes information on seismic design, performance, and research pertaining to nonstructural components. Funded by the National Center for Earthquake Engineering Research and the National Science Foundation.
ATC-29-2	Proceedings of Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities		2003	Focused principally on nonstructural components and systems in facilities with critical functions. Includes information on the state of the art, state of the practice, and efforts needed to improve both. Prepared in cooperation with the Multidisciplinary Center for Earthquake Engineering Research, and funded by the National Science Foundation.

Table B-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
ATC-38	Database on the Performance of Structures Near Strong-Motion Recordings: 1994 Northridge, California, Earthquake		2001	Effort to correlate structural and nonstructural damage with ground motion parameters recorded during the 1994 Northridge Earthquake. Report includes a CD-ROM with Access database, Excel files, text files, and collection of over 500 photos. Database includes some nonstructural damage data in the following categories: "cladding separation or damage," "partitions damage," "windows damage," "lights and ceilings damage," and "Building Contents Damage." Most photos do not show damage, but provide an overview of the building from street. Report also includes the ATC-38 Postearthquake Building Performance Assessment Form and Surveyor Instructions. Nonstructural categories include Exterior Cladding/Glazing; Partitions; Ceilings; Plumbing, Electrical, Lighting, HVAC; Fire Protection; Major Fixed Equipment, Elevators, Chimneys, and Unusual Contents.
ATC-58	Proceedings: Mini-Workshop/Invited Meeting on the Identification of Nonstructural Components of Significance		2005	ATC-58 Project workshop focusing on the selection of a nonstructural component taxonomy, and identifying nonstructural components that are significant to the estimation of casualty, direct economic, and downtime losses from earthquake damage.
ATC-58	Guidelines for Seismic Performance Assessment of Buildings, ATC-58 35% Complete Draft		2007	Interim report on methodology for seismic performance assessment of new and existing buildings. Methodology will be applicable to most common building types designed and constructed in the United States within the past 50 years, and will estimate losses in terms of causalities, direct economic losses, and downtime as a result of earthquake damage. Loss estimation is based on fragility curves, which will be provided for both structural and nonstructural components.
FEMA 349	Action Plan for Performance Based Seismic Design		2000	Predecessor document to FEMA 445. Prepared by the Earthquake Engineering Research Institute for FEMA.

Table B-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
FEMA 445	Next-Generation Performance-Based Seismic Design Guidelines: Program Plan for New and Existing Buildings	2006	Section 4.2	Describes how performance-based seismic design guidelines will be developed under the ATC-58 Project. Section 4.2 refers specifically to the development of nonstructural performance products.
EERI	Learning from Earthquakes: a Survey of Surveys.	Porter, K.	2002	Taken from an EERI Invitational Workshop: An Action Plan to Develop Earthquake Damage and Loss Data Protocols, September 19-20, 2002, Doubletree Hotel, Pasadena, California.
MCEER	ASHRAE Consortium Investigates Performance of Roof-Top Air Handling Unit		Future	MCEER's ASHRAE Consortium is beginning Phase II studies involving shake table testing of a rigidly anchored and vibration isolated roof-top air handling unit. Testing will begin in March 2008 in the Structural Engineering and Earthquake Simulation Laboratory (SEESL) at the University at Buffalo. Studies will focus on developing a specialized numerical model capable of analyzing the seismic response of various types of HVAC equipment mounted on ASHRAE-type isolation/restraint systems.
MCEER	Seismic Vulnerability and Protection of Nonstructural Components	T.T. Soong and D. Lopez Garcia	2003	Addresses seismic vulnerability and protection strategies. Divides nonstructural items into 3 categories: Unrestrained Nonstructural Components; Restrained Nonstructural components; and Nonstructural Systems, which consist of systems of nonstructural components. Cites examples of fragility curves developed for each category. Contains discussion of both damping systems and isolation systems as protection strategies. Ends with recommendations for 6 tasks: (1) Develop a Catalog of Nonstructural Components, Systems and Contents; (2) Identify Nonstructural Performance Measures; (3) Identify Engineering Demand Parameters; (4) Develop Damage Database; (5) Establish Comprehensive Testing and Certification Protocols; and (6) Performance Evaluation Case Studies/Test bed Checks.

Table B-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
MCEER-99-0014	MCEER Nonstructural Damage Database	Kao, A., and Soong, T.T.	1999	Database of earthquake damage to nonstructural elements.
MCEER-05-0005	"Simulation of Strong Ground Motions for Seismic Fragility Evaluation of Nonstructural Components in Hospitals"	Wanitkorkul, A. and Filiatrault, A.	2005	Published by the Multidisciplinary Center for Earthquake Engineering Research, University at Buffalo, State University of New York.
MCEER-06-0001	Seismic Fragility of Suspended Ceiling Systems	Badillo-Almaraz, Whittaker, Reinhorn, Cimellaro	2006	Report on testing of Armstrong ceiling systems. Concludes that compression bars and retention clips help in the behavior of ceilings, and that undersized tiles are a detriment.
PEER 1998/05	Rocking Response and Overturning of Equipment Under Horizontal Pulse-Type Motions	N. Makris, Y. Roussos	1998	Published by the Pacific Earthquake Engineering Research Center, Berkeley, California.
PEER 1999/06	Rocking Response and Overturning of Anchored Equipment under Seismic Excitations	N. Makris, J. Zhang	1999	Results of shake table testing.
PEER 2001/14	Rocking Response of Equipment Anchored to a Base Foundation	N. Makris, C. Black	2001	Example of PEER research related to Lifelines. PEER has done series of tests funded by PG&E on electrical substation equipment including rigid bus connectors, flexible bus connectors, transformer bushings, and heavy substation equipment.

Table B-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
PEER 2002/01	Nonstructural Loss Estimation: The UC Berkeley Case Study	M. Comerio, J. Stallmeyer	2002	Case studies of loss estimation for five University of California Berkeley campus buildings. Includes a table (Table 10) showing costs assumed for many types of equipment, and photos of lab equipment.
PEER 2002/05	Guidelines, Specifications, and Seismic Performance Characterization of Nonstructural Building Components and Equipment	Filiatrault, A., Christopoulus, C, and Stearns, C.	2001	Contents include chapters on nonstructural earthquake damage. Nonstructural items are divided into 5 groups: contents; building service equipment; building utilization equipment; interior architectural elements; and exterior architectural elements. Overview of various design guidelines and inventory of previous analytical and experimental studies. Includes recommendations, and comprehensive list of references.
PEER 2003/05	Response Assessment of Nonstructural Building Elements	S. Taghavi, E. Miranda	2003	Proposes a taxonomy (classification) of nonstructural elements by functionality, modes of failure, acceleration-sensitive or drift-sensitive response parameter, and repercussions of damage. Provides damageability, cost, and loss data for 200 elements. Includes a Nonstructural Damage Inventory Form used following the Nisqually Earthquake.
PEER 2003/12	Implementation Manual for the Seismic Protection of Laboratory Contents: Format and Case Studies	W. Holmes, M. Comerio	2003	Presents case studies for University of California Berkeley campus labs. Suggests format for User's Manual that could be used to help occupants install do-it-yourself details for a particular facility.
PEER 2005/03	A Taxonomy of Building Components for Performance-Based Earthquake Engineering	Porter, Keith	2005	Provides a detailed taxonomy (classification) of nonstructural components. Each component is assigned a unique identification number. The list differentiates between anchored and unanchored versions of the same item.
PEER 2005/05	Performance Characterization of Bench- and Shelf-Mounted Equipment	S. Chaudhuri and T. Hutchinson|	2005	
PEER 2005/07	Experimental and Analytical Studies on the Seismic Response of Freestanding and Anchored	D. Konstantinidis, N. Makris	2005	Shake table testing of equipment.

Table B-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
	Laboratory Equipment			
PEER 2005/12	PEER Test bed Study on a Laboratory Building: Exercising Seismic Performance Assessment	M. Comerio	2005	Test bed performance assessment of the UC Science Building linking performance of contents to operational failure. Shows the interdependence of building structure, systems, and contents in performance assessment, and highlights where further research is needed.
SUNY Buffalo	Nonstructural Components Simulator (NCS).		Future	Specialized equipment for testing nonstructural components. University at Buffalo's NEES (UB-NEES) facility is commissioning a dedicated Nonstructural Component Simulator (NCS). The NCS is a modular and versatile two-level platform for experimental performance evaluation of nonstructural components and equipment under realistic full scale floor motions. NCS can provide the dynamic stroke necessary to replicate full-scale displacements, velocities and accelerations at the upper levels of multi-story buildings during earthquake shaking. Both displacement sensitive and acceleration sensitive nonstructural components and equipment can be experimentally evaluated under full-scale floor motions to understand, quantify and control their seismic response.
SUNY Buffalo, CSEE-SEESL-2004-02	"Shake Table Testing of Frazier Industrial Storage Pallet Racks"	Filiatrault, A. and Wanitkorkul, A.	2004	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2005-01	"Seismic Qualification By Shake Table Testing of a Centrifugal Liquid Chiller according to AC-156 Testing Protocol"	Filiatrault, A. and Wanitkorkul, A.	2005	Published by the University at Buffalo, State University of New York, Buffalo, New York.

Table B-5 Recent and Ongoing Research Related to Nonstructural Components (continued)

Document Number/Source	Title	Author(s)	Publication Date	Comments
SUNY Buffalo, CSEE-SEESL-2005-03	"Shake Table Testing of Ridg-U-Rak Rigid Based and Ridg-U-Rak Patent Pending Base Isolated Industrial Storage Racks"	Filiatrault, A., Wanitkorkul, A. and Seo, J-M.	2005	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2005-05	"Seismic Qualification of a Centrifugal Liquid Chiller by Shake Table Testing"	Filiatrault, A. and Wanitkorkul, A.	2005	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2006-05	"Experimental Seismic Performance Evaluation of ASRAE-Type Isolation/Restraint Systems"	Fathali, S. and Filiatrault, A.	2006	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2006-07	"Shake Table Testing of Ridg-U-Rak Rigid Based and Ridg-U-Rak Patent Pending Base Isolated Industrial Storage Racks: Production Unit Testing"	Filiatrault, A., and Wanitkorkul, A.	2006	Published by the University at Buffalo, State University of New York, Buffalo, New York.
SUNY Buffalo, CSEE-SEESL-2006-19	"Shake Table Testing of Ridg-U-Rak Rigid Based and Ridg-U-Rak Patent Pending Base Isolated Industrial Storage Racks: Final Production Unit Testing"	Filiatrault, A., and Wanitkorkul, A.	2006	Published by the University at Buffalo, State University of New York, Buffalo, New York.
University of Chile	Controlled Overturning of Unanchored Rigid Bodies	Boroschek, R.L., and Iruretagoyena, A.		Review of test results for equipment on an inclined surface. Results show that an incline can force overturning to occur in a preferred direction. For example, a 3-degree angle will result in an 89% probability that blocks will overturn in that direction. Could be useful information for keeping contents on shelves.

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Applied Technology Council Projects and Report Information

One of the primary purposes of the Applied Technology Council is to develop resource documents that translate and summarize useful information to practicing engineers. This includes the development of guidelines and manuals, as well as the development of research recommendations for specific areas determined by the profession. ATC is not a code development organization, although ATC project reports often serve as resource documents for the development of codes, standards and specifications.

Applied Technology Council conducts projects that meet the following criteria:

1. The primary audience or benefactor is the design practitioner in structural engineering.
2. A cross section or consensus of engineering opinion is required to be obtained and presented by a neutral source.
    1. The project fosters the advancement of structural engineering practice.

Brief descriptions of completed ATC projects and reports are provided below. Funding for projects is obtained from government agencies and tax-deductible contributions from the private sector.

ATC-1: This project resulted in five papers that were published as part of *Building Practices for Disaster Mitigation, Building Science Series 46*, proceedings of a workshop sponsored by the National Science Foundation (NSF) and the National Bureau of Standards (NBS). Available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22151, as NTIS report No. COM-73-50188.

ATC-2: The report, *An Evaluation of a Response Spectrum Approach to Seismic Design of Buildings*, was funded by NSF and NBS and was conducted as part of the Cooperative Federal Program in Building Practices for Disaster Mitigation. Available through the ATC office. (Published 1974, 270 Pages)

ABSTRACT: This study evaluated the applicability and cost of the response spectrum approach to seismic analysis and design that was proposed by various segments of the engineering profession. Specific building designs, design procedures and parameter values were evaluated for future application. Eleven existing buildings of varying dimensions were redesigned according to the procedures.

ATC-3: The report, *Tentative Provisions for the Development of Seismic Regulations for Buildings* (ATC-3-06), was funded by NSF and NBS. The second printing of this report, which includes proposed amendments, is available through the ATC office. (Published 1978, amended 1982, 505 pages plus proposed amendments)

ABSTRACT: The tentative provisions in this document represent the results of a concerted effort by a multi-disciplinary team of 85 nationally recognized experts in earthquake engineering. The provisions serve as the basis for the seismic provisions of the 1988 and subsequent issues of the *Uniform Building Code* and the *NEHRP Recommended Provisions for the Development of Seismic Regulation for New Building and Other Structures*. The second printing of this document contains proposed amendments prepared by a joint committee of the Building Seismic Safety Council (BSSC) and the NBS.

ATC-3-2: The project, "Comparative Test Designs of Buildings Using ATC-3-06 Tentative Provisions", was funded by NSF. The project consisted of a study to develop and plan a program for making comparative test designs of the ATC-3-06 Tentative Provisions. The project report was written to be used by the Building Seismic Safety Council in its refinement of the ATC-3-06 Tentative Provisions.

ATC-3-4: The report, *Redesign of Three Multistory Buildings: A Comparison Using ATC-3-06 and 1982 Uniform Building Code Design Provisions*, was published under a grant from

NSF. Available through the ATC office. (Published 1984, 112 pages)

ABSTRACT: This report evaluates the cost and technical impact of using the 1978 ATC-3-06 report, *Tentative Provisions for the Development of Seismic Regulations for Buildings*, as amended by a joint committee of the Building Seismic Safety Council and the National Bureau of Standards in 1982. The evaluations are based on studies of three existing California buildings redesigned in accordance with the ATC-3-06 Tentative Provisions and the 1982 *Uniform Building Code*. Included in the report are recommendations to code implementing bodies.

ATC-3-5: This project, "Assistance for First Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety Council", was funded by the Building Seismic Safety Council to provide the services of the ATC Senior Consultant and other ATC personnel to assist the BSSC in the conduct of the first phase of its Trial Design Program. The first phase provided for trial designs conducted for buildings in Los Angeles, Seattle, Phoenix, and Memphis.

ATC-3-6: This project, "Assistance for Second Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety Council", was funded by the Building Seismic Safety Council to provide the services of the ATC Senior Consultant and other ATC personnel to assist the BSSC in the conduct of the second phase of its Trial Design Program. The second phase provided for trial designs conducted for buildings in New York, Chicago, St. Louis, Charleston, and Fort Worth.

ATC-4: The report, *A Methodology for Seismic Design and Construction of Single-Family Dwelling*s, was published under a contract with the Department of Housing and Urban Development (HUD). Available through the ATC office. (Published 1976, 576 pages)

ABSTRACT: This report presents the results of an in-depth effort to develop design and construction details for single-family residences that minimize the potential economic loss and life-loss risk associated with earthquakes. The report: (1) discusses the ways structures behave when subjected to seismic forces, (2) sets forth suggested design criteria for conventional layouts of dwellings constructed with conventional materials, (3) presents construction details that do not require the designer to perform analytical calculations, (4) suggests procedures for efficient plan-checking, and (5) presents recommendations including details and schedules for use in the field by construction personnel and building inspectors.

ATC-4-1: The report, *The Home Builders Guide for Earthquake Design*, was published under a contract with HUD. Available through the ATC office. (Published 1980, 57 pages)

ABSTRACT: This report is an abridged version of the ATC-4 report. The concise, easily understood text of the Guide is supplemented with illustrations and 46 construction details. The details are provided to ensure that houses contain structural features that are properly positioned, dimensioned and constructed to resist earthquake forces. A brief description is included on how earthquake forces impact on houses and some precautionary constraints are given with respect to site selection and architectural designs.

ATC-5: The report, *Guidelines for Seismic Design and Construction of Single-Story Masonry Dwellings in Seismic Zone 2*, was developed under a contract with HUD. Available through the ATC office. (Published 1986, 38 pages)

ABSTRACT: The report offers a concise methodology for the earthquake design and construction of single-story masonry dwellings in Seismic Zone 2 of the United States, as defined by the 1973 *Uniform Building Code*. The Guidelines are based in part on shaking table tests of masonry construction conducted at the University of California at Berkeley Earthquake Engineering Research Center. The report is written in simple language and includes basic house plans, wall evaluations, detail drawings, and material specifications.

ATC-6: The report, *Seismic Design Guidelines for Highway Bridges*, was published under a contract with the Federal Highway Administration (FHWA). Available through the ATC office. (Published 1981, 210 pages)

ABSTRACT: The Guidelines are the recommendations of a team of sixteen nationally recognized experts that included consulting engineers, academics, state and federal agency representatives from throughout the United States. The Guidelines embody several new concepts that were significant departures from then existing design provisions. Included in the Guidelines are an extensive commentary, an example demonstrating the use of the Guidelines, and summary reports on 21 bridges redesigned in accordance with the Guidelines. In 1991 the guidelines were adopted by the American Association of Highway and Transportation Officials as a standard specification.

ATC-6-1: The report, *Proceedings of a Workshop on Earthquake Resistance of Highway Bridges*, was published under a grant from NSF. Available through the ATC office. (Published 1979, 625 pages)

ABSTRACT: The report includes 23 state-of-the-art and state-of-practice papers on earthquake resistance of highway bridges. Seven of the twenty-three papers were authored by participants from Japan, New Zealand and Portugal. The Proceedings also contain recommendations for future research that were developed by the 45 workshop participants.

ATC-6-2: The report, *Seismic Retrofitting Guidelines for Highway Bridges*, was published under a contract with FHWA. Available through the ATC office. (Published 1983, 220 pages)

ABSTRACT: The Guidelines are the recommendations of a team of thirteen nationally recognized experts that included consulting engineers, academics, state highway engineers, and federal agency representatives. The Guidelines, applicable for use in all parts of the United States, include a preliminary screening procedure, methods for evaluating an existing bridge in detail, and potential retrofitting measures for the most common seismic deficiencies. Also included are special design requirements for various retrofitting measures.

ATC-7: The report, *Guidelines for the Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through the ATC office. (Published 1981, 190 pages)

ABSTRACT: Guidelines are presented for designing roof and floor systems so these can function as horizontal diaphragms in a lateral force resisting system. Analytical procedures, connection details and design examples are included in the Guidelines.

ATC-7-1: The report, *Proceedings of a Workshop on Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through the ATC office. (Published 1980, 302 pages)

ABSTRACT: The report includes seven papers on state-of-the-practice and two papers on recent research. Also included are recommendations for future research that were developed by the 35 workshop participants.

ATC-8: This report, *Proceedings of a Workshop on the Design of Prefabricated Concrete Buildings for Earthquake Loads*, was funded by NSF. Available through the ATC office. (Published 1981, 400 pages)

ABSTRACT: The report includes eighteen state-of-the-art papers and six summary papers. Also included are recommendations for future research that were developed by the 43 workshop participants.

ATC-9: The report, *An Evaluation of the Imperial County Services Building Earthquake Response and Associated Damage*, was published under a grant from NSF. Available through the ATC office. (Published 1984, 231 pages)

ABSTRACT: The report presents the results of an in-depth evaluation of the Imperial County Services Building, a 6-story reinforced concrete frame and shear wall building severely damaged by the October 15, 1979 Imperial Valley, California, earthquake. The report contains a review and evaluation of earthquake damage to the building; a review and evaluation of the seismic design; a comparison of the requirements of various building codes as they relate to the building; and conclusions and recommendations pertaining to future building code provisions and future research needs.

ATC-10: This report, *An Investigation of the Correlation Between Earthquake Ground Motion and Building Performance*, was funded by the U.S. Geological Survey (USGS). Available through the ATC office. (Published 1982, 114 pages)

ABSTRACT: The report contains an in-depth analytical evaluation of the ultimate or limit capacity of selected representative building framing types, a discussion of the factors affecting the seismic performance of buildings, and a summary and comparison of seismic design and seismic risk parameters currently in widespread use.

ATC-10-1: This report, *Critical Aspects of Earthquake Ground Motion and Building Damage Potential*, was co-funded by the USGS and the NSF. Available through the ATC office. (Published 1984, 259 pages)

ABSTRACT: This document contains 19 state-of-the-art papers on ground motion, structural response, and structural design issues presented by prominent engineers and earth scientists in an ATC seminar. The main theme of the papers is to identify the critical aspects of ground motion and building performance that currently are not being considered in building design. The report also contains conclusions and recommendations of working groups convened after the Seminar.

ATC-11: The report, *Seismic Resistance of Reinforced Concrete Shear Walls and Frame Joints: Implications of Recent Research for Design Engineers*, was published under a grant from NSF. Available through the ATC office. (Published 1983, 184 pages)

ABSTRACT: This document presents the results of an in-depth review and synthesis of research reports pertaining to cyclic loading of reinforced concrete shear walls and cyclic loading of joints in reinforced concrete frames. More than 125 research reports published since 1971 are reviewed and evaluated in this report. The preparation of the report included a consensus process involving numerous experienced design professionals from throughout the United States. The report contains reviews of current and past design practices, summaries of research developments, and in-depth discussions of design implications of recent research results.

ATC-12: This report, *Comparison of United States and New Zealand Seismic Design Practices for Highway Bridges*, was published under a grant from NSF. Available through the ATC office. (Published 1982, 270 pages)

ABSTRACT: The report contains summaries of all aspects and innovative design procedures used in New Zealand as well as comparison of United States and New Zealand design practice. Also included are research recommendations developed at a 3-day workshop in New Zealand attended by 16 U.S. and 35 New Zealand bridge design engineers and researchers.

ATC-12-1: This report, *Proceedings of Second Joint U.S.-New Zealand Workshop on Seismic Resistance of Highway Bridges*, was published under a grant from NSF. Available through the ATC office. (Published 1986, 272 pages)

ABSTRACT: This report contains written versions of the papers presented at this 1985 workshop as well as a list and prioritization of workshop recommendations. Included are summaries of research projects being conducted in both countries as well as state-of-the-practice papers on various aspects of design practice. Topics discussed include bridge design philosophy and loadings; design of columns, footings, piles, abutments and retaining structures; geotechnical aspects of foundation design; seismic analysis techniques; seismic retrofitting; case studies using base isolation; strong-motion data acquisition and interpretation; and testing of bridge components and bridge systems.

ATC-13: The report, *Earthquake Damage Evaluation Data for California*, was developed under a contract with the Federal Emergency Management Agency (FEMA). Available through the ATC office. (Published 1985, 492 pages)

ABSTRACT: This report presents expert-opinion earthquake damage and loss estimates for industrial, commercial, residential, utility and transportation facilities in California. Included are damage probability matrices for 78 classes of structures and estimates of time required to restore damaged facilities to pre-earthquake usability. The report also describes the inventory information essential for estimating economic losses and the methodology used to develop loss estimates on a regional basis.

ATC-13-1: The report, *Commentary on the Use of ATC-13 Earthquake Damage Evaluation Data for Probable Maximum Loss Studies of California Buildings*, was developed with funding from ATC's Henry J. Degenkolb Memorial Endowment Fund. Available through the ATC office. (Published 2002, 66 pages)

ABSTRACT: This report provides guidance to consulting firms who are using ATC-13 expert-opinion data for probable maximum loss (PML) studies of California buildings. Included are discussions of the limitations of the ATC-13 expert-opinion data, and the issues associated with using the data for PML studies. Also included are three appendices containing information and data not included in the original ATC-13 report: (1) ATC-13 model building type descriptions, including methodology for estimating the expected performance of standard, nonstandard, and special construction; (2) ATC-13 Beta damage distribution parameters for model building types; and (3) PML values for ATC-13 model building types.

ATC-14: The report, *Evaluating the Seismic Resistance of Existing Buildings*, was developed under a grant from the NSF. Available through the ATC office. (Published 1987, 370 pages)

ABSTRACT: This report, written for practicing structural engineers, describes a methodology for performing preliminary and detailed building seismic evaluations. The report contains a state-of-practice review; seismic loading criteria; data collection procedures; a detailed description of the building classification system; preliminary and detailed analysis procedures; and example case studies, including nonstructural considerations.

ATC-15: The report, *Comparison of Seismic Design Practices in the United States and Japan*, was published under a grant from NSF. Available through the ATC office. (Published 1984, 317 pages)

ABSTRACT: The report contains detailed technical papers describing design practices in the United States and Japan as well as recommendations emanating from a joint U.S.-Japan workshop held in Hawaii in March, 1984. Included are detailed descriptions of new seismic design methods for buildings in Japan and case studies of the design of specific buildings (in both countries). The report also contains an overview of the history and objectives of the Japan Structural Consultants Association.

ATC-15-1: The report, *Proceedings of Second U.S.-Japan Workshop on Improvement of Building Seismic Design and Construction Practices*, was published under a grant from NSF. Available through the ATC office. (Published 1987, 412 pages)

ABSTRACT: This report contains 23 technical papers presented at this San Francisco workshop in August, 1986, by practitioners and researchers from the U.S. and Japan. Included are state-of-the-practice papers and case studies of actual building designs and information on regulatory, contractual, and licensing issues.

ATC-15-2: The report, *Proceedings of Third U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. Available through the ATC office. (Published 1989, 358 pages)

ABSTRACT: This report contains 21 technical papers presented at this Tokyo, Japan, workshop in July, 1988, by practitioners and researchers from the U.S., Japan, China, and New Zealand. Included are state-of-the-practice papers on various topics, including braced steel frame buildings, beam-column joints in reinforced concrete buildings, summaries of comparative U. S. and Japanese design, and base isolation and passive energy dissipation devices.

ATC-15-3: The report, *Proceedings of Fourth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. Available through the ATC office. (Published 1992, 484 pages)

ABSTRACT: This report contains 22 technical papers presented at this Kailua-Kona, Hawaii, workshop in August, 1990, by practitioners and researchers from the United States, Japan, and Peru. Included are papers on postearthquake building damage assessment; acceptable earth-quake damage; repair and retrofit of earthquake damaged buildings; base-isolated buildings, including Architectural Institute of Japan recommendations for design; active damping systems; wind-resistant design; and summaries of working group conclusions and recommendations.

ATC-15-4: The report, *Proceedings of Fifth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. Available through the ATC office. (Published 1994, 360 pages)

ABSTRACT: This report contains 20 technical papers presented at this San Diego, California workshop in September, 1992. Included are papers on performance goals/acceptable damage in seismic design; seismic design procedures and case studies; construction influences on design; seismic isolation and passive energy dissipation; design of irregular structures; seismic evaluation, repair and upgrading; quality control for design and construction; and summaries of working group discussions and recommendations.

ATC-16: This project, "Development of a 5-Year Plan for Reducing the Earthquake Hazards Posed by Existing Nonfederal Buildings", was funded by FEMA and was conducted by a joint venture of ATC, the Building Seismic Safety Council and the Earthquake Engineering Research Institute. The project involved a workshop in Phoenix, Arizona, where approximately 50 earthquake specialists met to identify the major tasks and goals for reducing the earthquake hazards posed by existing nonfederal buildings nationwide. The plan was developed on the basis of nine issue papers presented at the workshop and workshop working group discussions. The Workshop Proceedings and Five-Year Plan are available through the Federal Emergency Management Agency, 500 "C" Street, S.W., Washington, DC 20472.

ATC-17: This report, *Proceedings of a Seminar and Workshop on Base Isolation and Passive Energy Dissipation*, was published under a grant from NSF. Available through the ATC office. (Published 1986, 478 pages)

ABSTRACT: The report contains 42 papers describing the state-of-the-art and state-of-the-practice in base-isolation and passive energy-dissipation technology. Included are papers describing case studies in the United States, applications and developments worldwide, recent innovations in technology development, and structural and ground motion issues. Also included is a proposed 5-year research agenda that addresses the following specific issues: (1) strong ground motion; (2) design criteria; (3) materials, quality control, and long-term reliability; (4) life cycle cost methodology; and (5) system response.

ATC-17-1: This report, *Proceedings of a Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control,* was published under a grant from NCEER and NSF. Available through the ATC office. (Published 1993, 841 pages)

ABSTRACT: The 2-volume report documents 70 technical papers presented during a two-day seminar in San Francisco in early 1993. Included are invited theme papers and competitively selected papers on issues related to seismic isolation systems, passive energy dissipation systems, active control systems and hybrid systems.

ATC-18: The report, *Seismic Design Criteria for Bridges and Other Highway Structures: Current and Future*, was developed under a grant from NCEER and FHWA. Available through the ATC office. (Published, 1997, 151 pages)

ABSTRACT: Prepared as part of NCEER Project 112 on new highway construction, this report reviews current domestic and foreign design practice, philosophy and criteria, and recommends future directions for code development. The project considered bridges, tunnels, abutments, retaining wall structures, and foundations.

ATC-18-1: The report, *Impact Assessment of Selected MCEER Highway Project Research on the Seismic Design of Highway Structures*, was developed under a contract from the Multidisciplinary Center for Earthquake Engineering Research (MCEER, formerly NCEER) and FHWA. Available through the ATC office. (Published, 1999, 136 pages)

ABSTRACT: The report provides an in-depth review and assessment of 32 research reports emanating from the MCEER Project 112 on new highway construction, as well as recommendations for future bridge seismic design guidelines. Topics covered include: ground motion issues; determining structural importance; foundations and soils; liquefaction mitigation methodologies; modeling of pile footings and drilled shafts; damage-avoidance design of bridge piers, column design, modeling, and analysis; structural steel and steel-concrete interface details; abutment design, modeling, and analysis; and detailing for structural movements in tunnels.

ATC-19: The report, *Structural Response Modification Factors* was funded by NSF and NCEER. Available through the ATC office. (Published 1995, 70 pages)

ABSTRACT: This report addresses structural response modification factors (R factors), which are used to reduce the seismic forces associated with elastic response to obtain design forces. The report documents the basis for current R values, how R factors are used for seismic design in other countries, a rational means for decomposing R into key components, a framework (and methods) for evaluating the key components of R, and the research necessary to improve the reliability of engineered construction designed using R factors.

ATC-20: The report, *Procedures for Postearthquake Safety Evaluation of Buildings*, was developed under a contract from the California Office of Emergency Services (OES), California Office of Statewide Health Planning and Development (OSHPD) and FEMA. Available through the ATC office (Published 1989, 152 pages)

ABSTRACT: This report provides procedures and guidelines for making on-the-spot evaluations and decisions regarding continued use and occupancy of earthquake damaged buildings. Written specifically for volunteer structural engineers and building inspectors, the report includes rapid and detailed evaluation procedures for inspecting buildings and posting them as "inspected" (apparently safe, green placard), "limited entry" (yellow) or "unsafe" (red). Also included are special procedures for evaluation of essential buildings (e.g., hospitals), and evaluation procedures for nonstructural elements, and geotechnical hazards.

ATC-20-1: The report, *Field Manual: Postearthquake Safety Evaluation of Buildings*, *Second Edition*, was funded by Applied Technology Council. Available through the ATC office (Published 2004, 143 pages)

ABSTRACT: This report, a companion Field Manual for the ATC-20 report, summarizes the postearthquake safety evaluation procedures in a brief concise format designed for ease of use in the field. The Second Edition has been updated to include improved versions of the posting placards and evaluation forms, as well as more detailed information on steel moment-frame buildings, mobile homes, and manufactured housing. It also includes new information on barricading and provides a list of internet resources pertaining to postearthquake safety evaluation.

ATC-20-2: The report, *Addendum to the ATC-20 Postearthquake Building Safety Procedures* was published under a grant from the NSF and funded by the USGS. Available through the ATC office. (Published 1995, 94 pages)

ABSTRACT: This report provides updated assessment forms, placards, including a revised yellow placard ("restricted use") and procedures that are based on an in-depth review and evaluation of the widespread application of the ATC-20 procedures following five earthquakes occurring since the initial release of the ATC-20 report in 1989.

ATC-20-3: The report, *Case Studies in Rapid Postearthquake Safety Evaluation of Buildings,* was funded by ATC and R. P. Gallagher Associates. Available through the ATC office. (Published 1996, 295 pages)

ABSTRACT: This report contains 53 case studies using the ATC-20 Rapid Evaluation procedure. Each case study is illustrated with photos and describes how a building was inspected and evaluated for life safety, and includes a completed safety assessment form and placard. The report is intended to be used as a training and reference manual for building officials, building inspectors, civil and structural engineers, architects, disaster workers, and others who may be asked to perform safety evaluations after an earthquake.

ATC-20-T: The *Postearthquake Safety Evaluation of Buildings Training CD* was developed by FEMA to replace the 1993 ATC-20-T Training Manual that included 160 35-mm slides. Available through the ATC office. (Published 2002, 230 PowerPoint slides with Speakers Notes)

ABSTRACT: This Training CD is intended to facilitate the presentation of the contents of the ATC-20 and ATC-20-2 reports in a 4½-hour training seminar. The Training CD contains 230 slides of photographs, schematic drawings and textual information. Topics covered include: posting system; evaluation procedures; structural basics; wood frame, masonry, concrete, and steel frame structures; nonstructural elements; geotechnical hazards; hazardous materials; and field safety.

ATC-21: The report, *Second Edition, Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*, was developed under a contract from FEMA. Available through the ATC office, or from FEMA by contacting 1-800-480-2520, as *FEMA 154 Second Edition*. (Published 2002, 161 pages)

ABSTRACT: This report describes a rapid visual screening procedure for identifying those buildings that might pose serious risk of loss of life and injury, or of severe curtailment of community services, in case of a damaging earthquake. The screening procedure utilizes a methodology based on a "sidewalk survey" approach that involves identification of the primary structural load-resisting system and its building material, and assignment of a basic structural hazards score and performance modifiers based on the observed building characteristics. Application of the methodology identifies those buildings that are potentially hazardous and should be analyzed in more detail by a professional engineer experienced in seismic design. In the Second Edition, the scoring system has been revised and the *Handbook* has been shortened and focused to ease its use.

ATC-21-1: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation*, *Second Edition*, was developed under a contract from FEMA. Available through the ATC office, or from FEMA by contacting 1-800-480-2520, as *FEMA 155 Second Edition*. (Published 2002, 117 pages)

ABSTRACT: Included in this report is the technical basis for the updated rapid visual screening procedure of ATC-21, including (1) a summary of the results from the efforts to solicit user feedback, and (2) a detailed description of the development effort leading to the basic structural hazard scores and the score modifiers.

ATC-21-2: The report, *Earthquake Damaged Buildings: An Overview of Heavy Debris and Victim Extrication*, was developed under a contract from FEMA. (Published 1988, 95 pages)

ABSTRACT: Included in this report, a companion volume to the first edition of the ATC-21 and ATC-21-1 reports, is state-of-the-art information on (1) the identification of those buildings that might collapse and trap victims in debris or generate debris of such a size that its handling would require special or heavy lifting equipment; (2) guidance in identifying these types of buildings, on the basis of their major exterior features, and (3) the types and life capacities of equipment required to remove the heavy portion of the debris that might result from the collapse of such buildings.

ATC-21-T: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards Training Manual Second Edition,* was developed under a contract with FEMA. Available through the ATC office. (Published 2004, 148 pages and PowerPoint presentation on companion CD)

ABSTRACT: This training manual and CD is intended to facilitate the presentation of the contents of the FEMA 154 report (*Second Edition*). The training materials consist of 120 slides in PowerPoint™ format and a companion training presentation narrative coordinated with the presentation. Topics covered include: description of procedure, building behavior, building types, building scores, occupancy and falling hazards, and implementation.

ATC-22: The report, *A Handbook for Seismic Evaluation of Existing Buildings (Preliminary)*, was developed under a contract from FEMA. (Originally published in 1989; revised by BSSC and published as FEMA 178: *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* in 1992, 211 pages; revised by ASCE for FEMA and published as FEMA 310: *Handbook for the Seismic Evaluation of Buildings – a Prestandard* in 1998, 362 pages; revised and published as ASCE 31-03, a standard of the American Society of Civil Engineers, in 2003). Available through ASCE, Reston, Virginia.

ABSTRACT: The ATC-22 handbook provides a methodology for seismic evaluation of existing buildings of different types and occupancies in areas of different seismicity throughout the United States. The methodology, which has been field tested in several programs nationwide, utilizes the information and procedures developed for the ATC-14 report and documented therein. The handbook includes checklists, diagrams, and sketches designed to assist the user.

ATC-22-1: The report, *Seismic Evaluation of Existing Buildings: Supporting Documentation*, was developed under a contract from FEMA. (Published 1989, 160 pages)

ABSTRACT: Included in this report, a companion volume to the ATC-22 report, are (1) a review and evaluation of existing buildings seismic evaluation methodologies; (2) results from field tests of the ATC-14 methodology; and (3) summaries of evaluations of ATC-14 conducted by the National Center for Earthquake Engineering

Research (State University of New York at Buffalo) and the City of San Francisco.

ATC-23A: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part A: Survey Description, Summary of Results, Data Analysis and Interpretation*, was developed under a contract from the Office of Statewide Health Planning and Development (OSHPD), State of California. Available through the ATC office. (Published 1991, 58 pages)

ABSTRACT: This report summarizes results from a seismic survey of 490 California acute care hospitals. Included are a description of the survey procedures and data collected, a summary of the data, and an illustrative discussion of data analysis and interpretation that has been provided to demonstrate potential applications of the ATC-23 database.

ATC-23B: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part B: Raw Data*, is a companion document to the ATC-23A Report and was developed under the above-mentioned contract from OSHPD. Available through the ATC office. (Published 1991, 377 pages)

ABSTRACT: Included in this report are tabulations of raw general site and building data for 490 acute care hospitals in California.

ATC-24: The report, *Guidelines for Seismic Testing of Components of Steel Structures*, was jointly funded by the American Iron and Steel Institute (AISI), American Institute of Steel Construction (AISC), National Center for Earthquake Engineering Research (NCEER), and NSF. Available through the ATC office. (Published 1992, 57 pages)

ABSTRACT: This report provides guidance for most cyclic experiments on components of steel structures for the purpose of consistency in experimental procedures. The report contains recommendations and companion commentary pertaining to loading histories, presentation of test results, and other aspects of experimentation. The recommendations are written specifically for experiments with slow cyclic load application.

ATC-25: The report, *Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous State*s, was developed under a contract from FEMA. Available through the ATC office. (Published 1991, 440 pages)

ABSTRACT: Documented in this report is a national overview of lifeline seismic vulnerability and impact of disruption. Lifelines considered include electric systems, water systems, transportation systems, gas and liquid fuel supply systems, and emergency service facilities (hospitals, fire and police stations). Vulnerability estimates and impacts developed are presented in terms of estimated first approximation direct damage losses and indirect economic losses.

ATC-25-1: The report, *A Model Methodology for Assessment of Seismic Vulnerability and Impact of Disruption of Water Supply Systems*, was developed under a contract from FEMA. Available through the ATC office. (Published 1992, 147 pages)

ABSTRACT: This report contains a practical methodology for the detailed assessment of seismic vulnerability and impact of disruption of water supply systems. The methodology has been designed for use by water system operators. Application of the methodology enables the user to develop estimates of direct damage to system components and the time required to restore damaged facilities to pre-earthquake usability. Suggested measures for mitigation of seismic hazards are also provided.

ATC-26: This project, U.S. Postal Service National Seismic Program, was funded under a contract with the U.S. Postal Service (USPS). Under this project, ATC developed and submitted to the USPS the following interim documents, most of which pertain to the seismic evaluation and rehabilitation of USPS facilities:

ATC-26 Report, *Cost Projections for the U. S. Postal Service Seismic Program* (completed 1990)

ATC-26-1 Report, *United States Postal Service Procedures for Seismic Evaluation of Existing Buildings (Interim)* (Completed 1991)

ATC-26-2 Report, *Procedures for Post-disaster Safety Evaluation of Postal Service Facilities (Interim)* (Published 1991, 221 pages, available through the ATC office)

ATC-26-3 Report, *Field Manual: Post-earthquake Safety Evaluation of Postal Buildings (Interim)* (Published 1992, 133 pages, available through the ATC office)

ATC-26-3A Report, *Field Manual: Post Flood and Wind Storm Safety Evaluation of Postal Buildings (Interim)* (Published 1992, 114 pages, available through the ATC office)

ATC-26-4 Report, *United States Postal Service Procedures for Building Seismic Rehabilitation (Interim)* (Completed 1992)

ATC-26-5 Report, *United States Postal Service Guidelines for Building and Site Selection in Seismic Areas (Interim)* (Completed 1992)

ATC-28: The report, *Development of Recommended Guidelines for Seismic Strengthening of Existing Buildings, Phase I: Issues Identification and Resolution*, was developed under a contract with FEMA. Available through the ATC office. (Published 1992, 150 pages)

ABSTRACT: This report identifies and provides resolutions for issues that will affect the development of guidelines for the seismic strengthening of existing buildings. Issues addressed include: implementation and format, coordination with other efforts, legal and political, social, economic, historic buildings, research and technology, seismicity and mapping, engineering philosophy and goals, issues related to the development of specific provisions, and nonstructural element issues.

ATC-29: The report, *Proceedings of a Seminar and Workshop on Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures*, was developed under a grant from NCEER and NSF. Available through the ATC office. (Published 1992, 470 pages)

ABSTRACT: These Proceedings contain 35 papers describing state-of-the-art technical information pertaining to the seismic design and performance of equipment and nonstructural elements in buildings and industrial structures. The papers were presented at a seminar in Irvine, California in 1990. Included are papers describing current practice, codes and regulations; earthquake performance; analytical and experimental investigations; development of new seismic qualification methods; and research, practice, and code development needs for specific elements and systems. The report also includes a summary of a proposed 5-year research agenda for NCEER.

ATC-29-1: The report, *Proceedings of a Seminar on Seismic Design, Retrofit, and Performance of Nonstructural Components*, was developed under a grant from NCEER and NSF. Available through the ATC office. (Published 1998, 518 pages)

ABSTRACT: These Proceedings contain 38 technical papers presented at a seminar in San Francisco, California in 1998. The paper topics include: observed performance in recent earthquakes; seismic design codes, standards, and procedures for commercial and institutional buildings; seismic design issues relating to industrial and hazardous material facilities; design analysis, and testing; and seismic evaluation and rehabilitation of conventional and essential facilities, including hospitals.

ATC-29-2: The report, *Proceedings of Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities*, was developed under a grant from MCEER and NSF. Available through the ATC office. (Published 2003, 574 pages)

ABSTRACT: These Proceedings contain 43 papers presented at a seminar in Newport Beach, California, in 2003. The purpose of the Seminar was to present state-of-the-art technical information pertaining to the seismic design, performance, and retrofit of nonstructural components in critical facilities (e.g., computer centers, hospitals, manufacturing plants with especially hazardous materials, and museums with fragile/valuable collection items). The technical papers address the following topics: current practices and emerging codes; seismic design and retrofit; risk and performance evaluation; system qualification and testing; and advanced technologies.

ATC-30: The report, *Proceedings of Workshop for Utilization of Research on Engineering and Socioeconomic Aspects of 1985 Chile and Mexico Earthquakes*, was developed under a grant from the NSF. Available through the ATC office. (Published 1991, 113 pages)

ABSTRACT: This report documents the findings of a 1990 technology transfer workshop in San Diego, California, co-sponsored by ATC and the Earthquake Engineering Research Institute. Included in the report are invited papers and working group recommendations on geotechnical issues, structural response issues, architectural and urban design considerations, emergency response planning, search and rescue, and reconstruction policy issues.

ATC-31: The report, *Evaluation of the Performance of Seismically Retrofitted Buildings*, was developed under a contract from the National Institute of Standards and Technology (NIST, formerly NBS) and funded by the USGS. Available through the ATC office. (Published 1992, 75 pages)

ABSTRACT: This report summarizes the results from an investigation of the effectiveness of 229 seismically retrofitted buildings, primarily unreinforced masonry and concrete tilt-up buildings. All buildings were located in the areas affected by the 1987 Whittier Narrows, California, and 1989 Loma Prieta, California, earthquakes.

ATC-32: The report, *Improved Seismic Design Criteria for California Bridges: Provisional Recommendations,* was funded by the California Department of Transportation (Caltrans). Available through the ATC office. (Published 1996, 215 pages)

ABSTRACT: This report provides recommended revisions to the then-current *Caltrans Bridge Design Specifications* (BDS) pertaining to seismic loading, structural response analysis, and component design. Special attention is given to design issues related to reinforced concrete components, steel components, foundations, and conventional bearings. The recommendations are based on recent research in the field of bridge seismic design and the performance of Caltrans-designed bridges in the 1989 Loma Prieta and other recent California earthquakes.

ATC-32-1: The report, *Improved Seismic Design Criteria for California Bridges: Resource Document,* was funded by Caltrans. Available through the ATC office. (Published 1996, 365 pages; also available on CD-ROM)

ABSTRACT: This report, a companion to the ATC-32 Report, documents pertinent background material and the technical basis for the recommendations provided in ATC-32, including potential recommendations that showed some promise but were not adopted. Topics include: design concepts; seismic loading, including ARS design spectra; dynamic analysis; foundation design; ductile component design; capacity protected design; reinforcing details; and steel bridges.

ATC-33: The reports, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 273), *NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 274), and *Example Applications of the NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 276), were developed under a contract with the Building Seismic Safety Council, for FEMA. (Published 1997, *Guidelines*, 440 pages; *Commentary*, 492 pages; *Example Applications*, 295 pages.) FEMA 273 and portions of FEMA 274 have been revised by ASCE for FEMA as FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*. Available through FEMA by contacting 1-800-480-2520 (Published 2000, 509 pages)

ABSTRACT: Developed over a 5-year period through the efforts of more than 60 paid consultants and several hundred volunteer reviewers, these documents provide nationally applicable, state-of-the-art guidance for the seismic rehabilitation of buildings. The FEMA 273 *Guidelines* contain several new features that depart significantly from previous seismic design procedures used to design new buildings: seismic performance levels and rehabilitation objectives; simplified and systematic rehabilitation methods; new linear static and nonlinear static analysis procedures; quantitative specifications of component behavior; and procedures for incorporating new information and technologies, such as seismic isolation and energy dissipation systems, into rehabilitation.

ATC-34: The report, *A Critical Review of Current Approaches to Earthquake Resistant Design***,** was developed under a grant from NCEER and NSF. Available through the ATC office. (Published, 1995, 94 pages)

ABSTRACT: This report documents the history of U. S. codes and standards of practice, focusing primarily on the strengths and deficiencies of current code approaches. Issues addressed include: seismic hazard analysis, earthquake collateral hazards, performance objectives, redundancy and configuration, response modification factors (*R* factors), simplified analysis procedures, modeling of structural components, foundation design, nonstructural component design, and risk and reliability. The report also identifies goals that a new seismic code should achieve.

ATC-35: This report, *Enhancing the Transfer of U.S. Geological Survey Research Results into Engineering Practice* was developed under a cooperative agreement with the USGS. Available through the ATC office. (Published 1994, 120 pages)

ABSTRACT: The report provides a program of recommended "technology transfer" activities for the USGS; included are recommendations pertaining to management actions, communications with practicing engineers, and research activities to enhance development and transfer of information that is vital to engineering practice.

ATC-35-1: The report, *Proceedings of Seminar on New Developments in Earthquake Ground Motion Estimation and Implications for Engineering Design Practice*, was developed under a cooperative agreement with USGS. Available through the ATC office. (Published 1994, 478 pages)

ABSTRACT: These Proceedings contain 22 technical papers describing state-of-the-art information on regional earthquake risk (focused on five specific regions—Northern and Southern California, Pacific Northwest, Central United States, and northeastern North America); new techniques for estimating strong ground motions as a function of earthquake source, travel path, and site parameters; and new developments specifically applicable to geotechnical engineering and the seismic design of buildings and bridges.

ATC-35-2: The report, *Proceedings: National Earthquake Ground Motion Mapping Workshop*, was developed under a cooperative agreement with USGS. Available through the ATC office. (Published 1997, 154 pages)

ABSTRACT: These Proceedings document the technical presentations and findings of a workshop in Los Angeles in 1995 on several key issues that affect the preparation and use of national earthquake ground motion maps for design. The following four key issues were the focus of the workshop: ground motion parameters; reference site conditions; probabilistic versus deterministic basis, and the treatment of uncertainty in seismic source characterization and ground motion attenuation.

ATC-35-3: The report, *Proceedings: Workshop on Improved Characterization of Strong Ground Shaking for Seismic Design,* was developed under a cooperative agreement with USGS. Available through the ATC office. (Published 1999, 75 pages)

ABSTRACT: These Proceedings document the technical presentations and findings of a workshop in Rancho Bernardo, California in 1997 on the Ground Motion Initiative (GMI) component of the ATC-35 Project. The workshop focused on identifying needs and developing improved representations of earthquake ground motion for use in seismic design practice, including codes.

ATC-37: The report, *Review of Seismic Research Results on Existing Buildings***,** was developed in conjunction with the Structural Engineers Association of California and California Universities for Research in Earthquake Engineering under a contract from the California Seismic Safety Commission (SSC). Available through the Seismic Safety Commission as Report SSC 94-03. (Published, 1994, 492 pages)

ABSTRACT: This report describes the state of knowledge of the earthquake performance of nonductile concrete frame, shear wall, and infilled buildings. Included are summaries of 90 recent research efforts with key results and conclusions in a simple, easy-to-access format written for practicing design professionals.

ATC-38: This report, *Database on the Performance of Structures near Strong-Motion Recordings: 1994 Northridge, California, Earthquake*, was developed with funding from the USGS, the Southern California Earthquake Center (SCEC), OES, and the Institute for Business and Home Safety (IBHS). Available through the ATC office. (Published 2000, 260 pages, with CD-ROM containing complete database).

ABSTRACT: The report documents the earthquake performance of 530 buildings within 1000 feet of sites where strong ground motion was recorded during the 1994 Northridge, California, earthquake (31 recording sites in total). The project required the development of a suitable survey form, the training of licensed engineers for the survey, the selection of the surveyed areas, and the entry of the survey data into an electronic relational database. The full database is contained in the ATC-38 CD-ROM. The ATC-38 database includes information on the structure size, age and location; the structural framing system and other important structural characteristics; nonstructural characteristics; geotechnical effects, such as liquefaction; performance characteristics (damage); fatalities and injuries; and estimated time to restore the facility to its pre-earthquake usability. The report and CD also contain strong-motion data, including acceleration, velocity, and displacement time histories, and acceleration response spectra.

ATC-40: The report, *Seismic Evaluation and Retrofit of Concrete Buildings***,** was developed under a contract from the California Seismic Safety Commission. Available through the ATC office. (Published, 1996, 612 pages)

ABSTRACT: This 2-volume report provides a state-of-the-art methodology for the seismic evaluation and retrofit of concrete buildings. Specific guidance is provided on the following topics: performance objectives; seismic hazard; determination of deficiencies; retrofit strategies; quality assurance procedures; nonlinear static analysis procedures; modeling rules; foundation effects; response limits; and nonstructural components. In 1997 this report received the Western States Seismic Policy Council "Overall Excellence and New Technology Award."

ATC-41 (SAC Joint Venture, Phase 1): This project, Program to Reduce the Earthquake Hazards of Steel Moment-Resisting Frame Structures, Phase 1, was funded by FEMA and OES and conducted by a Joint Venture partnership of SEAOC, ATC, and CUREe. Under this Phase 1 program SAC prepared the following documents:

SAC-94-01, *Proceedings of the Invitational Workshop on Steel Seismic Issues, Los Angeles, September 1994* (Published 1994, 155 pages, available through the ATC office)

SAC-95-01, *Steel Moment-Frame Connection Advisory No. 3* (Published 1995, 310 pages, available through the ATC office)

SAC-95-02, *Interim Guidelines: Evaluation, Repair, Modification and Design of Welded Steel Moment-Frame Structures* (FEMA 267 report) (Published 1995, 215 pages, available through ATC and by calling FEMA: 1-800-480-2520)

SAC-95-03, *Characterization of Ground Motions During the Northridge Earthquake of January 17, 1994* (Published 1995, 179 pages, available through the ATC office)

SAC-95-04, *Analytical and Field Investigations of Buildings Affected by the Northridge Earthquake of January 17, 1994* (Published 1995, 2 volumes, 900 pages, available through the ATC office)

SAC-95-05, *Parametric Analytical Investigations of Ground Motion and Structural Response, Northridge Earthquake of January 17, 1994* (Published 1995, 274 pages, available through the ATC office)

SAC-95-06, *Surveys and Assessment of Damage to Buildings Affected by the Northridge Earthquake of January 17, 1994* (Published 1995, 315 pages, available through the ATC office)

SAC-95-07, *Case Studies of Steel Moment Frame Building Performance in the Northridge Earthquake of January 17, 1994* (Published 1995, 260 pages, available through the ATC office)

SAC-95-08, *Experimental Investigations of Materials, Weldments and Nondestructive Examination Techniques* (Published 1995, 144 pages, available through the ATC office)

SAC-95-09, *Background Reports: Metallurgy, Fracture Mechanics, Welding, Moment Connections and Frame systems, Behavior* (FEMA 288 report) (Published 1995, 361 pages, available through ATC and by calling FEMA: 1-800-480-2520)

SAC-96-01, *Experimental Investigations of Beam-Column Subassemblages, Part 1 and 2* (Published 1996, 2 volumes, 924 pages, available through the ATC office)

SAC-96-02, *Connection Test Summaries* (FEMA 289 report) (Published 1996, available through ATC and by calling FEMA: 1-800-480-2520)

ATC-41-1 (SAC Joint Venture, Phase 2): This project, Program to Reduce the Earthquake Hazards of Steel Moment-Resisting Frame Structures, Phase 2, was funded by FEMA and conducted by a Joint Venture partnership of SEAOC, ATC, and CUREe. Under this Phase 2 program SAC prepared the following documents:

SAC-96-03, *Interim Guidelines Advisory No. 1 Supplement to FEMA 267 Interim Guidelines* (FEMA 267A Report) (Published 1997, 100 pages, and superseded by FEMA-350 to 353.)

SAC-99-01, *Interim Guidelines Advisory No. 2 Supplement to FEMA-267 Interim Guidelines* (FEMA 267B Report, superseding FEMA-267A). (Published 1999, 150 pages, and superseded by FEMA-350 to 353.)

FEMA-350, *Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings*. (Published 2000, 190 pages, available through ATC and by calling FEMA: 1-800-480-2520)

FEMA-351, *Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings*. (Published 2000, 210 pages, available through ATC and by calling FEMA: 1-800-480-2520)

FEMA-352, *Recommended Postearthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings*. (Published 2000, 180 pages, available through ATC and by calling FEMA: 1-800-480-2520)

FEMA-353, *Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications*. (Published 2000, 180 pages, available through ATC and by calling FEMA: 1-800-480-2520)

FEMA-354, *A Policy Guide to Steel Moment-Frame Construction*. (Published 2000, 27 pages, available through ATC and by calling FEMA: 1-800-480-2520)

FEMA-355A, *State of the Art Report on Base Materials and Fracture*. (Published 2000, 107 pages; available on CD-ROM through ATC and by calling FEMA: 1-800-480-2520. Printed version also available through ATC).

FEMA-355B, *State of the Art Report on Welding and Inspection*. (Published 2000, 185 pages; available on CD-ROM through ATC and by calling FEMA: 1-800-480-2520. Printed version also available through ATC).

FEMA-355C, *State of the Art Report on Systems Performance of Steel Moment Frames Subject to Earthquake Ground Shaking*. (Published 2000, 322 pages; available on CD-ROM through ATC and by calling FEMA: 1-800-480-2520. Printed version also available through ATC).

FEMA-355D, *State of the Art Report on Connection Performance*. (Published 2000, 292 pages; available on CD-ROM through ATC and by calling FEMA: 1-800-480-2520. Printed version also available through ATC).

FEMA-355E, *State of the Art Report on Past Performance of Steel Moment-Frame Buildings in Earthquakes*. (Published 2000, 190 pages; available on CD-ROM through ATC and by calling FEMA: 1-800-480-2520. Printed version also available through ATC).

FEMA-355F, *State of the Art Report on Performance Prediction and Evaluation of Steel Moment-Frame Structures*. (Published 2000, 347 pages; available on CD-ROM through ATC and by calling FEMA: 1-800-480-2520. Printed version also available through ATC).

ATC-43: The reports, *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual* (FEMA 306), *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Technical Resources* (FEMA 307), and *The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings* (FEMA 308), were developed for FEMA under a contract with the Partnership for Response and Recovery, a Joint Venture of Dewberry & Davis and Woodward-Clyde. Available on CD-ROM through ATC; printed versions available through FEMA by contacting 1-800-480-2520 (Published, 1998, *Evaluation Procedures Manual*, 270 pages; *Technical Resources*, 271 pages, *Repair Document*, 81 pages)

ABSTRACT: Developed by 26 nationally recognized specialists in earthquake engineering, these documents provide field investigation techniques, damage evaluation procedures, methods for performance loss determination, repair guides and recommended repair techniques, and an in-depth discussion of policy issues pertaining to the repair and upgrade of earthquake damaged buildings. The documents have been developed specifically for buildings with primary lateral-force-resisting systems consisting of concrete bearing walls or masonry bearing walls, and vertical-load-bearing concrete frames or steel frames with concrete or masonry infill panels. The intended audience includes design engineers, building owners, building regulatory officials, and government agencies.

ATC-44: The report, *Hurricane Fran, North Carolina, September 5, 1996: Reconnaissance Report***,** was funded by the Applied Technology Council. Available through the ATC office. (Published 1997, 36 pages)

ABSTRACT: Written for an intended audience of design professionals and regulators, this report contains information on hurricane size, path, and rainfall amounts; coastal impacts, including storm surges and waves, forces on structures, and the role of erosion; the role of beach nourishment in reducing wave energy and crest height; building code requirements; observations and interpretations of damage to buildings, including the effect of debris acting as missiles; and lifeline performance.

ATC-45: The *Field Manual*, *Safety Evaluation of Buildings After Wind Storms and Floods* was developed with funding from ATC, the ATC Endowment Fund, and the Institute for Business and Home Safety. Available through the ATC office. (Published 2004, 132 pages)

ABSTRACT: The Field Manual provides guidelines and procedures to determine whether damaged or potentially damaged buildings are safe for use after wind storms or floods, or if entry should be restricted or prohibited. Formatted as an easy-to-use pocket guide, the Manual is intended to be used by structural engineers, building inspectors, and others involved in postdisaster building safety assessments. Advice is provided on evaluating structural, geotechnical, and nonstructural risks. Also included are procedures for Rapid Safety Evaluation, procedures for Detailed Safety Evaluation, information on how to deal with owners and occupants of damaged buildings, information on field safety for those making damage assessments, and example applications of the procedures.

ATC-48 (ATC/SEAOC Joint Venture Training Curriculum): The training curriculum, *Built to Resist Earthquakes, The Path to Quality Seismic Design and Construction for Architects, Engineers, and Inspectors*, was developed under a contract with the California Seismic Safety Commission and prepared by a Joint Venture partnership of ATC and SEAOC. Available through the ATC office. (Published 1999, 314 pages)

ABSTRACT: Bound in a three-ring notebook, the curriculum contains training materials pertaining to the seismic design and retrofit of wood-frame buildings, concrete and masonry construction, and nonstructural components. Included are detailed, illustrated, instructional material (lessons) and a series of multi-part Briefing Papers and Job Aids to facilitate improvement in the quality of seismic design, inspection, and construction.

ATC-49: The 2-volume report, *Recommended LRFD Guidelines for the Seismic Design of Highway Bridges; Part I: Specifications* and *Part II: Commentary and Appendices*, were developed under the ATC/MCEER Joint Venture partnership with funding from the Federal Highway Administration. Available through the ATC office. (Published 2003, *Part I*, 164 pages and *Part II*, 294 pages)

ABSTRACT: The Recommended Guidelines are based on significant enhancements in the state of knowledge and state of practice resulting from research investigations and lessons learned from earthquakes over the last 15 years. The Guidelines consist of specifications, commentary, and appendices developed to be compatible with the existing load-and-resistance-factor design (LRFD) provisions for highway bridges published by the American Association of State Highway and Transportation Officials (AASHTO). The new, updated, provisions are nationally applicable and cover all seismic zones, as well as all bridge construction types and materials. They reflect the latest design philosophies and design approaches that will result in highway bridges with a high level of seismic performance.

ATC-49-1: The document, *Liquefaction Study Report, Recommended LRFD Guidelines for the Seismic Design of Highway Bridges,* was developed under the ATC/MCEER Joint Venture partnership with funding from the Federal Highway Administration. Available through the ATC office. (Published 2003, 208 pages)

ABSTRACT: This report documents a comprehensive study of the effects of liquefaction and the associated hazards — lateral spreading and flow. It contains detailed discussions on: (1) recommended procedures to evaluate liquefaction potential and lateral spread effects; (2) ground mitigation design approaches and procedures to evaluate the

beneficial effects of pile pinning in straining lateral spread; (3) study results from two bridge sites (one in the western U. S. and one in the central U. S.) that provide an assessment of liquefaction effects based on several types of analyses; an assessment of implications of predicted lateral spread/flow using a pushover-type analysis; and development and evaluation of structural and/or geotechnical mitigation alternatives; and (4) study conclusions, including cost implications.

ATC-49-2: The report, *Design Examples, Recommended LRFD Guidelines for the Seismic Design of Highway Bridges*, was developed under the ATC/MCEER Joint Venture partnership with funding from the Federal Highway Administration. Available through the ATC office. (Published 2003, 316 pages)

ABSTRACT: The report contains two design examples that illustrate use of the *Recommended LRFD Guidelines for the Seismic Design of Highway Bridges*. These design examples are the eighth and ninth in a series originally developed for the Federal Highway Administration (FHWA) to illustrate the use of the American Association of State Highway and Transportation Officials (AASHTO) Division 1-A Standard Specifications for Highway Bridges. The design examples contain flow charts and detailed step-by-step procedures, including: preliminary design; basic requirements; determination of seismic design and analysis procedure; determination of elastic seismic forces and displacements; determination of design forces; design displacements and checks; design of structural components; design of foundations; design of abutments; and consideration of liquefaction.

ATC-51: The report, *U.S.-Italy Collaborative Recommendations for Improved Seismic Safety of Hospitals in Italy*, was developed under a contract with Servizio Sismico Nazionale of Italy (Italian National Seismic Survey). Available through the ATC office. (Published 2000, 154 pages)

ABSTRACT: Developed by a 14-person team of hospital seismic safety specialists and regulators from the United States and Italy, the report provides an overview of hospital seismic risk in Italy; six recommended short-term actions and four recommended long-term actions for improving hospital seismic safety in Italy; and supplemental information on (a) hospital seismic safety regulation in California, (b) requirements for nonstructural components in California and for buildings regulated by the Office of U. S. Foreign Buildings, and (c) current seismic evaluation standards in the United States.

ATC-51-1: The report, *Recommended U.S.-Italy Collaborative Procedures for Earthquake Emergency Response Planning for Hospitals in Italy*, was developed under a contract with Servizio Sismico Nazionale of Italy (Italian National Seismic Survey, NSS). Available in English and Italian through the ATC office. (Published 2002, 120 pages)

ABSTRACT: The report addresses one of the short-term recommendations — planning for emergency response and postearthquake inspection — made in the first phase of the ATC-51 project. The report contains: (1) descriptions of current procedures and concepts for emergency response planning in the United States and Italy, (2) an overview of relevant procedures for both countries for evaluating and predicting the seismic vulnerability of buildings, including procedures for postearthquake inspection, (3) recommended procedures for earthquake emergency response planning and postearthquake assessment of hospitals, to be implemented through the use of a Postearthquake Inspection Notebook and demonstrated through the application on two representative hospital facilities; and (4) recommendations for emergency response training, postearthquake inspection training, and the mitigation of seismic hazards.

ATC-51-2: The report, *Recommended U.S.-Italy Collaborative Guidelines for Bracing and Anchoring Nonstructural Components in Italian Hospitals*, was developed under a contract with the Department of Civil Protection, Italy. Available in English and Italian through the ATC office. (Published 2003, 164 pages)

ABSTRACT: The report supports one of the short-term recommendations — implement bracing and anchorage for new installations of nonstructural components — made in the first phase of the ATC-51 project. The report contains: (1) technical background information, including an overview of nonstructural component damage in prior earthquakes;(2) generalized recommendations for assessment of nonstructural components and recommended performance objectives and requirements; (3) specific recommendations pertaining to twenty-seven different types of nonstructural components; (4) design examples that illustrate in detail how a structural engineer evaluates and designs the retrofit of a nonstructural component; (5) additional seismic design considerations for nonstructural components; and (6) guidance pertaining to the design and selection of devices for seismic anchorage.

ATC-52: The project, "Development of a Community Action Plan for Seismic Safety (CAPSS), City and County of San Francisco", was conducted under a contract with the San Francisco Department of Building Inspection. Under Phase I, completed in 2000, ATC defined the tasks to be conducted under Phase II, a multi-year ATC effort that commenced in 2001. The Phase II tasks include: (1) development of a reliable estimate of the size and nature of the impacts a large earthquake will have on San Francisco; (2) development of technically sound consensus-based guidelines for the evaluation and repair of San Francisco's most vulnerable building types; and (3) identification, definition, and ranking of other activities to reduce the seismic risks in the City and County of San Francisco.

ATC-53: The report, *Assessment of the NIST 12-Million-Pound (53 MN) Large-Scale Testing Facility*, was developed under a contract with NIST. Available through the ATC office. (Published 2000, 44 pages)

ABSTRACT: This report documents the findings of an ATC Technical Panel engaged to assess the utility and viability of a 30-year-old, 12-million pound (53 MN) Universal Testing Machine located at NIST headquarters in Gaithersburg, Maryland. Issues addressed include: (a) the merits of continuing operation of the facility; (b) possible improvements or modifications that would render it more useful to the earthquake engineering community and other potential large-scale structural research communities; and (c) identification of specific research (seismic and non-seismic) that might require the use of this facility in the future.

ATC-54: The report, *Guidelines for Using Strong-Motion Data and ShakeMaps in Postearthquake Response*, was developed under a contract with the California Geological Survey. Available through the ATC office. (Published 2005, 222 pages)

ABSTRACT: The report addresses two main topics: (1) effective means for using computer-generated ground motion maps (ShakeMaps) in postearthquake emergency response; and (2) procedures for rapidly evaluating (on a near-real-time basis) strong-motion data from ground sites and instrumented buildings, bridges, and dams to determine the potential for earthquake-induced damage in those structures. The document also provides guidance on the form, type, and extent of data to be collected from structures in the vicinity of strong-motion recordings, and pertinent supplemental information, including guidance on replacement of strong-motion instruments in/on and near buildings, bridges, and dams.

ATC-55: The report, FEMA 440, *Improvement of Nonlinear Static Seismic Analysis Procedures*, was developed under a contract with FEMA. Available through FEMA or the ATC office. (Published 2005, 152 pages)

ABSTRACT: The report presents the results of a four year study carried out to develop guidelines for improved application of the Coefficient Method, as detailed in the FEMA-356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings,* and the Capacity Spectrum Method, as detailed in the ATC-40 Report, *Seismic Evaluation and Retrofit of Concrete Buildings*. The report also addresses improved application of nonlinear static analysis procedures in general, including new procedures for incorporating soil-structure interaction effects, and options for addressing multiple-degree-of-freedom effects. An example application of the recommended nonlinear static analysis procedures is included to illustrate use of the procedures in estimating the maximum displacement of a model building.

ATC-56: The report, FEMA 389, *Primer for Design Professionals: Communicating with Owners and Managers of New Buildings on Earthquake Risk*, was developed under a contract with FEMA. Available through FEMA or the ATC office. (Published 2004, 194 pages)

ABSTRACT: The report has been developed to facilitate the process of educating building owners and managers about seismic risk management tools that can be effectively and economically employed by them during the building development phase—from site selection through design and construction—as well as the operational phase. Written principally for design professionals (architects and structural engineers), the document introduces and discusses (1) seismic risk management and the means to develop a risk management plan; (2) guidance for identifying and assessing earthquake-related hazards during the site selection process; (3) emerging concepts in performance-based seismic design; and (4) seismic design and performance issues related to six specific building occupancies—commercial office facilities, commercial retail facilities, light manufacturing facilities, healthcare facilities, local schools (kindergarten through grade 12), and higher education facilities (universities).

ATC-56-1: The report, FEMA 427, *Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks – Providing Protection to People and Buildings*, was developed under a contract with FEMA. Available through FEMA or the ATC office. (Published 2003, 106 pages)

ABSTRACT: The report provides guidance to building designers, owners and state and local governments to mitigate the effects of hazards resulting from terrorist attacks on new buildings. While the guidance provided focuses principally on explosive attacks and design strategies to mitigate the effects of explosions, the document also addresses design strategies to mitigate the effects of chemical, biological and radiological attacks. Qualitative discussions are provided on the following topics: terrorist threats; weapons effects, building damage, design approach, design guidance, occupancy types, and cost considerations.

ATC-57: The report, *The Missing Piece: Improving Seismic Design and Construction Practices*, was developed under a contract with NIST. Available through the ATC office. (Published 2003, 102 pages)

ABSTRACT: The report was developed to provide a framework for eliminating the technology transfer gap that has emerged within the National Earthquake Hazards Reduction Program (NEHRP) that limits the adaptation of basic research knowledge into practice. The report defines a much-expanded problem-focused knowledge development, synthesis and transfer program to improve seismic design and construction practices. Two subject areas, with a total of five Program Elements, are proposed: (1) systematic support of the seismic code development process; and (2) improve seismic design and construction productivity.

ATC-58: This project, *Development of Next-Generation Performance-Based Seismic Design Guidelines for New and Existing Buildings*, is a multi-year, multi-phase effort funded by FEMA. Reports prepared under this project include:

FEMA 445, *Next-Generation Performance-Based Seismic Design Guidelines, Program Plan for New and Existing Buildings*. (Published 2006, 131 pages, available through FEMA or the ATC office). This Program Plan offers background on current code design procedures, introduces performance-based seismic design concepts, identifies improvements needed in current seismic design practice, and outlines the tasks and projected costs for a two-phase program to develop next-generation performance-based seismic design procedures and guidelines.

FEMA 461, *Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components* (Published 2007, 113 pages, available through FEMA or the ATC office). Two interim protocol types are provided in this document: Interim Protocol I, Quasi-Static Cyclic Testing, which should be used for the determination of performance characteristics of components whose behavior is primarily controlled by the application of seismic forces or seismic-induced displacements; and Interim Protocol II, Shake Table Testing, which should be used to assess performance characteristics of components whose behavior is affected by the dynamic response of the component itself, or whose behavior is velocity sensitive, or sensitive to strain-rate effects.

ATC-60: The 2-volume report, *SEAW Commentary on Wind Code Provisions, Volume 1* and *Volume 2 - Example Problems,* was developed by the Structural Engineers Association of Washington (SEAW) and edited and published by the Applied Technology Council. (ATC). Available through the ATC office. (Published 2004; *Volume 1*, 238 pages; *Volume 2*, 245 pages)

ABSTRACT: Written for designers, building code officials, instructors and anyone who designs and/or analyzes structures for wind, this report provides commentary on the wind provisions in the 2000 and 2003 editions of the *International Building Code* (IBC), and the 1998 and 2002 editions of ASCE Standard No. 7, *Minimum Design Loads for Buildings and Other Structures*. Volume 1 contains the main body of the commentary, including a technical and historic overview of wind codes and discussions on a broad range of topics: basic wind speed; importance factors; exposure and topographic effects; gust response; design for wind pressures on main wind-force-resisting systems; wind pressures on components and cladding of structures; glass and glazing; prescriptive provisions; miscellaneous and non-building structures; unusual wind loading configurations; high winds, hurricanes, and tornadoes; serviceability; wind tunnel tests applied to design practice; and wind design of equipment and non-building systems. Volume 2 consists of appendices containing over a dozen example problems with solutions.

ATC-61: The 2-volume report, *Natural Hazard Mitigation Saves: An Independent Study to Assess the Future Savings from Mitigation Activities, Volume 1 – Findings, Conclusions, and Recommendations*, and *Volume 2 – Study Documentation,* was prepared by the Applied Technology Council for the Multihazard Mitigation Council of the National Institute of Building Sciences, with funding provided by FEMA. Available through MMC or the ATC office. (Published 2005; *Volume 1*, 11 pages; *Volume 2*, 366 pages)

ABSTRACT: This report presents the results of an independent study to assess the future savings from hazard mitigation activities showing that funding spent on reducing the risk of natural hazards is a sound investment. Volume 1 contains an overview of the study and its findings and conclusions. Volume 2 contains a detailed description of the benefit-cost analysis methods, data collection, processing, studies, and results.

ATC-70: The report, NIST Technical Note 1476, *Performance of Physical Structures in Hurricane Katrina and Hurricane Rita: A Reconnaissance Report*, was developed under a contract with NIST. Available through NIST. (Published 2006, 222 pages)

ABSTRACT: This report describes the findings of the NIST-led reconnaissance effort to assess the performance of physical structures along the U. S. Gulf Coast during Hurricane Katrina and Hurricane Rita in 2005. The report provides documentation of environmental conditions (wind speed, storm surge, and flooding) and observed damage to major buildings, infrastructure and residential structures. Twenty-three recommendations are provided pertaining to: (1) needed improvements in design and construction practice; (2) needed improvements in standards and codes; and (3) needed further study, research, and development.

ATC-72: The report, *Proceedings of Workshop on Tall Building Seismic Design and Analysis Issues,* was prepared for the Building Seismic Safety Council of the National Institute of Building Sciences, with funding provided by FEMA. Available through the ATC office. (Published 2007, 84 pages)

ABSTRACT: This report presents the results of a Workshop on Tall Building Seismic Design and Analysis Issues that was conducted in San Francisco in January 2007. It includes a prioritized list of the most important tall building modeling and acceptance criteria issues needing resolution, based on the opinions of practitioners, regulators, and researchers actively involved in the design, permitting, and construction of tall buildings.

ATC-73: The report, *Prioritized Research for Reducing the Seismic Hazards of Existing Buildings,* was developed under a grant from NSF. Available through the ATC office. (Published 2007, 16 pages)

ABSTRACT: This report was developed specifically for individuals and institutions planning to submit proposals in response to the NSF program solicitation for research using the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). It includes a prioritized list of research needs based on consensus developed during a National Earthquake Hazards Reduction Program (NEHRP) Workshop on Meeting the Challenges of Existing Buildings, conducted in San Francisco in September 2007.

ATC-74: The report, *Collaborative Recommended Requirements for Automatic Natural Gas Shutoff Valves in Italy,* was funded by the Department of Civil Protection, Italy. Available through the ATC office. (Published 2007; 76 pages)

ABSTRACT: This report contains: (1) technical background information pertaining to the use of automatic natural shutoff valves as a means for seismic hazard mitigation, including the development of requirements in ASCE Standard 25-97, *Earthquake-Actuated Automatic Gas Shutoff Devices*; (2) a brief review of considerations and actions in the United States related to assuring adequate natural gas safety in earthquakes; (3) an assessment of issues related to the adoption of ASCE 25-97 as a standard for earthquake actuated automatic gas shutoff devices in Italy; (4) a summary and recommendations; and (5) appendices containing example U.S. jurisdiction ordinances pertaining to gas shutoff valves and related information.

ATC-R-1: The report, *Cyclic Testing of Narrow Plywood Shear Walls,* was developed with funding from the Henry J. Degenkolb Memorial Endowment Fund of the Applied Technology Council. Available through the ATC office (Published 1995, 64 pages)

ABSTRACT: This report documents ATC's first self-directed research program: a series of static and dynamic tests of narrow plywood wall panels having the standard 3.5-to-1 height-to-width ratio and anchored to the sill plate using typical bolted, 9-inch, 5000-lb. capacity hold-down devices. The report provides a description of the testing program and a summary of results, including comparisons of drift ratios found during testing with those specified in the seismic provisions of the 1991 *Uniform Building Code*. The report served as a catalyst for changes in code-specified aspect ratios for narrow plywood wall panels and for new thinking in the design of hold-down devices. It also stimulated widespread interest in laboratory testing of wood-frame structures.

ATC Design Guide 1: The report, *Minimizing Floor Vibration***,** was developed with funding from ATC's Henry J. Degenkolb Memorial Endowment Fund. Available through the ATC office. (Published, 1999, 64 pages)

ABSTRACT: Design Guide 1 provides guidance on design and retrofit of floor structures to limit transient vibrations to acceptable levels. The document includes guidance for estimating floor vibration properties and example calculations for a variety of currently used floor types and designs. The criteria for acceptable levels of floor vibration are based on human sensitivity to the vibration, whether it is caused by human behavior or machinery in the structure.

ATC TechBrief 1: The ATC TechBrief 1, *Liquefaction Maps*, was developed under a contract with the United States Geological Survey. Available through the ATC office. (Published 1996, 12 pages)

ABSTRACT: The technical brief inventories and describes the available regional liquefaction hazard maps in the United States and gives information on how to obtain them.

ATC TechBrief 2: The ATC TechBrief 2, *Earthquake Aftershocks − Entering Damaged Buildings*, was developed under a contract with the United States Geological Survey. Available through the ATC office. (Published 1996, 12 pages)

ABSTRACT: The technical brief offers guidelines for entering damaged buildings under emergency conditions during the first hours and days after the initial damaging event.

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