5. Nonstructural Risk Reduction for New Buildings

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

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

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

5.1 Program Objectives and Scope

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

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

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

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

Additional Questions for an Architect or Engineer to Consider

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

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

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

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

5.1.1 Voluntary vs Mandatory Risk Reduction

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

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

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

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

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

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

Voluntary Adoption of Enhanced Performance Criteria

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

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

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

5.1.2 Performance-Based Design concepts

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

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

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

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

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

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

5.2 Design Considerations

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

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

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

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

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

5.3 Building code requirements

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

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

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

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

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

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

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

Alternative Methods

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

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

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

The most stringent design provisions are driven by the Component Importance Factor, I_p. Any component with an I_p of 1.5 is considered a "Designated Seismic System" for which special provisions apply. This includes systems required to function for life safety purposes after an earthquake, including sprinkler systems and egress stairways and components used to convey, support or contain toxic, highly toxic, or explosive substances or hazardous materials. Risk Category IV structures are intended to be functional following a Design Earthquake; critical nonstructural components and equipment in such structures that are needed for continued operation following an earthquake are designed with $I_p = 1.5$.

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

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

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

The seismic design forces are based on a variety of factors including the weight of the item, the ground acceleration and soil type, the flexibility of the component and its attachments, the location in the building, and an importance factor. In general, design forces are higher for flexible components and flexible attachments; higher for items anchored in the upper levels of the building; higher for items that contain hazardous materials, that are needed for life safety functions, or that are needed for continued operations of an essential facility; and lower for items with high deformability or high ductility.

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

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

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

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

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

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

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

Exemptions for Nonstructural Components

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

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

5.3.2 *Enforcement of Code Requirements*

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

Plan Review

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

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

Construction Inspection

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

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

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

5.3.3 Requirements for Contents

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

5.3.4 Other Standards and Protocols

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

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

5.3.5 Validation and Refinement of Code Requirements

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

5.4 Responsibility and Project Management

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

Architects, mechanical, electrical and civil or structural engineers, interior designers, landscape architects, construction managers, contractors, specialty subcontractors, equipment manufacturers, vendors, inspectors, testing agencies, plan reviewers, developers, owners, tenants – all these parties may be involved. Coordination of this effort is not a trivial task; the issue of nonstructural seismic risk reduction must be part of the initial planning, so that decisions regarding the structural system, the architectural finishes, the MEP systems, the landscaping immediately adjacent to the building, and the equipment purchases are all made in accordance with a unified plan that is consistent with the performance goals and the project objectives. It may be advisable to assign a dedicated design professional to the oversight of the design and installation of the nonstructural items.

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

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

Potential Issues for Specialized Facilities

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

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

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

5.4.1 Example: Responsibility Matrix

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

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

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

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

MECHANICAL AND PLUMBING EQUIPMENT COMPONENTS
EARTHQUAKE LOAD RESISTANCE

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

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

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

Figure 5.4.2-1 Seismic Code Block worksheet.

ELECTRICAL SYSTEM COMPONENTS
EARTHQUAKE LOAD RESISTANCE

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

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

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

Figure 5.4.2-2 Seismic Code Block worksheet.

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