Earthquake Design Considerations for Non-Residential Buildings

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Communicating with Owners and Managers of New Buildings on Earthquake Risk

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DESIGN AND PERFORMANCE ISSUES RELATING TO COMMERCIAL OFFICE BUILDINGS 6

6.1 INTRODUCTION

Commercial office buildings represent a large building segment and house the core of American business operations. Corporate headquarters, banks, law firms, consulting firms, accountants, insurance companies, non-profit organizations – the list is almost endless – use office space in buildings around the country to house their operations. As these companies make decisions about the buildings that they construct or office space that they lease, seismic considerations can easily be factored into the decision process.

The following are some unique issues associated with commercial office buildings that should be kept in mind during the design and construction phase of new facilities:

- Protection of building occupants is a very high priority.
- Occupants are predominantly work-force, with high daytime "8 am to 5 pm" occupancy.
- Most office building occupants are generally familiar with the characteristics of their building; a small percentage of occupants may be

disabled to some degree and visitors will generally not be familiar with the building.

- Office buildings change their interior layouts frequently, to respond to tenant needs, fluctuations in work-force or organizational changes.
- Ensuring the survival of business records, whether in electronic or written form, is essential for continued business operation.
- Closure of the building for any length of time represents a serious business problem.

6.2 OWNERSHIP, FINANCING, AND PROCUREMENT

Commercial buildings may be owner operated, particularly if owned by national or global corporations, but many are developer owned (at least initially) housing tenant (lease holder) operations. In many instances the developer and building designers provide an empty "shell," which is fitted out according to the tenants' planning, spatial and environmental needs; design and construction is generally undertaken by the tenant's consultants and contractors. This tends to split the responsibility for interior nonstructural and other risk reduction design and construction measures between the building designers and contractor, and a multiplicity of tenant designers and contractors.

Financing for these facilities is typically through private loans. The effective life of an office building is 20 to 30 years, after which major renovation and updating is normally necessary. Interior renovation is usually on a much shorter interval, particularly for rental office structures.

6.3 PERFORMANCE OF OFFICE BUILDINGS IN PAST EARTHQUAKES

The seismic performance of modern office buildings designed to recent codes (adopted since the late 1970s) has been good as far as providing life safety. However, the recognition by building owners that satisfactory life-safety code-level performance may still encompass considerable damage (see Figure 6-1), along with repair costs and possible business interruption of the building for weeks or even months, even in a moderate earthquake, suggests that some performance-based design strategies may be useful.

Figure 6-1 Typical earthquake damage to contents and nonstructural components in a modern office building. (photo courtesy of the Earthquake Engineering Research Institute)

Where severe structural damage has occurred in commercial office buildings, it has generally been to older buildings, often the result of configuration irregularities. Figure 6-2 shows an older medical office building, which had a vertical irregularity that caused one floor to pancake during the 1994 Northridge earthquake in Southern California; a failure resulting from inadequate attachment of heavy nonstructural walls in an older 5-story office building is shown in Figure 6-3.

Newer office buildings have also been damaged, most notably the more than 100 welded steel moment-frame buildings (healthcare and residential structures as well as commercial, higher education and industrial buildings) that failed during the 1994 Northridge earthquake. The damage occurred primarily at welded beam-to-column connections, which had been designed to act in a ductile manner and to be capable of withstanding repeated cycles of large inelastic deformation.

While no casualties or collapses occurred as a result of these failures, the incidence of damage was sufficiently high in regions of strong motion to cause wide-spread concern by structural engineers and building officials. Initial investigations showed that in some cases, 50% of the connections were broken and very occasionally the beam or column was totally fractured. Possible causes focused on incorrect connection

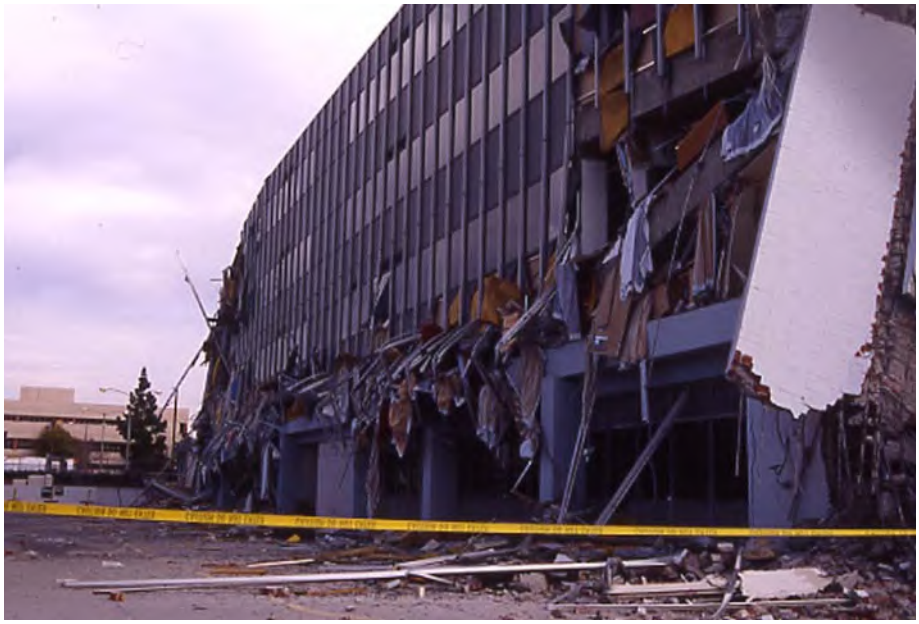

Figure 6-2 Exterior view of medical office building severely damaged by the 1994 Northridge earthquake. (C. Arnold photo)

Figure 6-3 Partially collapsed end-wall in 5-story office building caused by severe earthquake ground shaking. (C. Arnold photo)

design, incorrect fabrication, poor welding techniques and materials, and the impact of the need for economy on design strategies and construction techniques.

As a result, a large research program was initiated, sponsored primarily by FEMA, to identify the problems and arrive at solutions. Many structural specimens were tested in university laboratories. New guidelines for these types of structures have been developed (SAC, 2000a, b), but remedial measures have resulted in more costly designs and extended approval procedures, with the result that many engineers have avoided welded steel moment-resistant frames in recent projects.

Resources for the Seismic Design of New Steel Moment-Frame Buildings

1. FEMA 350, *Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings* (SAC, 2000a)
2. FEMA 353, *Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications* (SAC, 2000b)

6.4 PERFORMANCE EXPECTATIONS AND REQUIREMENTS

The following guidelines are suggested as seismic performance objectives for commercial office buildings:

- Persons within and immediately outside the building must be protected to at least a life safety performance level during design-level earthquake ground motions.
- Persons should be able to evacuate the building quickly and safely after the occurrence of design-level earthquake ground motions.
- Emergency systems in the facility should remain operational after design-level earthquake ground motions.
- Emergency workers should be able to enter the building immediately after the occurrence of design-level earthquake ground motions, encountering minimum interference and danger.

6.5 SEISMIC DESIGN ISSUES

The information in this section summarizes the characteristics of commercial office buildings, notes their relationship to achieving good seismic performance, and suggests seismic risk management solutions that should be considered.

Seismic Hazard and Site Issues

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design. If any of these other suspected conditions are geologic hazards, a geotechnical engineering consultant

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design.

should conduct a site-specific study. If defects are encountered, an alternative site should be considered (if possible), or appropriate soil stabilization, foundation and structural design approaches should be employed to reduce consequences of ground motion beyond code design values, or costly damage caused by geologic or other seismic hazards (see Chapter 3 for additional information). If possible, avoid sites that lack redundant access and are vulnerable to bridge or highway closure.

Structural System Issues

Office buildings are typically low- to mid-rise in suburban locations and occasionally high-rise in downtown locations of larger cities or in satellite suburban office complexes. Office buildings are intrinsically simple, and often are of simple rectangular configuration, not least because economy is usually a prime concern for commercial structures. Thus, their seismic design can be economical and use simple equivalent lateral force analysis procedures with a good probability of meeting code performance expectations as far as life safety is concerned. The protection of nonstructural components, systems and concepts requires structural design to a higher performance level. Configuration irregularities may be introduced for image reasons or site constraints in odd-shaped urban lots, and the structural design may become more complex and expensive. To assist the protection of nonstructural components, special attention should be paid to drift control.

The need for planning flexibility requires minimization of fixed interior structural elements and a preference for column-free space. Need for flexibility in power and electronic servicing has resulted in increasing use of under floor servicing to work cubicles, and structural systems have been developed to provide this.

Office buildings typically employ steel or reinforced concrete frames to permit maximum planning flexibility. Steel or reinforced concrete moment frames provide maximum flexibility, but tend to be expensive in high and moderate seismic zones. New guidelines for the design of welded moment-frame connections, noted above, have increased the cost of these types of structural system, increasing the already common use of steel braced frames. Elevator cores duct shafts and toilet rooms, being permanent, can be used as shear walls if of suitable size and location. Since these elements are much stiffer than a surrounding frame they may be a source of stress concentration and torsion, if asymmetrically located. If severe asymmetry of core locations is essential for plan-

ning reasons, the cores should not form part of the lateral-force resisting system.

Nonstructural System Issues

The extensive use of frame structures for commercial office buildings, together with the tendency for them to be designed to minimum code standards, has resulted in structures that are subject to considerable drift and motion (sway). The result has been a high level of nonstructural damage, particularly to partitions, ceilings and lighting. This kind of damage is costly and its repair is disruptive.

In addition, storage units, free standing work stations and filing cabinets are subject to upset. Excessive drift and motion may also lead to damage to roof-top equipment, and localized damage to water systems and fire suppression piping and sprinklers; thus the likelihood of water damage is greater.

The responsibilities within the design team for nonstructural component support and bracing design should be explicit and clear. The checklist for responsibility of nonstructural design in Chapter 12 (see Figure 12-5) provides a guide to establishing responsibilities for the design, installation, review and observation of all nonstructural components and systems

DESIGN AND PERFORMANCE ISSUES RELATING TO RETAIL COMMERCIAL FACILITIES 7

7.1 INTRODUCTION

Retail commercial facilities house shops and stores, which contribute a signficiant portion of the nation's economic output. Department store malls, big-box retailers, grocery stores and strip malls are but a few of the almost endless list of retail operations housed in these types of facilities. As these companies make decisions about the buildings that they construct or spaces that they lease, seismic considerations can easily be factored into the decision process.

The following are some unique issues associated with retail commercial buildings that should be kept in mind during the design and construction phase of new facilities:

- Protection of building occupants is a very high priority.
- Occupants are predominantly work-force and shoppers; shopping malls and large retail stores typically are open from about 10 am to 9

pm for 7 days a week, typically with higher occupancy at weekends. "Big box" stores also have a high evening occupancy.

- Most shoppers are generally familiar with the characteristics of the shopping malls stores they frequent, but large retail stores are confusing to the first-time shopper. Familiarity with exit locations and egress routes is questionable.
- Retail stores, particularly department stores, change their interior layouts frequently to respond to market changes and retailing fashions. Big box stores generally retain a simple aisle layout, though some large electronic and furniture stores employ subdivided and clustered layouts related to groups of merchandise.
- Ensuring the survival of business records, whether in electronic or written form, is essential for continued business operation.

7.2 OWNERSHIP, FINANCING, AND PROCUREMENT

Retail malls are generally developer sponsored. Department stores and "big boxes" are developed by regional or national owners; their design and construction are independent of the retail mall developments in which they may be located. In retail malls, the mall developer designs and constructs "shell" structures in which space is leased to retail store owners who use their own design and subcontracting teams to fit out the space to their requirements. This tends to split the responsibility for interior nonstructural and other risk-reduction design and construction measures between the building designers and contractor, and a multitude of tenant store designers and contractors.

Financing for these facilities is typically through private loans. The effective life of a retail mall or store is about 20 years, after which major renovation and updating is necessary. Interior renovation is usually on a much shorter interval.

Shopping malls and stores are generally constructed using a single contractor selected by competitive bid. Large shopping malls may have a number of contractors working on the site because each department store will usually have its own general contractor and subcontractors. Low cost and very rapid construction with reliable achievement of construction schedules are prime considerations. The opening of new retail facilities is often timed to meet key shopping periods such as Christmas or opening of the school year.

7.3 PERFORMANCE OF COMMERCIAL RETAIL FACILITIES IN PAST EARTHQUAKES

There has been considerable damage to retail facilities of all sizes in recent earthquakes.

In the Northridge earthquake of 1994 near Los Angeles, a large regional shopping mall with 1.5 million sq.ft. of retail space suffered severe damage and was closed for 18 months. Some 200 mall stores were closed and six department stores under independent ownership received varying amounts of damage. One department store suffered a partial collapse, and was demolished and replaced (Figure 7-1). The

Figure 7-1 Severe damage to a department store severely shaken by the 1994 Northridge earthquake. Shear failure between the waffle slabs and columns caused the collapse of several floors. (photo courtesy of the Earthquake Engineering Research Institute.)

other stores were repaired. Other shopping malls in the area suffered damage, but their performance was considerably better. The Topanga Plaza Mall in Canoga Park, approximately 5 miles from the epicenter, was built in the early 60's but was seismically upgraded in 1971. Structural damage was confined to cracking of reinforced masonry shear walls and damage to concrete columns in infilled shear walls. Nonstructural damage was significant, however, ranging from damage to floor, ceiling and wall finishes to frequently shattered or dislodged store-front glass panels.

7.4 PERFORMANCE EXPECTATIONS AND REQUIREMENTS

The following guidelines are suggested as seismic performance objectives for retail facilities:

- Staff and shoppers within and immediately outside retail stores must be protected to at least a life-safety performance level during design-level earthquake ground motions.
- Emergency systems in the facility should remain operational after the occurrence of design-level earthquake ground motions.
- Shoppers and staff should be able to evacuate the building quickly and safely after the occurrence of design-level earthquake ground motions.
- Emergency workers should be able to enter the building immediately after the occurrence of design-level earthquake ground motions, encountering minimum interference and danger.

7.5 SEISMIC DESIGN ISSUES

The information in this section summarizes the characteristics of retail facilities, notes their relationship to achieving good seismic performance, and suggests seismic risk management solutions that should be considered.

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design.

Seismic Hazard and Site Issues

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design. If any of these other suspected conditions are geologic hazards, a geotechnical engineering consultant should conduct a site-specific study. If defects are encountered, an alternative site should be considered (if possible) or appropriate soil stabilization, foundation and structural design approaches should be employed to reduce consequences of ground motion beyond code design values, or costly damage caused by geologic or other seismic hazards (see Chapter 3 for additional information). If possible, avoid sites that lack redundant access and are vulnerable to bridge or highway closure.

Structural System Issues

Retail facilities are usually one or two stories; mall structures and "big boxes" are usually light steel frames or mixed steel frame/wood/con-

crete/concrete masonry structures. Reinforced concrete block masonry perimeter walls often provide lateral resistance; for these systems, connections of roof diaphragms to walls are critical. The large building size and long-span light-frame load bearing structures of many of these facilities often lead to large drifts (or sway) during earthquake shaking. When designed to code minimums these drifts may be excessive and cause nonstructural damage, particularly to ceilings and partitions.

Retail buildings are intrinsically simple in their architectural/structural configuration, and basically are large open box-like structures with few interior walls and partitions. This enables their structural design to be simple and their seismic design can be carried out using the basic equivalent lateral force analysis procedures with a good probability of meeting code performance expectations as far as life safety is concerned. The desire for low cost, however, coupled with a tendency to meet only the minimum code requirements, sometimes results in inadequately engineered and poorly constructed structures. The protection of nonstructural components, systems and contents requires structural design to a higher performance level. Configuration irregularities are sometimes introduced for image reasons and the structural design may become more complex and expensive.

Nonstructural System Issues

The extensive use of light-steel-frame structures for retail facilities, together with the tendency for them to be designed to minimum codes and standards, has resulted in structures that are subject to considerable drift and motion. The result has been a high level of nonstructural damage, particularly to ceilings and lighting. This kind of damage is costly and its repair is disruptive.

In most “big box” stores the building structure forms only a weatherproof cover and is lightly loaded. Often there is no suspended ceiling and light fixtures are hung directly from the building’s structure. The merchandise is stacked on metal storage racks, which provide vertical and lateral support. These racks are supplied and installed by specialist vendors. The correct sizing and bracing of these racks is critical because the merchandise is often heavy and located at a high elevation. Even if the racks remain, material may be displaced and fall on the aisles, which are often crowded.

More upscale department stores have complete suspended ceilings and often have elaborate settings for the display of merchandise. These can be hazardous to staff and shoppers.

Excessive drift and motion (building sway) may also lead to damage to roof-top equipment and localized damage to water systems and fire suppression piping and sprinklers.

The responsibilities within the design team for nonstructural component support and bracing design should be explicit and clear. The checklist for responsibility of nonstructural design in Chapter 12 (see Figure 12-5) provides a guide to establishing responsibilities for the design, installation, review and observation of all nonstructural components and systems.

DESIGN AND PERFORMANCE ISSUES RELATING TO LIGHT MANUFACTURING FACILITIES 8

8.1 INTRODUCTION

This chapter addresses a broad range of facilities used for industries engaged in the manufacturing assembly, testing and packaging of specialized products within workbench production areas. Much of this manufacturing is associated with the electronics, or "high-tech" industry, and in some cases, special environments such as "clean-rooms" are required. Most light manufacturing operations are relatively new and take place in recently designed and constructed buildings using modern equipment installations.

The following are some unique issues associated with light manufacturing facilities that should be kept in mind during the design and construction phase of new facilities:

- Protection of building occupants is a very high priority.

- Building occupancy is relatively low, except in buildings with major production or assembly functions. Occupants are predominantly work-force, with high daytime "8 am to 5 pm" occupancy, although favorable market conditions may entail the use of additional work-shifts. Visitors are few in number.
- Ensuring the survival of production, testing and other expensive equipment is an important economic concern.
- Closure of the building for any length of time represents a very serious business problem, which will involve loss of revenue and possibly loss of market share.
- Most manufacturing building occupants are generally familiar with the characteristics of their building; a small percentage may be disabled to some degree.
- Frequent provision must be made for the production of new products and the removal of existing equipment and its replacement.
- Ensuring the survival of business records, whether in electronic or written form, is essential for continued business operation.

8.2 OWNERSHIP, FINANCING AND PROCUREMENT

Many light manufacturing facilities are owner developed, particularly if owned by national or global corporations, but some are also developer owned providing for tenant operations. Some large corporations may use a developer to build facilities that suit their operations, and thus avoid becoming involved in possibly troublesome development and building operations. Buildings that are constructed by developers as speculation tend to be occupied by start-up or young companies. In these instances the developer and building designers provide an empty "shell," which is fitted out according to the tenants' planning, spatial and environmental needs; design and construction is generally undertaken by the tenant's designers and subcontractors. This tends to split the responsibility for interior nonstructural and other risk-reduction design and construction measures between the building designers and contractor, and the tenant designers and contractors.

Financing for these facilities is typically through private loans. The effective life of the building may be about 50 years, particularly in the electronic industry. Light manufacturing buildings are generally constructed using a single contractor selected by competitive bid. Low cost and very rapid construction, with reliable achievement of construction schedules, are prime considerations.

8.3 PERFORMANCE OF LIGHT MANUFACTURING FACILITIES IN PAST EARTHQUAKES

Starting in the late 1950s larger light manufacturing buildings have been predominantly tilt-up structures, particularly in California. In seismic regions the perimeter precast walls were used as shear walls and roof structures were generally glued-laminated beams and plywood diaphragms. In the 1964 Alaska earthquake and the 1971 San Fernando (Los Angeles) event, performance of these buildings was poor, with considerable damage being sustained. The most common type of failure was to the wall/diaphragm anchors, but large out-of-plane movement of the panels, out-of-plane bending cracks in pilasters at mezzanine levels, and roof separations were all encountered and many roof collapses occurred. Due to the relatively large size of these buildings roof collapses were localized, rarely extending beyond one or two bays, and the buildings were sparsely occupied, so casualties were few. (Figure 8-1)

Following the 1971 San Fernando earthquake code changes were introduced, with the result that subsequent performance was improved. During the 1994 Northridge earthquake near Los Angeles, there were a number of failures of tilt-up structures and there were some collapsed wall panels along the sides of buildings resulting in partial roof collapse.

Figure 8-1 Roof and wall collapse of tilt-up building during the 1994 Northridge earthquake. (Photo courtesy of the Earthquake Engineering Research Institute)

Changes to wall anchorage requirements were introduced in the 1997 *Uniform Building Code*.

8.4 PERFORMANCE EXPECTATIONS AND REQUIREMENTS

The following guidelines are suggested as seismic performance objectives for light manufacturing facilities:

- Persons within and immediately outside manufacturing facilities must be protected at least to a life-safety performance level during design-level earthquake ground motions.
- Building occupants should be able to evacuate the building quickly and safely after the occurrence of design-level earthquake ground motions.
- Emergency systems in the facility should remain operational after the occurrence of design-level earthquake ground motions.
- Emergency workers should be able to enter the building immediately after the occurrence of design-level earthquake ground motions, encountering minimum interference and danger.
- Key manufacturing equipment, supplies and products should be protected from damage.
- In "high-tech" manufacturing facilities most services and utilities should be available within three hours of the occurrence of design-level earthquake ground motions.
- There should be no release of hazardous substances as a result of the occurrence of design-level earthquake ground motions.

8.5 SEISMIC DESIGN ISSUES

The information in this section summarizes the characteristics of light manufacturing facilities, notes their relationship to achieving good seismic performance, and suggests seismic risk management solutions that should be considered.

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design.

Seismic Hazard and Site Issues

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design. If any of these other suspected conditions are geological hazards, a geotechnical engineering consultant should conduct a site-

specific study. If defects are encountered, an alternative site should be considered (if possible) or appropriate soil stabilization, foundation and structural design approaches should be employed to reduce consequences of ground motion beyond code design values, or costly damage caused by geologic or other seismic hazards (see Chapter 3 for additional information). If possible, avoid sites that lack redundant access and are vulnerable to bridge or highway closure.

Structural System Issues

Light manufacturing facilities are usually one story; sometimes office/administrative accommodation is provided in a mezzanine space. There has been increasing use of light steel frames and steel deck structure for roofs and mezzanines. Most large buildings now use braced steel frame structures. Exteriors may be of masonry or metal insulated panels.

Manufacturing buildings are intrinsically simple in their architectural/structural configuration, and basically are large open box-like structures with few interior walls and partitions. This enables their structural design to be simple, and their seismic design can be carried out using the basic equivalent lateral force analysis procedures with a good probability of meeting code performance expectations as far as life safety is concerned. The desire for low cost, however, coupled with a tendency to meet only the minimum code requirements sometimes results in inadequately engineered and poorly constructed structures, The protection of valuable equipment and contents requires structural design to a higher performance level.

The large building size and long-span light frame load bearing structures of many of these facilities often lead to large drifts (or sway). When designed to code minimums these drifts may be excessive and cause nonstructural damage, particularly to ceilings and partitions.

Nonstructural System Issues

Continued operation is particularly dependent on nonstructural components and systems

Continued operation is particularly dependent on nonstructural components and systems, including purchased equipment, much of which is often of great sensitivity and cost. Many specialized utilities must be provided, some of which involve the storage of hazardous substances, such as pharmaceuticals, or hazardous gases. These must be protected against spillage during an earthquake. Distribution systems for hazardous gases must be well supported and braced.

The extensive use of light-steel-frame structures for manufacturing facilities, together with the tendency for them to be designed to minimum codes and standards, has resulted in structures that are subject to considerable drift and motion. As a result, recent earthquakes have caused a high level of nonstructural damage, particularly to ceilings and lighting. This kind of damage is costly and its repair is disruptive.

Research and production areas may need special design attention to specialized equipment services and materials to ensure continued production and delivery.

In most manufacturing facilities the building structure forms only a weatherproof cover and is lightly loaded. Often there is no suspended ceiling and light fixtures are hung directly from the building's structure. In storage areas, materials are stacked on metal storage racks that provide their own vertical and lateral support. These racks are supplied and installed by specialist vendors. The correct sizing and bracing of these racks are critical if the materials are heavy and located at a high elevation. Even if the racks remain stable, material may be displaced and fall on the aisles or on equipment

Storage units, free standing work stations, and filing cabinets are also subject to upset. Excessive drift and motion may lead to damage to rooftop equipment and localized damage to water systems and fire suppression piping and sprinklers.

The responsibilities within the design team for nonstructural component support and bracing design should be explicit and clear. The checklist for responsibility of nonstructural design in Chapter 12 (see Figure 12-5) provides a guide to establishing responsibilities for the design, installation, review and observation of all nonstructural components and systems.

DESIGN AND PERFORMANCE ISSUES RELATING TO HEALTHCARE FACILITIES 9

9.1 INTRODUCTION

Healthcare facilities are the places where America goes for treatment for most of its healthcare and are the places that need to be available to them after being injured in an earthquake. Regional or local hospitals, outpatient clinics, long-term care facilities are all examples of healthcare facilities that serve in this role. As healthcare companies make decisions about the buildings that they construct, seismic considerations can easily be factored into the decision process.

The following are some unique issues associated with healthcare facilities that should be kept in mind during the design and construction phase of new facilities:

- Protection of patients and healthcare staff is a very high priority.
- Healthcare occupancy is a 24 hour/7 day-per-week function.
- Acute-care hospitals have a large patient population that is immobile and helpless, for whom a safe environment is essential. This particularly requires a safe structure and prevention of falling objects.

- Hospitals are critical for emergency treatment of earthquake victims and recovery efforts.
- Medical staff has a crucial role to play in the immediate emergency and during the recovery period.
- Ensuring the survival of all equipment and supplies used for emergency diagnosis and treatment is essential for patient care.
- Ensuring the survival of medical and other records, whether in electronic or written form, is essential for continued patient care.
- Closure of hospitals for any length of time represents a very serious community problem exacerbated by the possibility of the loss of healthcare personnel who are in high demand or unable to work because of personal earthquake-related consequences (e.g., their own injury).
- Many hospitals are not only service providers but also profit or non-profit businesses and, since their operating costs and revenues are high, every day that the facility is out of operation represents serious financial loss.

9.2 OWNERSHIP, FINANCING, AND PROCUREMENT

Healthcare facilities are typically developed by a private non-profit or for-profit hospital corporation or an HMO (health maintenance organization). Many are also developed by a local, state or federal government agency. Financing of privately owned facilities is typically by private loan, possibly with some state or federal assistance; for-profit hospitals may issue stock when access to capital is required, and hospitals also conduct fund-raising activities, a large part of which assist in capital improvement program financing. State and local public institutions are financed by state and local bond issues. Non-profit hospitals sometime issue bonds to the public.

Private institutions have no restrictions on methods of procurement; projects may be negotiated, conventionally bid, use construction management or design–build. Public work must be competitively bid. Typically, contracts are placed for all site and building work (structural and nonstructural). Medical equipment and furnishings and their installation are purchased separately from specialized vendors.

Hospitals typically emphasize high quality of design and construction and long facility life, though all institutions are also budgeting conscious. An attractive and well equipped hospital site and building cam-

pus are seen as an important asset, particularly by private institutions that are in a competitive situation.

9.3 PERFORMANCE OF HEALTHCARE FACILITIES IN PAST EARTHQUAKES

The most significant experience of seismic performance of healthcare facilities in recent earthquakes was that of the Northridge (Los Angeles), California, earthquake of 1994. The San Fernando, California, earthquake of 1971 seriously damaged several medical facilities, including the then brand-new Los Angeles County Olive View Hospital. Most of the fatalities in this earthquake occurred in hospitals, principally the result of the collapse of an older unreinforced masonry Veterans Hospital building. In response to the recognized need for superior seismic performance by hospitals, the California Legislature enacted the Alfred E. Alquist Hospital Facilities Seismic Safety Act, which became effective in 1973. This Act mandated enhanced levels of design and construction. The Act proved very effective in limiting structural damage in the Northridge earthquake; no post–Act hospitals were red-tagged (posted with a red UNSAFE postearthquake safety inspection placard) and only one was yellow-tagged (posted with a yellow RESTRICTED USE placard). However, nonstructural damage was extensive, resulting in the temporary closure of several of the post-1973 buildings and the evacuation of patients.

Long-term closure only occurred in hospitals affected by the 1994 Northridge earthquake when there was structural damage; this only affected some pre-1973 hospitals. While structural damage can cause severe financial losses, the more important loss of ability to serve the community during the hours following the earthquake is more likely to be caused by nonstructural damage. At Holy Cross Medical Center, for example, damage to the air handling system and water damage from broken sprinklers and other piping required evacuation, but most services were restored within a week and paramedic units opened within 3 weeks (Figure 9-1). At Olive View Hospital (the replacement for the hospital damaged in the 1971 San Fernando earthquake) the structure was virtually undamaged (Figure 9-2), even though it was subject to horizontal ground accelerations approaching 1 g (g = acceleration of gravity). Broken piping and leakage, however, caused the evacuation of all patients and closure for one week.

During the 1994 Northridge earthquake, most nonstructural damage in healthcare facilities occurred to water related components. Damage

Figure 9-1 Exterior view of Holy Cross Medical Center, which was evacuated after the 1994 Northridge earthquake due to damage to the HVAC system. (photo courtesy of the Earthquake Engineering Research Institute)

Figure 9-2 Aerial view of Olive View Hospital, which sustained no structural damage during the 1994 Northridge earthquake, but was closed for a short while after the earthquake because of water leakage from broken sprinklers and waterlines. (photo courtesy of the Earthquake Engineering Research Institute)

was caused by leakage from sprinklers and domestic water and chilled water lines; water shortages were caused by lack of sufficient on-site storage. Twenty-one buildings at healthcare facilities suffered broken non-sprinkler water lines with most of the damage in small lines, less than 2-1/2 inches in diameter, for which bracing was not required by code. Sprinkler line breakage occurred at 35 buildings, all of which was caused by small unbraced branch lines.

Following the 1994 Northridge earthquake, a new state law was passed that required all hospitals that are deemed at "significant risk of collapse" to be rebuilt, retrofitted or closed by 2008, and all acute care hospitals to meet stringent safety codes by 2030. All hospital plans are to be reviewed by the Office of Statewide Health Planning and Development (OSHPD). The 1972 and 1994 hospital legislation is similar in scope to the 1933 and 1976 Field legislation enacted to protect schools, which is generally regarded to have been very successful in achieving its objectives of providing earthquake-safe schools.

9.4 PERFORMANCE EXPECTATIONS AND REQUIREMENTS

The following guidelines are suggested as seismic performance objectives for healthcare facilities:

- Patients, staff and visitors within and immediately outside healthcare facilities must be protected at least to a life-safety performance level during design-level earthquake ground motions.
- Safe spaces in the facility (which, depending on climatic conditions, may be outside) should be available for emergency care and triage activities within two hours of the occurrence of design-level earthquake ground motions.
- Most hospital services should be available within three hours of the occurrence of design-level earthquake ground motions.
- Emergency systems in the facility should remain operational after the occurrence of design-level earthquake ground motions.
- The facility services and utilities should be self-sufficient for four days after the occurrence of design-level earthquake ground motions.
- Patients and staff should be able to evacuate the building quickly and safely after the occurrence of design-level earthquake ground motions.

- Emergency workers should be able to enter the building immediately after the occurrence of design-level earthquake ground motions, encountering minimum interference and danger.
- There should be no release of hazardous substances as a result of the occurrence of design-level earthquake ground motions.

9.5 SEISMIC DESIGN ISSUES

The information in this section summarizes the characteristics of healthcare facilities, notes their relationship to achieving good seismic performance, and suggests seismic risk management solutions that should be considered.

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design.

Seismic Hazard and Site Issues

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design. If any of these other suspected conditions are geologic hazards, a geotechnical engineering consultant should conduct a site-specific study. If defects are encountered, an alternative site should be considered (if possible) or appropriate soil stabilization, foundation and structural design approaches should be employed to reduce consequences of ground motion beyond code design values, or costly damage caused by geologic or other seismic hazards (see Chapter 3 for additional information). If possible, avoid sites that lack redundant access and are vulnerable to bridge or highway closure.

Structural System Issues

Healthcare facilities are of great variety and size, encompassing all types of structure and services. Large hospitals accommodate several occupancy types. Acute care is a highly serviced short-term residential occupancy, and many diagnostic, laboratory and treatment areas require high-tech facilities and services. Service areas such as laundry, food service receiving, storage and distribution are akin to industrial functions, and administration includes typical office, communication and record-keeping functions.

Smaller healthcare facilities may encompass one or more functions such as predominantly longer residential care, or specialized treatment such as physical rehabilitation or dialysis. This functional variety influences some structural choices but the structure, as in all buildings, plays a background role in providing a safe and secure support for the facility

activities. Since continued operation is a desirable performance objective, structural design beyond life safety is necessary and design for both structural integrity and drift control need special attention to provide an added level of reliability for the nonstructural components and systems.

Since continued operation is a desirable performance objective for healthcare facilities, structural design beyond life safety is necessary and design for both structural integrity and drift control need special attention to provide an added level of reliability for the nonstructural components and systems.

The heavy and complex service demands of hospitals require greater floor-to-floor heights than for other buildings (such as offices) to provide more space above a suspended ceiling to accommodate the services. A number of hospitals have been designed with "interstitial" service space—a complete floor inserted above each functional floor to accommodate the services and make their initial installation and future change easier to accomplish (see Figure 9-3).

Because of their functional complexity, hospitals often have complex and irregular configurations. Broadly speaking, smaller hospitals are planned as horizontal layouts; large hospitals often have a vertical tower for the patient rooms elevated above horizontally planned floors for the diagnostic, treatment and administrative services. Emergency services are generally planned at the ground floor level with direct access for emergency vehicles. The structural design should focus on reducing configuration irregularities to the greatest extent possible and ensuring direct load paths. Framing systems need careful design to provide the great variety of spatial types necessary without introducing localized irregularities.

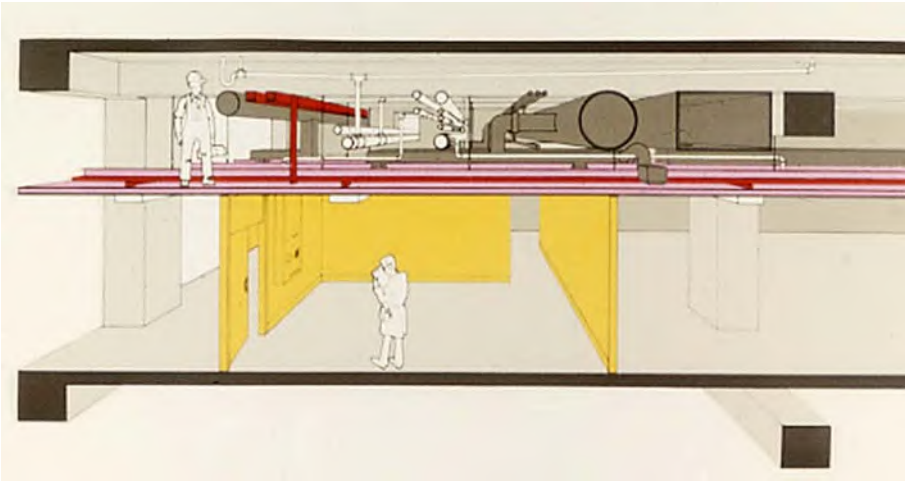

Figure 9-3 Sketch showing typical interstitial space for nonstructural components and systems in new hospitals.

Nonstructural System Issues

As noted above excessive structural motion and drift may cause damage to ceilings, partitions, light fixtures, and glazing. In addition, storage units, library shelving, and filing cabinets may be hazardous if not braced. Excessive drift and motion may also lead to damage to roof-top equipment, and localized damage to water systems and fire suppression piping and sprinklers. Heavy equipment such as shop machinery, kilns and heavy mechanical and electrical equipment may also be displaced, and be hazards to occupants in close proximity.

Continued operation is particularly dependent on nonstructural components and systems, including purchased equipment, much of which is often of great sensitivity and cost. Many specialized utilities must be provided, some of which involve the storage of hazardous substances, such as pharmaceuticals and oxygen in tanks. These must be protected against spillage during an earthquake. Distribution systems for hazardous gases must be well supported and braced. Water must be provided to many spaces, unlike an office building, where the provision is much more limited, and thus the likelihood of water damage in healthcare facilities is greater.

The responsibilities within the design team for nonstructural component support and bracing design should be explicit and clear. The checklist for responsibility of nonstructural design in Chapter 12 (see Figure 12-5) provides a guide to establishing responsibilities for the design, installation, review and observation of all nonstructural components and systems.

DESIGN AND PERFORMANCE ISSUES RELATING TO LOCAL SCHOOLS (K-12) 10

10.1 INTRODUCTION

Primary and secondary (kindergarten through grade 12) schools house thousands of America's children every school day. These buildings come in a variety of configurations and sizes and are constructed from all types of structural materials like steel, concrete, masonry and wood. As school districts make decisions about the buildings that they construct, seismic considerations can easily be factored into the decision process.

The following are some unique issues associated with kindergarten through grade 12 (K-12) schools that should be kept in mind during the design and construction phase of new facilities:

- Protection of children is an emotional societal issue and has very high priority.

- Occupancy density is one of the highest of any building type (typically 1 person per 20 square feet by code), with the exception of summer months, and after an earthquake, children are likely to be very frightened, creating difficulties for evacuation of a damaged structure.
- Occupancy by children is required by law, thus the moral and legal responsibilities for properly protecting the occupants are very great.
- School facilities are critical for immediate earthquake disaster shelter and recovery efforts.
- Closure of schools for any length of time represents a very serious community problem, and major school damage can have long-term economic and social effects.

10.2 OWNERSHIP, FINANCING, AND PROCUREMENT

Public schools are programmed and developed by the local school district. Financing is typically by local or state bond issues, possibly with the addition of federal assistance.

Public work must be competitively bid. Typically, contracts are placed for all site and building work, both structural and nonstructural. Equipment and furnishings and their installation are purchased separately from specialized vendors.

School districts typically try to emphasize high quality of design and construction and long facility life, though all districts are necessarily very budget conscious.

10.3 PERFORMANCE OF LOCAL SCHOOLS IN PAST EARTHQUAKES

There has been surprisingly little severe structural damage to schools, except in the Long Beach, California, earthquake of 1933, and there have been very few casualties. In California, no school child has been killed or seriously injured since 1933. This good fortune results primarily because all major California earthquakes since 1925 have occurred outside school hours.

Damage in the Long Beach earthquake was so severe that it was realized that if the schools had been occupied there would have been many casualties. As a result, the State passed the Field Act within a month after the earthquake. This act required that all public school buildings be designed by a California licensed architect or structural engineer, all

plans must be checked by the Office of the State Architect, and construction must be continuously inspected by qualified independent inspectors retained by the local school board. The State Architect set up a special division, staffed by structural engineers, to administer the provisions of the Act. While time of day limited casualties, the Field Act, which is still enforced today, has greatly reduced structural damage.

In the Northridge, California, earthquake of 1994, State inspectors posted red UNSAFE placards on 24 school buildings, and yellow RESTRICTED USE placards on 82, although this was later considered overly conservative. No structural elements collapsed. There was, however, considerable nonstructural damage as shown in Figure 10-1. This was costly to repair, caused closure of a number of schools and, if the schools had been in session, would have caused casualties. The Field Act focused on structural design and construction, and only recently were nonstructural components included in the scope of the Act.

Figure 10-1 Nonstructural damage at Northridge Junior High where lights fell onto desks during the 1994 Northridge earthquake. (photo courtesy of the Earthquake Engineering Research Institute)

10.4 PERFORMANCE EXPECTATIONS AND REQUIREMENTS

Students and teachers within and outside elementary and secondary school buildings must be protected during an earthquake. Any damage that jeopardizes the provision of educational services impacts not only the facility but also the community, since the school is an important

community center. Primary and secondary educational establishments are important community service providers and service interruption is a major problem. In addition to these general seismic performance expectations, the following guidelines are suggested as seismic performance objectives for elementary and secondary schools:

- The school should be capable of substantial use for shelter purposes within 3 hours of the occurrence of earthquake design-level ground motions.
- Emergency systems in the school should remain operational after the occurrence of earthquake design-level ground motions.
- Students and teachers should be able to evacuate the school quickly and safely after the occurrence of earthquake design-level ground motions.
- Emergency workers should be able to enter the school immediately after the occurrence of earthquake design-level ground motions, encountering minimum interference and danger.

10.5 SEISMIC DESIGN ISSUES

The information in this section summarizes the characteristics of local schools (K-12), notes their relationship to achieving good seismic performance, and suggests seismic risk management solutions that should be considered.

Seismic Hazard and Siting Issues

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design.

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design. If any of these suspected conditions are geologic hazards, a geotechnical engineering consultant should conduct a site-specific study. If defects are encountered, an alternative site should be considered (if possible) or appropriate soil stabilization, foundation and structural design approaches should be employed to reduce consequences of ground motion beyond code design values, or costly damage caused by geologic or other seismic hazards (see Chapter 3 for additional information). If possible, avoid sites that have restricted access.

Structural System Issues

Schools are a wide variety of sizes, from one-room rural school houses to 2000-student high schools. Each size will have its own code requirements and cost implications. A wide variety of structural approaches are available and careful selection must be made to meet the educational and financial program.

Traditional schools with rows of standard classrooms are relatively simple buildings, with few partitions since the structural walls can provide much of the space division. Classroom walls can act efficiently as shear walls but the school is likely to have very limited flexibility for space changes. The structure, as in all buildings, plays a background role in providing a safe and secure support for the facility activities. The structural problems are, however, relatively simple, and a well designed and constructed school should provide a safe environment.

Newer schools are usually one or two stories with light steel frame or mixed steel frame, wood and concrete or concrete masonry structures. When designed to code minimum requirements, these light and relatively long-span structures may have excessive drift characteristics. Excessive motion and drift may cause damage to ceilings, light fixtures, partitions, glazing, roof-top equipment, utilities and fire suppression piping. The structural design should pay special attention to drift control and to appropriate support of vulnerable nonstructural components and systems.

Urban schools are sometimes mid-rise (up to 4 stories), with reinforced masonry, reinforced concrete, or steel frame structures. For these structures, configuration irregularities, such as soft stories, may become critical. The structural design should focus on reducing configuration irregularities and ensuring direct load paths.

Larger schools may have long-span gymnasia or multi-use spaces in which wall-to-diaphragm connections are critical. These larger spaces may be used for post-disaster shelters. Seismic resistance must typically be provided by perimeter frames or walls. The structural design should pay special attention to reducing perimeter opening irregularities, and providing direct load path and appropriate structural connections. Larger schools also often tend to become more complex in layout because of new program needs, and the desire to provide a more supportive and attractive environment. The complexities in layout may introduce irregularities in plan shapes and require complicated fram-

ing. The structural design should focus on reducing plan irregularity, and providing appropriate structural connections.

Nonstructural System Issues

School occupants are vulnerable to nonstructural damage, particularly falling nonstructural components and systems.

School occupants are particularly vulnerable to nonstructural damage. Although school children may duck under desks and be safe from falling objects such as light fixtures and ceiling tiles, ceiling components that fall in hallways and stairs can make movement difficult, particularly if combined with power failure and loss of lighting. As discussed in the *Structural System Issues* Section, most traditional primary and elementary school buildings are relatively simple buildings, with few partitions since the structure provides the space division. Excessive motion and drift (sway) may cause damage to ceilings, partitions, light fixtures, and glazing. In addition, storage units, library shelving, and filing cabinets may be hazardous if not braced. Excessive drift and motion may also lead to damage to roof-top equipment, and localized damage to water systems and fire suppression piping and sprinklers. Heavy mechanical and electrical equipment may also be displaced.

Falling nonstructural components and systems present a significant potential for injuries to building occupants as shown in Figure 10-1. In addition to the injury potential and economic loss resulting from repair and clean-up costs, excessive service interruption can result from lighting fixture and water, mechanical, and electrical equipment damage. As discussed in the *Structural System Issues* Section, the structure should be designed for enhanced drift control to limit nonstructural damage. Lightweight hung ceilings should be avoided in light frame or large structures, and the safety of suspended lighting fixtures should always be verified. In general, the responsibilities within the design team for nonstructural component support and bracing design should be explicit and clear (Use Figure 12-5 responsibility checklist to facilitate this process).

Schools should be designed for enhanced drift control to limit nonstructural damage

DESIGN AND PERFORMANCE ISSUES RELATING TO HIGHER EDUCATION FACILITIES (UNIVERSITIES) 11

11.1 INTRODUCTION

University campuses generally consist of many different types of buildings, in a broad variety of sizes, housing many different functions. As a result, higher education facilities are, in many ways, a microcosm of the larger community. In addition to teaching classrooms, university facilities include auditoriums, laboratories, museums, stadiums and arenas, libraries and physical plant facilities, to name a few. As universities make decisions about the buildings that they construct, seismic considerations can easily be factored into the decision process.

The following are some unique issues associated with higher education facilities that should be kept in mind during the design and construction phase of new facilities:

- Protection of students, faculty and staff is a very high priority.
- Higher education facilities have a high daytime occupancy and some evening use, with reduced use in the summer months. Classrooms in particular often have high intensity usage.

- Closure of higher education facilities represents a very serious problem, and major college and university damage can have long-term economic and social effects.
- Ensuring the survival of records, whether in electronic or written form, is essential for continued operation.
- Protection of valuable contents such as library inventories, research equipment and materials is a high priority.

11.2 OWNERSHIP, FINANCING, AND PROCUREMENT

Higher education facilities are typically developed by the institution, which may be privately, state or local-community owned. Financing of privately owned facilities is typically by private loan, possibly with some state or federal assistance; large universities also have large endowments and fund-raising activities, a large part of which assist in capital improvement program financing. Public institutions may also be financed by state and local bond issues.

Private institutions have no restrictions on methods of procurement; projects may be negotiated, conventionally bid, use construction management or design-build. Public work must be competitively bid. Typically, contracts are placed for all site and building work, both structural and nonstructural. Equipment and furnishing and their installation are purchased separately from specialized vendors.

Higher education institutions typically emphasize high quality of design and construction and long facility life, though all institutions are also budget conscious. An attractive campus is seen, particularly by institutions which are in a competitive situation, as an important asset.

11.3 PERFORMANCE OF HIGHER EDUCATION FACILITIES (UNIVERSITIES) IN PAST EARTHQUAKES

The most significant experiences of seismic performance of higher education facilities in recent earthquakes has been those related to the Whittier (Los Angeles region) earthquake of 1987, the Loma Prieta (San Francisco Bay region) earthquake of 1989, and the Northridge (Los Angeles) earthquake of 1994. During the Whittier earthquake, a number of buildings at the California State University at Los Angeles suffered some structural damage and extensive nonstructural disruption. One student was killed by a concrete facade panel that fell from a parking structure. During the Loma Prieta earthquake, the Stanford

University campus experienced considerable damage, forcing the closure of a dozen buildings. Subsequently, Stanford convened a special committee to review steps that should be taken to protect the campus against future events. One result was to set up its own seismic safety office with structural engineering staff to determine, in concert with departmental and university representatives, performance objectives for buildings and to review proposed designs. The university played a strong role in the early application of performance-based design strategies for its capital programs.

In the Northridge earthquake, the California State University at Northridge was forced to close for a month and re-open in temporary buildings. Severe damage was done to the welded steel frame of the University Library (Figure 11-1), and buildings on the University of California at Los Angeles (UCLA) campus were slightly damaged. For the most part the serious structural damage to all these campuses was experienced by older reinforced buildings or to unreinforced masonry structures.

The implications of the above-described damage caused a number of universities to become concerned about the ability of their facilities to support continued teaching and research following a more severe event.

Figure 11-1 Fractured 4-inch-thick steel base plate, university building, Northridge, 1994. (photo courtesy of the Earthquake Engineering Research Institute)

In 1997 the University of California at Berkeley committed $1 million to intensify campus planning and developed a 10-point action plan that included a high-level administrative restructuring to focus on campus planning and construction, with extensive focus on seismic safety. The 10-point plan included:

- Creation of a new Chancellor's cabinet-level position of Vice Chancellor to oversee all aspects of the program.
- Determination of the need for full or partial closure of any facilities deemed an unacceptable risk.
- Development of plans for a variety of temporary relocation or "surge" space, sites and buildings.
- Development and initiation of a multi-source financing plan to implement the master plan and implement a seismic retrofit program.
- Conduct of a comprehensive emergency preparedness review, including mitigating nonstructural hazards, assuring that emergency and critical facilities are available, and providing emergency response training.

This plan is now being implemented; a number of key facilities have been retrofitted, and others are in process, with priorities based on a seismic evaluation of all the campus buildings. New buildings are subject to a peer-review process of the proposed seismic design.

11.4 PERFORMANCE EXPECTATIONS AND REQUIREMENTS

The following guidelines are suggested as seismic performance objectives for higher education facilities:

- Students, faculty, staff and visitors within and immediately outside the facilities must be protected at least to a life safety performance level during design-level earthquake ground motions.
- Emergency systems in the facilities should remain operational after the occurrence of design-level earthquake ground motions.
- All occupants should be able to evacuate the school quickly and safely after the occurrence of design-level earthquake ground motions.
- Emergency workers should be able to enter the facility immediately after the occurrence of design-level earthquake ground motions, encountering minimum interference and danger.

11.5 SEISMIC DESIGN ISSUES

The information in this section summarizes the characteristics of higher education facilities, notes their relationship to achieving good seismic performance, and suggests seismic risk management solutions that should be considered.

Seismic Hazard and Site Issues

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design.

Unusual site conditions, such as a near-source location, poor soil characteristics, or other seismic hazards, may lead to lower performance than expected by the code design. If any of these other suspected conditions are geologic hazards, a geotechnical engineering consultant should conduct a site-specific study. If defects are encountered, an alternative site should be considered (if possible) or appropriate soil stabilization, foundation and structural design approaches should be employed to reduce consequences of ground motion beyond code design values, or costly damage caused by geologic or other seismic hazards (see Chapter 3 for additional information). If possible, avoid sites that lack redundant access and are vulnerable to bridge or highway closure.

Structural System Issues

Higher education facilities are of great variety and size, encompassing all types of structure and services. The basic occupancies are teaching, research and administration, but assembly facilities may range from a small rehearsal theater to a multi-thousand seat sports stadium. A large student center may be a cross between a small shopping mall and a community center with retail stores, food service and places of recreation and assembly. As universities become more competitive to attract a wider audience, student-life facilities are tending to become larger and more complex. In addition, many universities provide extensive dormitory facilities.

Teaching requires spaces for small seminar groups, classrooms that are often larger in size than those of a grade school, and large lecture halls with sloped seating and advanced audio-visual equipment. Science teaching requires laboratories and support spaces with services and equipment related to traditional scientific and engineering fields, such as chemistry, biology, physics and computer sciences.

The administration function includes all office functions, including extensive communication services and extensive record keeping. Science research requires laboratories and other special facilities (e.g.,

greenhouses) that can accommodate a variety of unique spatial, service and utility needs required by researchers; some laboratories such as material sciences, physics, and engineering require heavy equipment with large power demands. Departmental buildings in the humanities may encompass a small administrative function, a variety of teaching facilities, many of them small. Departmental buildings in the sciences may include laboratories and their support space within the same building, and faculty offices may include direct access to research laboratories. Departmental buildings may also include a departmental library. Teaching and research in the biological sciences may include the storage, distribution and use of hazardous substances.

The library is a major campus facility, and a large campus may have several campus-wide libraries. Notwithstanding the rapid advance of computerized information technology and information sources such as the internet, the hard-copy resources of the library continue to be of major importance, and the library is a distinct building type with some specific structural and service demands, such as the ability to safely accommodate heavy dead loads, and to provide a high level of electronic search and cataloging functions.

Because of their functional complexity, large higher education facilities often have complex and irregular architectural/structural configurations. In addition, the spatial variety within many higher education buildings influences some structural choices, and structural design tends to be complex in its detailed layout with a variety of spans and floor-to-floor heights. Some laboratory equipment requires a vibration free environment, which entails special structural and mechanical equipment design. The structural design should focus on reducing configuration irregularities to the greatest extent possible and ensuring direct load paths. Framing systems need careful design to provide the great variety of spatial types necessary without introducing localized irregularities.

Since continued operation is a desirable performance objective, structural design of higher education facilities beyond life safety is necessary and design for both structural integrity and drift control need special attention to provide an added level of reliability for the nonstructural components and systems.

Since continued operation is a desirable performance objective, structural design beyond life safety is necessary and design for both structural integrity and drift control need special attention to provide an added level of reliability from the nonstructural components and systems.

Nonstructural System Issues

As noted above, excessive structural motion and drift may cause damage to ceilings, partitions, light fixtures, and glazing. In addition, storage

units, library shelving, and filing cabinets may be hazardous if not braced. Excessive drift and motion may also lead to damage to roof-top equipment, and to localized damage to water systems and fire suppression piping and sprinklers. Heavy laboratory equipment and heavy mechanical and electrical equipment may also be displaced, and be hazards to occupants in close proximity.

Continued operation is particularly dependent on nonstructural components and systems. Laboratory and research areas may need special design attention to nonstructural components and systems to ensure continued operation of critical experiments and equipment.

Continued operation is particularly dependent on nonstructural components and systems, including purchased scientific equipment, much of which is often of great sensitivity and cost. Many specialized utilities must be provided, some of which involve the storage of hazardous substances. These must be protected against spillage during an earthquake. Distribution systems for hazardous gases must be well supported and braced. Water must be provided to many spaces, and thus the likelihood of water damage is greater. Cosmetic wall and ceiling damage that can easily be cleaned up in an office building may shut down a research laboratory.

Laboratory and research areas may need special design attention to nonstructural components and systems to ensure continued operation of critical experiments and equipment.

The responsibilities within the design team for nonstructural component support and bracing design should be explicit and clear. The checklist for responsibility of nonstructural design in Chapter 12 (see Figure 12-5) provides a guide to establishing responsibilities for the design, installation, review and observation of all nonstructural components and systems.

RESPONSIBILITIES FOR SEISMIC CONSIDERATIONS WITHIN THE DESIGN TEAM 12

12.1 RESPONSIBILITIES OF THE STRUCTURAL ENGINEER, ARCHITECT, AND MEP ENGINEER

Seismic considerations should apply to every building system, subsystem, and component, and the performance of each component or system is often interdependent. The traditional organization of the design team and the assignment of responsibilities to the architect, structural engineer, MEP (mechanical, electrical, and plumbing) consultants, and other specialty consultants (e.g., geotechnical engineer, curtain wall consultant, elevator consultant, or security consultant) is critically important to address cross-cutting seismic design issues or problems.

For example, the seismic design and performance of glazing systems, windows, and curtain walls have improved significantly in recent years through the adoption of improved code provisions for these building systems. These improvements can impact both life safety in an earthquake (broken glass can kill or seriously injure) and immediate occupancy following an earthquake (integrity of the building envelope). The trade-offs involve drift limits, curtain wall clearances and design details, and glazing design. In this example, the architect, structural engineer, and curtain wall consultant must work together closely to arrive at the appropriate designs.

12.2 DEVELOPING A UNIFIED APPROACH WITHIN THE DESIGN TEAM

The first step in the design process should be the development, with active participation of the owner, of a set of clear performance objectives that address how the building is expected to perform before, during, and following an earthquake. These performance objectives should be based on owner needs and decisions, and should be expanded into detailed performance statements that apply to every subsystem of the building. Throughout the design development, there should be explicit reviews of each element of the design against the performance statements in order to assure that the completed building meets the expectations articulated in the original performance objectives. In addition, the owner should be encouraged to develop and carry out a risk management plan compatible with the performance objectives.

The term "performance objective," discussed in Chapters 2 and 4, should include a statement regarding the seismic performance that is expected of the building, subsystem, or component that is being addressed. Wherever possible, it should include quantifiable performance criteria that can be measured. For example, an objective may be that a subsystem (such as the HVAC system) should be operable following an earthquake of a certain magnitude. The specific criteria related to this may specify how long the system is expected to operate, under what operating conditions, and with what resulting interior environmental conditions.

12.3 ENGINEERING SERVICES FOR ADDED VALUE OF RISK MANAGEMENT

The owner should establish a process in which the risk management function and the facilities management function are fully coordinated in the development of a capital improvement and new construction program. The risk manager should balance seismic risk with all other facility-related risks. In order to do so, the risk manager should have an understanding of seismic risks. Once the risk manager gains such an understanding, the risk manager should be educated to prepare a return-on-investment analysis for investments in seismic performance.

The risk manager should balance seismic risk with all other facility-related risks.

The design team has an opportunity to offer the owner a service of educating the risk manager on the details of seismic risk in buildings. This service could be independent of any specific capital improvement or design project, or it can be offered as a pre-design orientation activity that is linked to a design project.

12.4 COMMUNICATING SEISMIC CONSIDERATIONS ISSUES TO THE BUILDING OWNER

Issues of building performance should be communicated to a building owner in terms that relate how the building is expected to perform following an earthquake, and the potential impacts that this level of performance may have on the post-earthquake functionality of the building.

Issues of building performance should be communicated to a building owner in terms that relate how the building is expected to perform following an earthquake, and the potential impacts that this level of performance may have on the postearthquake functionality of the building. In order to accomplish this, the design team must learn to communicate using terminology that is familiar to the owner. This can best be accomplished through interaction with the owner's facilities or risk manager.

It is typically more difficult to explain earthquake risk issues to a building owner, since such considerations are probabilistic in nature, and less specific with respect to magnitude, location, or even how often they will occur. The design team must understand the owner's extent of risk aversion or risk tolerance. The more risk neutral the owner is, the simpler the communication is likely to be, in that various outcomes can be multiplied by their respective probabilities and then communicated directly to the owner. This process, however, becomes more complicated with a more risk averse or tolerant owner. The best way this communication can be accomplished is through close interaction and coordination with the owner's risk or facilities manager.

The design team must understand the owner's extent of risk aversion or risk tolerance.

As the member of the design team who initiates the design concept and develops it through design development and the preparation of construction documentation, the architect should play a key role in the seismic design process. To ensure that consideration of seismic issues occurs with the right degree of priority, and at the right time in the design process, the architect should have a clear conceptual understanding of seismic design issues that impact the design.

The structural engineer's role is to provide the structural design for a building. While the structural engineer must play the major role in providing an earthquake-resistant design, the overall design responsibility is shared between the architect and engineer, because of architectural decisions that may impact the effectiveness of the engineer's design solution and hence the building's seismic performance. The use of performance-based design can reinforce the importance of the recommendation that the architect and structural engineer work together from the inception of a design project, and to discuss seismic issues before and during the conceptual design stage. Many of the critical architectural decisions occur at the conceptual design stage, at which point the building configuration is set and issues such as the nature of the structure and structural materials and architectural finishes are identified.

The concept of structural engineers participating with architects during the early conceptual design phase of a project is not new, yet it is often confined to a cursory conversation or does not occur at all, for a variety of economic, cultural, and professional reasons. Developmental projects often require a partial design in order to procure project financing; at this point, the owner typically attempts to minimize upfront costs and the architect will not involve, or only peripherally involve, structural consultants. Some architects see the structural engi-

neer as providing a purely service role in enabling the architect to achieve the forms and spaces that are desired. In a successful project, the architect and structural engineer typically collaborate on layout and design issues from the inception of the project, in order to ensure that the architectural and structural objectives are achieved.

In a successful project, the architect and structural engineer typically collaborate on layout and design issues from the inception of the project.

As the servicing needs of contemporary buildings continue to increase, the impact of the MEP (mechanical, electrical, and plumbing systems) consultant's work on seismic design becomes increasingly important. An example of this is the need for penetrations or blockouts in the structure to accommodate ductwork, piping, and equipment, which requires early design consideration. These penetrations are fundamental to the integration of the structural and mechanical system, and their size and location should be carefully worked out between the architect, structural, and mechanical engineers. There are many instance of damage to buildings in earthquakes caused by structural member penetrations that have not been adequately coordinated with the structural design.

There are many instance of damage to buildings in earthquakes caused by structural member penetrations that have not been adequately coordinated with the structural design.

Protecting against nonstructural damage requires clear allocation of roles and responsibilities. An important question is: Is the structural design of mechanical equipment supports the responsibility of the equipment vendor, the mechanical engineer, or the structural engineer? Similarly, is the design of the connections for precast concrete cladding the responsibility of the precast element vendor or the building structural engineer? And, is the layout and design of bracing for ductwork the responsibility of the mechanical contractor or the building structural engineer? If these responsibilities are not called out at the outset of the job, the result will be disputes, extra costs, and potentially serious omissions.

Protecting against nonstructural damage requires clear allocation of roles and responsibilities.

Design-Build and Fast-Track Projects

Large projects are often "fast-tracked" to some degree, with the construction contract separated into a number of bid packages that may be sole-source negotiated or competitively bid. The objective here is to speed the project's overall completion, but the process can substantially complicate coordination of tasks. Among the reasons for this are the following.

- The complete design team may not be in existence before the preparation of construction documents has begun. This arrangement

can create problems when decisions early in the project determine design approaches and delegate responsibility to entities who are not yet under contract, or who have had no input into such early decisions.

- Communication among designers during fast-track projects is usually more difficult because the development of separate bidding packages means that the design process is fragmented, rather than one which undergoes continuous evolution. At any stage during design development and contract document preparation stages of a project, a complete set of drawings of the project may not exist.
- Because of demands in the project schedule, the design and fabrication, or preparation of shop drawings, many items are not always thoroughly reviewed by the architect or engineer, and in some cases may not even be submitted to the local building department.

Design-build and fast-track construction can be very efficient for simple projects and for design teams that have a track record in working together, but for more complex projects and for design teams that have not previously worked together, both the design and construction phases of a project will need special attention. The assignment of roles and responsibilities is critical if the performance objectives are to be adequately defined and for integrated seismic design and construction to be achieved.

Design-build and fast-track construction can be very efficient for simple projects and for design teams that have a track record in working together, but for more complex projects and for design teams that have not previously worked together, both the design and construction phases of a project will need special attention.

Checklists to Facilitate the Design and Construction Process

A useful aid for the development of performance objectives and the coordination of the design and construction process within the design team is the use of checklists. These may be maintained by hand for smaller jobs, or computerized for larger or more complicated ones. Checklists can highlight key seismic design issues that require consideration and resolution, and can serve to ensure that all issues are adequately dealt with. The checklists discussed below are suggested as models that may be modified to suit the nature of the design team and the construction delivery process.

Figure 12-1 provides a seismic performance checklist, intended to focus the building owner and the design team on issues related to seismic performance expectations. The checklist presents a set of questions that are used to help the client focus on available seismic performance alternatives, leading to a recorded statement of the client's expectations of seismic performance goals that, hopefully, are in line with available

SEISMIC EXPECTATIONS

A. Earthquake Performance of Structure

	Damage			
Seismic Shaking Hazard Level	No Life Threat, Collapse	Repairable Damage: Evacuation	Repairable Damage: no Evacuation	No Significant Damage
Low				
Moderate				
High				

B. Earthquake Performance of Nonstructural Components

	Damage			
Seismic Shaking Hazard Level	No Life Threat, Collapse	Repairable Damage: Evacuation	Repairable Damage: no Evacuation	No Significant Damage
Low				
Moderate				
High				

C. Function Continuance: Structural/Nonstructural

	Time to Reoccupy			
Seismic Shaking Hazard Level	6 Months +	To 3 Months	To 2 weeks	Immediate
Low				
Moderate				
High				

Notes:

Seismic Shaking Hazard Level	Spectral Acceleration (short period or 0.2 sec)	Spectral Acceleration (long period or 1.0 sec)
Low	<0.167 g	<0.067 g
Moderate	≥0.167 g and <0.50 g	≥0.067 g and <0.2 g
High	≥0.50 g	≥0.20 g

Figure 12-1 Checklist for seismic expectations. (adapted from Elssesser, 1992))

resources. Agreement on such goals and expectations forms the beginning of a performance-based design procedure and can limit future "surprises" due to unanticipated earthquake damage. The checklist statements can become a part of the project's building program, in a manner similar to statements about acoustical or thermal performance, and can serve as the basis for the use of more formal performance-based design procedures during the design.

Figure 12-2 provides a checklist intended to facilitate a discussion between the architect and the structural engineer on the importance of various building siting, layout, and design issues. The checklist identifies a number of issues that should be discussed and resolved by the architect and structural engineer at the early stages of a new project. The checklist should be used when a conceptual design has been prepared and transmitted to the structural engineer. The checklist is intended primarily to provoke a discussion, and is not intended to be filled in and used as a document of record. Most of the items in the checklist will need varying levels of discussion; the checklist is only intended to identify the existence of a potential problem and indicate the importance and priority, or significance, of the problem.

Figure 12-2 also ensures that all significant issues are covered, and that the architect and structural engineer have reached mutual understanding on the resolution of problems. This is the point at which the structural engineer should explain any issues that are not clear. Similarly, if planning or other constraints appear to have resulted in a questionable seismic configuration or a building with other undesirable seismic characteristics, the use of this checklist will ensure the identification of these characteristics fairly early in the design process, and should open the way to their resolution.

Figure 12-3 provides a list of structural and nonstructural components which are typically included in a building project. It is intended to define the responsibilities within the design team for various aspects of the design, and establishes the scope of work among the major consultants and suppliers. The checklist provides the basis for consultant agreements between the architect, construction manager, and specialist consultants. In most projects, costs and a competitive market tend to limit the time and money available for design. Working within a limited budget and timeframe, current practice is for architects and structural engineers to leave some design tasks to engineers employed by subcontractors and vendors (e.g., the design of precast concrete panels and their connections, prefabricated stairs, and truss assemblies). This

CHECKLIST TO FACILITATE ARCHITECT/ENGINEER INTERACTION

Item	Minor Issue	Major Issue	Significant Issue
Goals			
Life Safety			
Damage Control			
Continued Function			
Site Characteristics			
Near Fault			
Ground Failure Possibility			
(landslide, liquefaction)			
Soft Soil (amplification, long period)			
Building Configuration			
Height			
Size Effects			
Architectural Concept			
Core Location			
Stair Locations			
Vertical Discontinuity			
Soft Story			
Set Back			
Offset Resistance Elements			
Plan Discontinuity			
Re-entrant Corner			
Eccentric Mass			
Adjacency-Pounding Possibility			
Structural System			
Dynamic Resonance			
Diaphragm Integrity			
Torsion			
Redundancy			
Deformation Compatibility			
Out-Of-Plane Vibration			
Unbalanced Resistance			
Resistance Location			
Drift/Interstory Effect			
Strong Column/Weak Beam Condition			
Structural System			
Ductility			
Inelastic Demand Constant or Degrading			
Damping			
Energy Dissipation Capacity			
Yield/Fracture Behavior			
Special System (e.g., base isolation)			
Mixed System			
Repairability			
Nonstructural Components			
Cladding, Glazing			
Deformation Compatability			
Mounting System			
Random Infill			
Ceiling Attachment			
Partition Attachment			
Rigid			
Floating			
Replaceable Partitions			
Stairs			
Rigid			
Detached			
Elevators			
MEP Equipment			
Special Equipment			
Computer/Communications Equipment			

Figure 12-2 Checklist for Architect/Engineer Interaction. (from Elssesser, 1992)

DESIGN SCOPE-OF-WORK GUIDELINES

Project: _____

Item	Activity: Design	Coordinate	Check	Shop Drawings	Sign/Stamp	Field Review
Foundation						
Super Structure Elements and Systems:						
_____						
_____						
_____						
_____						
_____						
_____						
Cladding						
_____						
_____						
_____						
_____						
Stairs						
Elevator						
Ceilings						
Equipment						
MEP Systems						

Key:

A = Architect
SE = Structural Engineer
MEP = Mechanical, Electrical, Plumbing Consultant
V = Vendor, Subcontractor or Manufacturer of manufactured, assembled or prefabricated components or systems
G = Geotechnical Engineer
___ = Other Specialty Consultant: _____
___ = Other Specialty Consultant: _____

Figure 12-3 Checklist for defining project responsibilities. Key professional personnel responsible for various aspects of design should be indicated in the appropriate cell of the check list (adapted from Elsesser, 1992).

checklist can be used to identify where and when these procedures will be used.

Figure 12-4 provides an example that shows how the checklist in Figure 12-3 may be completed for a representative project. This example shows a traditional design and construction process in which the architect plays the key role in design management and project coordination. The assigned responsibilities would vary depending on the nature of the project, the composition of the project team, and the proposed design and construction procedures.

Figure 12-5 provides a list of typical building non-structural components and, similar to Figure 12-2, is intended to delineate the roles and responsibilities of design team members for the design and installation of nonstructural components and systems. In current practice, this area is often unclear and important non-structural protective measures may become the subject of dispute; in some extreme cases, they may be omitted altogether. Both this checklist and that shown in Figure 12-2 are expected to play an important role in establishing the total scope of work for the various project consultants, and in ensuring that important tasks do not fall between the cracks of the various involved design and construction parties.

12.5 DESIGN AND CONSTRUCTION QUALITY ASSURANCE

Building codes require that "special inspections" be carried out for specific critical elements of a building during construction. These inspections are intended to assure that a high degree of quality has been achieved in constructing the approved design, and in the manner in which it is intended. As related to seismic design, special inspections typically apply to important construction and fabrication considerations, such as ensuring the use of pre-certified weld procedures and adequate weld quality.

Performance-based seismic design also requires specific performance from nonstructural systems and components in the building. In order to obtain the intended seismic performance in these areas, additional quality assurance activities are needed, above and beyond those typically required by code or employed on normal non-seismic construction projects. The following is a partial list of some nonstructural system components in need of special consideration or inspection.

DESIGN SCOPE-OF-WORK GUIDELINES

Project: Hypothetical*

Item	Activity: Design	Coordinate	Check	Shop Drawings	Sign/Stamp	Field Review
Foundation	SE	A	G	SE	SE	A, SE
Super Structure						
Elements and Systems:						
Steel Frame	SE	A	SE	SE	SE	SE
Concrete Frame	SE	A	SE	SE	SE	SE
Precast or Post-Tensioned Floors	V	SE	SE	SE	V, SE	SE
Open Web Joists	V	SE	SE	SE	V, SE	SE
Cladding						
Precast, Stone	V	A, SE	SE	SE	V	A, SE
Metal	V	A	SE	A	V	A
Glass	V	A	A	A		A
Stairs	A, SE, V	A	SE	SE	V, SE	A, SE
Elevator	V	A	SE	A, SE	V	A, SE
Ceilings	A	A	SE	A	A	A
Equipment	V	A	SE	A	V, SE	A, SE
MEP Systems	MEP	A	SE	MEPMEP	MEP	

*This table represents a hypothetical project and should not be taken as a suggestion for assigning specific responsibilities, which must be uniquely established for each project.

Key:

A = Architect
SE = Structural Engineer
MEP = Mechanical, Electrical, Plumbing Consultant
V = Vendor, Subcontractor or Manufacturer of manufactured, assembled or prefabricated components or systems
G = Geotechnical Engineer
___ = Other Specialty Consultant: _____
___ = Other Specialty Consultant: _____

Figure 12-4 Example of completed checklist shown in Figure 12-3. (adapted from Elssesser, 1992)

NONSTRUCTURAL COMPONENT SEISMIC RESISTANCE RESPONSIBILITY MATRIX

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

Figure 12-5 Checklist for responsibility of nonstructural component design. (from ATC/SEAOC Joint Venture, 1999)

- Inspection of the anchorage and bracing of architectural and mechanical elements.
- Labeling of fenestration products to ensure that they have been provided as specified, and inspection to ensure proper installation.
- Inspection of ceiling and partition attachments.
- Inspection of special equipment.

The report, *ATC-48, Built to Resist Earthquakes: The Path to Quality Seismic Design and Construction* (ATC/SEAOC, 1999), provides comprehensive guidance on issues pertaining to the quality design and construction of wood-frame, concrete, and masonry buildings, and anchorage and bracing of non-structural components.

Design and Construction Quality Assurance

ATC-48, *Built to Resist Earthquakes: The Path to Quality Seismic Design and Construction* (ATC/SEAOC, 1999).

REFERENCES

ASCE, 2002, *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers, Standard *ASCE-7*, Reston, Virginia.

ASCE, 2000, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, prepared by the American Society of Civil Engineers, published by the Federal Emergency Management Agency, *FEMA 356 Report*, Washington, DC.

ATC, 1978, *Tentative Provisions for the Development of Seismic Regulations for Buildings*, Applied Technology Council, *ATC-03 Report*, Redwood City, California.

ATC, 1989a, *Procedures for Postearthquake Safety Evaluation of Buildings*, Applied Technology Council, *ATC-20 Report*, Redwood City, California.

ATC, 1989b, *Field Manual: Postearthquake Safety Evaluation of Buildings*, Applied Technology Council, *ATC-20-1 Report*, Redwood City, California.

ATC, 1993, *ATC-20 Postearthquake Safety Evaluation of Buildings Training Slide Set*, Applied Technology Council, *ATC-20-T Report*, Redwood City, California.

ATC, 1995, *Addendum to the ATC-20 Procedures for Postearthquake Safety Evaluation of Buildings*, Applied Technology Council, *ATC-20-2 Report*, Redwood City, California.

ATC, 1996a, *Case Studies in Rapid Postearthquake Safety Evaluation of Buildings*, Applied Technology Council, *ATC-20-3 Report*, Redwood City, California.

ATC, 1996b, *Seismic Evaluation and Retrofit of Concrete Buildings*, Volumes 1 and 2, Applied Technology Council, *ATC-40 Report*, Redwood City, California.

ATC, 1997, *Example Applications of the NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, prepared by the Applied Technology Council for the Building Seismic Safety Council; published by the Federal Emergency Management Agency, *FEMA 276 Report*, Washington, D.C.

ATC, 2002, *Recommended U.S.-Italy Collaborative Procedures for Earthquake Emergency Response Planning for Hospitals in Italy*, Applied Technology Council, *ATC-51-1 Report*, Redwood City, California.

ATC, 2004a (in preparation), *Improvement of Inelastic Seismic Analysis Procedures,* prepared by the Applied Technology Council for the Federal Emergency Management Agency, FEMA 440, Washington, D.C.

ATC, 2004b (in preparation), *Program Plan for Development of Performance-Based Seismic Design Guidelines,* prepared by the Applied Technology Council for the Federal Emergency Management Agency, FEMA 445, Washington, D.C.

ATC, 2004c (in preparation), *Characterization of Seismic Performance for Buildings*, prepared by the Applied Technology Council for the Federal Emergency Management Agency, FEMA 446, Washington, D.C.

ATC/BSSC, 1997a, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, prepared by the Applied Technology Council (ATC-33 project) for the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 273 Report*, Washington, DC.

ATC/BSSC, 1997b, *NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings*, prepared by the Applied Technology Council (ATC-33 project) for the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 274 Report*, Washington, DC.

BSSC, 1988a, *Seismic Considerations – Apartment Buildings*, prepared by the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 152 Report*, Washington, DC.

BSSC, 1988b, *Seismic Considerations – Office Buildings*, prepared by the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 153 Report*, Washington, DC.

BSSC, 1988c, *NEHRP Recommended Provisions for Seismic Regulations for New Building and Other Structures, Part 1 – Provisions*, prepared by the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 152 Report*, Washington, DC.

BSSC, 1990a, *Seismic Considerations – Elementary and Secondary Schools*, prepared by the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 149 Report*, Washington, DC.

BSSC, 1990b, *Seismic Considerations – Health Care Facilities*, prepared by the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 150 Report*, Washington, DC.

BSSC, 1990c, *Seismic Considerations – Hotels and Motels*, prepared by the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 151 Report*, Washington, DC.

BSSC, 1995, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings*, 1994 edition, prepared by the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 222A Report*, Washington, DC.

BSSC, 1998, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, 1997 edition, prepared by the Building Seismic Safety Council, published by the Federal Emergency Management Agency, *FEMA 303 Report*, Washington, DC.

BSSC, 2001, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Part I: Provisions,* and *Part II, Commentary*, 2000 Edition, prepared by the Building Seismic Safety Council, published by the Federal Emergency Management Agency, Publications, *FEMA 368 Report* and *FEMA 369 Report*, Washington, DC.

Benuska, L. (Editor), 1990, *Loma Prieta Earthquake of October 17, 1989: Reconnaissance Report*, Supplement to *Earthquake Spectra*, Volume 6, Earthquake Engineering Research Institute, Oakland, California, 450 pages.

Comartin, C.D. (Editor), 1995, *The Guam Earthquake of August 8, 1993: Reconnaissance Report*, Supplement to *Earthquake Spectra*, Volume 11, Earthquake Engineering Research Institute, Oakland, California, 175 pages.

Comartin, C.D., Greene, M., and Tubbesing, S.K., (Editors), 1995, *The Hyogo-ken Nanbu Earthquake, January 17,1995: Preliminary Reconnaissance Report*, Earthquake Engineering Research Institute, Oakland, California, 116 pages.

Chung, R. (Editor), 1995, *Hokkaido-nansei-oki, Japan, Earthquake of July 12, 1993: Reconnaissance Report*, Supplement to *Earthquake Spectra*, Volume 11, Earthquake Engineering Research Institute, Oakland, California, 166 pages.

Cole, E.E. and Shea, G.H., (Editors), 1991, *Costa Rica Earthquake of April 22, 1991: Reconnaissance Report*, Special Supplement B to *Earthquake*

Spectra, Volume 7, Earthquake Engineering Research Institute, Oakland, California, 170 pages.

EERI, 1985, *Impressions of the Guerrero-Michoacan, Mexico, Earthquake of 19 September 1985: A Preliminary Reconnaissance Report*, Earthquake Engineering Research Institute, published in cooperation with the National Research Council of the National Academy of Sciences, Oakland, California, 36 pages.

EERI, 2000, *Action Plan for Performance-Based Seismic Design*, prepared by the Earthquake Engineering Research Institute, published by the Federal Emergency Management Agency, *FEMA 349 Report*, Washington, DC.

Elsesser, E., 1992, "Structures for Seismic Resistance," *Buildings at Risk : Seismic Design Basics for Practicing Architects*, AIA/ACSA Council on Architectural Research, Washington, DC.

Frankel, A.D., and Leyendecker, E.V., 2000, "Uniform hazard response spectra and seismic hazard curves for the United States: CD-ROM," U.S. Geological Survey, National Seismic Hazard Mapping Project.

Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E., Dickman, N., Hanson, S., and Hopper M., 1996, *National Seismic Hazard Maps: Documentation June 1996*, U.S. Geological Survey, Open-File Report 96-532, 110 p.

Frankel, A.D., Mueller, C.S., Barnhard, T.P., Leyendecker, E.V., Wesson, R.L., Harmsen, S.C., Klein, F.W., Perkins, D.M., Dickman, N.C., Hanson, S.L., and Hopper, M.G., 2000, "USGS national seismic hazard maps," *Earthquake Spectra*, V. 16, No. 1, Earthquake Engineering Research Institute, Oakland, California, pages 1-19.

Hall, J. (Editor), 1995, *Northridge Earthquake of January 17, 1994: Reconnaissance Report*, Vol. I, Supplement to *Earthquake Spectra*, Volume 11, Earthquake Engineering Research Institute, Oakland, California, 523 pages.

Hall, J. (Editor), 1996, *Northridge Earthquake of January 17, 1994: Reconnaissance Report*, Vol. II, Earthquake Engineering Research Institute, Oakland, California, 280 pages.

ICBO, 1997, *Uniform Building Code*, International Conference of Building Officials, Whittier, California.

ICC, 2000, *International Building Code*, International Code Council (formerly: Building Officials and Code Administrators International,

Inc., International Conference of Building Officials, and Southern Building Code Congress International, Inc.), Birmingham, Alabama.

Malley, J.O., Shea, G.H., and Gulkan, P., (Editors), 1993, *Erzincan, Turkey, Earthquake of March 13, 1992: Reconnaissance Report*, Supplement to *Earthquake Spectra,* Volume 9, Earthquake Engineering Research Institute, Oakland, California, 210 pages.

NFPA, 2003, *5000 Building Construction and Safety Code*, National Fire Protection Association, Quincy, Massachusetts.

SAC, 2000a, *Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings*, prepared by the SAC Joint Venture, a partnership of the Structural Engineers Association of California, Applied Technology Council, and California Universities for Research in Earthquake Engineering, published by the Federal Emergency Management Agency, *FEMA 350 Report*, Washington, DC

SAC, 2000b, *Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications*, prepared by the SAC Joint Venture, a partnership of the Structural Engineers Association of California, Applied Technology Council, and California Universities for Research in Earthquake Engineering, published by the Federal Emergency Management Agency, *FEMA 353 Report*, Washington, DC

SBCCI, 1997, *Standard Building Code*, Southern Building Code Congress, International, Birmingham, Alabama.

Schiff, A.J. (Editor), 1991, *Philippines Earthquake of July 16, 1990: Reconnaissance Report*, Special Supplement A to *Earthquake Spectra,* Volume 7, Earthquake Engineering Research Institute, Oakland, California, 150 pages.

SEAOC, 1995, *Vision 2000: Performance-Based Seismic Engineering of Buildings*, Structural Engineers Association of California, Sacramento, California.

SEAOC, 1999, *Recommended Lateral Force Requirements and Commentary*, prepared by the Structural Engineers Association of California, published by the International Conference of Building Officials, Whittier, California.

USACE, 1998, *Seismic Design for Buildings*, U.S. Army Corps of Engineers, Publication TI809-04.

Working Group on California Earthquake Probabilities, 2003, *Earthquake probabilities in the San Francisco Bay region: 2002-2031*, U. S. Geological Survey, Open-file Report 03-214, Menlo Park, California

Wyllie, L.A. and Filson, J.R., (Editors), 1989, *Armenia Earthquake of December 7, 1988: Reconnaissance Report*, Supplement to *Earthquake Spectra,* Volume 5, Earthquake Engineering Research Institute, Oakland, California, 175 pages.

Ziony, J. I. (Editor), 1985, *Evaluating Earthquake Hazards in the Los Angeles Region—An Earth Science Perspective*, U. S. Geological Survey, Professional Paper 1360, Reston, Virginia.

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