RESEARCH NEEDS
IDENTIFIED DURING DEVELOPMENT OF THE 2009 *NEHRP RECOMMENDED SEISMIC PROVISIONS FOR NEW BUILDINGS AND OTHER STRUCTURES*

As part of its efforts to regularly update the *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*, the Building Seismic Safety Council (BSSC) is charged by the Federal Emergency Management Agency (FEMA) to identify research needed to advance the state of the art of earthquake-resistant design and to serve as the basis for future refinement of the *Provisions*. During the project to generate the 2009 edition of the *Provisions*, the various working groups identified specific needed research that was beyond the scope of the 2009 *Provisions* update. Please direct any feedback regarding these research issues to: bssc@nibs.org.

DESIGN AND ANALYSIS

Several items related to the design and analysis requirements of the 2009 *Provisions* require fundamental research based on the methodology outlined in *Quantification of Building Seismic Performance Factors*, FEMA P-695. In addition, specific issues requiring attention if defensible changes are to be made in current requirements include system irregularities (both vertical and horizontal), dual frame systems, strong-column/weak-beam requirements for special moment frames, and importance factors for Occupancy Category III and IV structures.

Among the design and analysis issues identified for attention are the following:

1. With FEMA P-695 now complete and benchmarking of the methodology with several existing system types identified in ASCE/SEI 7-05 Table 12.2-1 (including the requirement that $C_d = R$, which has specific consequences), Design Coefficients and Factors for Seismic Force-Resisting Systems, under way, efforts to simplify Table 12.2-1 are warranted. Envisioned is a table that would be more generically based on anticipated level of ductility (ordinary, intermediate, and special) for all material types (i.e., special, intermediate, and ordinary systems would have the same seismic design coefficient factors regardless of material type). Likewise, the need for the system to be dependent on Seismic Design Category and the need for height limits should be reviewed and verified. Finally, the *R* factor basis should be verified (i.e., whether seismic designs are best categorized as "life safety" or "collapse"). Clearly, however, the performance goals of nonstructural systems also need to be considered, refined, and modified as necessary to produce the desired results. The determination of the structural performance goals should be based, at least in part, on

the efforts associated with the development of FEMA P-695 and the results associated with Tasks 1 and 4 of the NIST-funded NEHRP Consultants Joint Venture project.[1]

2. Occupancy Category III and IV structures are assigned importance factors of 1.25 and 1.5, respectively; however, the degree to which use of these factors improves structural and nonstructural performance is not clear. Although this design approach provides for a lower probability of collapse given maximum considered earthquake (MCE) ground shaking at the site for essential facilities relative to ordinary occupancy structures, it is not clear whether the factors are appropriate for the intended functionality of these essential structures. The methodology outlined in FEMA P-695 could be used to evaluate the anticipated performance of Occupancy Category III and IV structures and modifications to the importance factors could be proposed based on the outcome of such a study.

3. The degree to which design requirements in the *Provisions* vary by Seismic Design Category (SDC) is not entirely consistent (e.g., the range associated with SDC D is larger than that associated with the lower SDCs). If SDCs are deemed necessary, a reassessment of the cut-offs between the various SDCs should be conducted, especially in light of the new risk-targeted MCE (i.e., MCE_R) approach to ground motion mapping developed as part of the 2009 *Provisions* update.

4. As currently written, the requirements concerning orthogonality are dependent upon Seismic Design Category but, in some cases, clarification is needed to ensure that these requirements are interpreted properly.

5. Vertical acceleration spectra were developed during the 2009 *Provisions* update, but an in-depth assessment of these spectra should be conducted. Results from this study could be used to determine both vertical acceleration requirements for the ASCE/SEI 7 load combinations (i.e., a critical review of the term $0.2S_{DS}$) and the vertical period appropriate for analysis and design.

6. Needed is review and potential modification of dual frame system requirements and associated design coefficients. This is notably relevant to dual systems with both special and intermediate moment-frame back-up systems. It is not clear whether the design requirements currently prescribed will provide the desired low probability of

---

[1] The Applied Technology Council (ATC) and the Consortium of Universities for Research in Earthquake Engineering (CUREE) have formed the NEHRP Consultants Joint Venture in cooperation with the Mid-America Earthquake (MAE) Center, the Multidisciplinary Center for Earthquake Engineering Research (MCEER), and the Pacific Earthquake Engineering Research (PEER) Center in order to provide resources for conducting earthquake engineering research funded by the National Institute of Standards and Technology (NIST) to support its role in the National Earthquake Hazards Reduction Program (NEHRP).

collapse given MCE_R ground shaking at the site. The methodology outlined in FEMA P-695 could be used to assess these requirements.

7. System irregularity provisions, both horizontal and vertical, include both penalty factors (in the case of excessive torsional response) and prohibitions (in the case of weak-story mechanisms) that have not necessarily been supported on a technical basis. A review of these requirements using the FEMA P-695 methodology could provide insight into more appropriate penalty factors.

8. Research and testing is needed to evaluate a proposed change (Proposal 2-1)[2] not adopted for the 2009 *Provisions*. This proposal focused on the minimum flexural strength of columns in special moment frames (strong-column/weak-beam). One intent of the proposal was to encourage researchers to test the nonlinear response and seismic performance associated with the proposed requirements as well as their effects on the economy of the resulting design.

9. Needed are FEMA P-695 studies of the current structural systems listed in ASCE/SEI 7-05 Table 12.2-1, especially those systems permitted for buildings assigned to Seismic Design Category C. These studies should be for the full range of permitted heights and possible configurations and permitted detailing, not just the worst cases. Of particular importance are ordinary systems and those for which no seismic detailing is required (e.g., ordinary steel concentrically braced frames, ordinary steel moment frames, and steel systems not specifically detailed for seismic resistance). The studies should include appropriate component and system testing to support the analytical evaluations and should provide for appropriate minimum wind loading since member design in the lower SDCs often is controlled by wind forces regardless of the seismic design and detailing requirements.

10. Needed is a robust representative subset of three-dimensional FEMA P-695 studies, including vertical ground motions, to validate the two-dimensional and three-dimensional judgmental factors provided in FEMA P-695. These studies should cover both regular and irregular archetypes, and appropriate component and system testing should be conducted to support the analytical evaluations. Similar studies are needed for:

    a. Nonbuilding structures similar to buildings using system configurations and detailing common used for nonbuilding structures and industrial buildings;

    b. Nonbuilding structures not similar to buildings using system configurations and detailing common to these types of structure (see ASCE/SEI 7-05 Table 15.4-2); and

[2] For a copy of this proposal, please write bmurphy@nibs.org.

c. Stiff-wall/flexible-diaphragm structures including the range of commonly constructed systems to heights of at least 160 feet.

These studies should be conducted using the current limits provided for Seismic Design Categories B, C, and D and for cases where S_{D1} = 0.60, S_{D1} = 0.75, and S_{D1} = 1.25. It is recognized that these values are inconsistent with the current change from deterministic to probabilistic ground motions, but it is important to gain an understanding of current collapse margins considering near-fault minimum design requirements for all structural systems. These studies should consider near-fault ground motion characteristics (including randomness of near-fault effects) and the random orientation of structures relative to causative faults.

11. Although it may not be appropriate for all locations, consideration should be given to the development of fixed boundary maps (different maps for different occupancies) for Seismic Design Categories (SDCs), perhaps based on default Site Class D and jurisdictional boundaries. The SDC for different occupancies then could be determined using the U.S. Geological Survey website based on latitude/longitude.

12. Research is needed to determine whether any changes to the *Provisions* drift analysis requirements are warranted given the adoption of the MCE_R ground motions associated with a 1 percent probability of collapse in 50 years. Additionally, a methodology is needed to incorporate a structure-specific fragility curve in the development of a site-specific probability of collapse.

GEOTECHNICAL CONSIDERATIONS

1. New generation attenuation (NGA) equations for shallow crustal earthquakes in the western United States have been developed, and the U.S. Geological Survey used them to generate the 2008 seismic hazard maps on which the 2009 *Provisions* ground-motion maps are based. A similar NGA project is under way for earthquakes in the eastern United States, and the USGS plans to use those equations in developing maps for the next code development cycle. An NGA project for the subduction-zone earthquakes that govern the hazard in the Pacific Northwest and southern Alaska also is needed. The need for this project was identified during the ATC-35 Ground-Motion Mapping Workshop in December 2006 and two researchers plan to develop such equations; however, these development efforts need to be coordinated and managed so that the resulting equations can be used for updating the ground-motion hazard in these two regions where magnitude M8-9+ earthquakes have occurred roughly every several hundred years. With the NGA updates for the eastern United States and the subduction zones, it will be possible to add a new set of maps for very long period motions so that the T_L maps currently in ASCE/SEI 7 can be removed.

2. The use of the NGA equations for the western United States in generating the 2008 USGS ground-motion maps and the additional ground-motion data recorded since the site coefficient values, F_a and F_v, were originally developed in the early 1990s indicate the need to re-evaluate and update the tables of these values in ASCE/SEI 7. The F_a and F_v tables were originally developed as a result of a coordinated effort involving several funded research studies.

3. Although determination of design and MCE_R spectra was studied by the 2009 *Provisions* Seismic Design Procedures Review Group, additional research is needed due to both the introduction of maps of PGA and the longer periods at which the USGS has now been able to compute hazard results for the western United States. Furthermore, at short periods besides 0.2 seconds, the current design/MCE spectrum can be significantly different from the ground motions the USGS has directly calculated for periods such as 0.1 and 0.3 second. The possibility of using these and other USGS values at additional periods (e.g., 0.5, 2, and perhaps as long as 5 or 10 seconds) requires consideration.

4. It is widely acknowledged that the uniform-hazard shape of the design and maximum considered earthquake spectrum is conceptually not the most appropriate shape for the target spectrum used to select and modify acceleration histories. This issue may have been exacerbated by the introduction of risk-targeted ground motions and the maximum-direction spectral response acceleration. Research is needed to define a more appropriate target spectrum (e.g., a conditional mean spectrum). To a lesser extent, research on more appropriate selection/modification criteria and a better justified number of acceleration histories also may be warranted.

5. The maximum direction ground motion adopted in the 2009 *NEHRP Recommended Seismic Provisions* for seismic design remains a topic of discussion. While the maximum direction ground motion used in the 2009 *Provisions* is converted from the USGS geomean ground motion, some have suggested that future USGS hazard maps might feature ground motion values based on maximum direction rather than geometric mean. To this end, consideration should be given to adjusting attenuation equations to provide maximum direction ground motion values for use in the *Provisions* design maps even though other users likely would continue to require geometric mean ground motion values.

CONCRETE STRUCTURES

1. The current design code for concrete buildings provides detailed provisions for the seismic design of shear walls based primarily on flexural performance considerations. In practice, however, many concrete shear walls have proportions and loading that result in their performance being governed by shear, rather than flexural,

considerations. Requirements for the detailing of shear walls whose behavior is shear controlled need to be developed.

2. The current seismic design requirements for anchoring to concrete are not well validated. The provisions of ACI 318 Appendix D and ASCE/SEI 7-05 need to be unified so that lower strength-reduction factors in the ACI standard are not combined with the increased load factors in ASCE/SEI 7 unless justified by test data and reliability analyses.

3. Design requirements for tilt-up wall systems are based primarily on data for systems with plywood and timber roofs. Many modern tilt-up systems use other roofing systems. Seismic design requirements for the walls of such structures and the anchorage of the walls of such structures to the diaphragms need correlation with the performance of such structures as measured in recent earthquakes.

4. Seismic design requirements for the body of concrete piles are well defined. However, few test data are available and detailed design requirements are needed for the anchorage of piles to pile caps, mats, and other foundation systems.

5. The use of high strength steels (up to 100 ksi) and high strength concretes (up to 20 ksi) in seismic applications should be studied. The current seismic requirements for detailing limit steel strengths to 60 ksi for longitudinal and shear reinforcement. Although no limits currently are placed on concrete strengths for normal weight concrete, there is a paucity of information on response for strengths above 6 ksi.

6. Studies are needed of the seismic performance of lightweight concrete structures with specified concrete strengths greater than the 5 ksi limit currently imposed by ACI 318.

MASONRY STRUCTURES

1. Research is needed to provide for experimental and analytical verification of the hysteretic behavior of:

   a. Masonry shear walls with different aspect ratios, axial loads, and configurations of prescriptive reinforcement;

   b. Steel or concrete frames with concrete block or clay-unit masonry infills; and

   c. Masonry shear walls with confined boundary elements.

2. Needed are seismic design procedures for masonry shear walls with irregular configurations of openings.

STEEL STRUCTURES

1. Studies that have been conducted to determine the seismic performance of staggered truss systems, which are used in areas of lower seismicity for high-rise residential and hotel-type buildings, should be assessed. The studies also should include high wind considerations

2. The use of 65 ksi steels in seismic applications should be studied. The seismic applications and seismic requirements for steel that might not be valid with 65 ksi steel (e.g., slenderness limits, local buckling parameters, flange bracing) should be identified.

3. Research is needed on the seismic capacity of steel ordinary concentrically braced frames and steel ordinary moment frames for a variety of configurations commonly used in buildings and nonbuilding structures designed to reflect the *Provisions* (which are expected to be manifested in ASCE/SEI 7-10 for seismic loads) in conjunction with AISC 341 (for detailing). Relaxation of the height and other limitations of lower ductility systems (e.g., ordinary concentrically braced frames) should be considered. Opportunities for such limit relaxations on nonbuilding structures similar to buildings should be studied, perhaps in the context of a FEMA P-695 analysis.

4. Research is needed on the design of composite metal deck concrete diaphragms supported by steel framing with vertical offsets and openings.

5. Data are needed on the behavior of long encased composite columns under cyclic loads, particularly when high-strength steel or concrete is used. Moreover, data on the importance of the detailing of the transverse reinforcement on the performance of these columns are lacking.

6. For concrete-filled steel tube beam-columns, more accurate axial, flexural, and interaction formulas are needed, particularly with respect to the use of high strength concrete and high performance steel materials. With respect to connections, more detailed design provisions are needed for both braced and unbraced frames to facilitate the design of such systems.

7. Research is needed to determine the influence of partial composite action on the performance of diaphragms. The current values for shear stud strengths have been found to be optimistic and the issue of connector ductility needs to be investigated for cases of low interaction such as those that occur when the studs are used only to transfer the diaphragm shears to the lateral-load-resisting system.

8. Experimental research is needed on steel moment frame systems that use member types different from typical H shapes. Hollow structural sections (HSS) for both beams and columns are used in relatively small buildings and other structures (e.g., walkways and canopies), and different connection configurations should be considered. Results from Japanese research and applications will need to be considered in such studies.

9. Research is needed to establish a method for determining appropriate design forces for columns in multistory braced frames and steel plate shear walls (SPSW) based on linear analysis.

10. Research is needed to develop and validate a design method for special concentrically braced frame (SCBF) columns without lateral bracing at beam levels (e.g., a three-level frame with out-of-plane bracing only at top and bottom).

11. Research is needed to develop and validate a design method for concentrically braced frame (CBF) and eccentrically braced frame (EBF) beams without lateral bracing between columns.

12. Research is needed to establish a method for estimating link and buckling restrained braced frame ductility demands based on linear analysis.

13. An investigation is needed to better understand the performance of unreinforced HSS brace connections detailed to permit significant tension ductility (e.g., long slots in tubes) as an alternative to reinforcement.

14. An investigation is needed to study the effect, if any, of attachments to protected zones such as flanges of shear-governed EBF links, SCBF braces, and SPSW web plates.

15. A comparison is needed of various approaches for establishing building period for design, including parameters such as limit-state stiffness (as used in the direct analysis method) and second-order effects. This comparison should assess building performance and drift prediction.

16. Research is needed to develop a robust nonlinear membrane element for SPSW analysis and design.

17. The design of systems in which energy dissipation is focused in optimized replaceable energy-dissipating fuses should be examined. Ideally, such research will include self-centering capabilities to maximize the value of fuse replacement.

18. System design and detailing procedures are needed for steel and composite structures in low and moderate seismic zones.

19. Strength and ductility for steel anchors subjected to cyclic interaction of tension plus shear requires study.

20. Seismic shear design requirements are needed for concrete filled tubes (CFT).

21. Restructuring is needed for how composite construction is addressed for $R = 3$ systems to be comparable with how steel systems are addressed for $R = 3$ systems.

22. Requirements for column splices in composite moment-resisting frame, braced frame, and wall systems should be refined.

23. Needed is work to support the development of steel and composite prefabricated structural systems that utilize skilled labor in the shop, maximize mass production of modules that are then erected in the field efficiently, and optimize these modules based on design objectives that are broadened to allow optimization on a wide range of issues such as structural safety and serviceability (the current dominant criteria), minimizing fabrication/construction time and costs, minimizing ecological impact of the fabrication process and the structure itself, repairability or partial replaceability of the structure, and application of functionally graded materials (e.g., steel, concrete, composites) for optimized multifunction use (e.g., structural, environmental).

WOOD STRUCTURES

1. Research is needed to determine detailing requirements to achieve intended seismic performance of light-frame shear walls. Resource Paper 11, "Shear Wall Load-Deflection Parameters and Performance Expectations," in Part 3 of the 2009 *Provisions* defines the load deflection parameters and performance expectations for wood structural panel sheathed shear walls with wood or cold-formed steel (CFS) framing in order to guide development of detailing recommendations. A conflict currently exists between the philosophical concept that detailing for overstrength should be provided and the practical observation that much of the testing conducted to date has shown detailing without overstrength provisions to be adequate. Issue-focused research is needed to determine whether current detailing practice can consistently provide adequate performance. The research should consider both wood and CFS framing, the range of wall configurations and sheathing materials permitted under current design standards, and implications for both single-story and multistory walls. Detailing considerations should include both force and deformation.

2. Needed are performance-based seismic design procedures for light-frame buildings that take into account the effect of nonstructural interior and exterior wall finishes. The CUREE and NEESWood projects and FEMA P-695 indicate that finish materials significantly influence the seismic performance of light-frame buildings; however,

meaningful guidance on how to consider these effects in building design is lacking. (See Resource Paper 13, "Light-Frame Wall Systems with Wood Structural Panel Sheathing," in Part 3 of the 2009 *Provisions*, FEMA P-750.)

3. Research is needed to provide definitive guidance to designers on distribution of forces in the design of light-frame buildings. Significant controversy exists concerning whether seismic forces in light-frame buildings should be distributed using flexible or rigid diaphragm assumptions or whether some other solution is needed. General ASCE/SEI 7 provisions require semi-rigid analysis, which is both impractical and impossible for light-frame buildings at this time. Guidance needs to be based on the building performance resulting from practical analysis techniques. Research is needed to quantify performance.

4. Research is needed to assess the performance of and develop design guidance for light-frame hillside construction. The 1994 Northridge earthquake demonstrated the vulnerability of hillside dwellings with several collapses and a number of damaged buildings. Concern has been voiced about both the torsional response of hillside dwellings due to significant differences in stiffness of uphill and downhill walls and the performance of stepped or sloped cripple walls. Outside of the Los Angeles area, however, no design guidance has been provided to structural engineers. As a result, vulnerable dwellings continue to be constructed. Research is needed to quantify at what slope or under what circumstances hillside dwellings become vulnerable and to identify design approaches for reducing that vulnerability.

5. Research is needed to assess the performance of and develop design guidance for open-front light-frame construction. Although significant performance issues were seen with open-front light-frame construction in both the Loma Prieta and Northridge earthquakes, current seismic requirements still permit construction of this building configuration. Research is needed to quantify at what point this configuration becomes vulnerable and to identify design approaches for reducing that vulnerability.

6. Critical review is needed of the seismic design coefficients recommended in Resource Paper 7, "Special Requirements for Seismic Design of Structural Glued Laminated Timber (Glulam) Arch Members and Their Connections in Three-Hinge Arch Systems," in Part 3 of the 2009 *Provisions*. Currently recommended seismic design coefficients are based on calibration with past seismic base shear determined using the 1997 *Uniform Building Code*; however, it is preferred that such coefficients be based on methods defined in FEMA P-695. Full-scale testing of frames and connections is needed as is development of structural models to permit full analysis in accordance with FEMA P-695. Testing of critical frame connections in a manner commensurate with those associated with CFS special bolted moment frames also should be conducted to enable extension of tested and modeled connection behavior to overall frame behavior. Capacity-based design is used in the Resource Paper 7 detailing recommendations. If such a study were pursued, evaluation of the detailing

recommendations would occur and could enable extension of the capacity-based design concept to other wood frames. In addition, conducting an analysis in accordance with FEMA P-695 would provide a sound basis for substantiating seismic design coefficients for this familiar structure type.

7. Quantification of seismic performance and design coefficients also is needed for heavy timber systems such as moment frames and braced frames.

8. Work related to FEMA P-695 studies of *R* factors for shear wall systems is needed to:

   a. Evaluate FEMA P-695 methodologies and results as they relate to seismic coefficients for shear wall structures.

   b. Review issues related to meeting margin of collapse criteria for short period shear wall buildings.

   c. Provide guidelines to users of FEMA P-695 on the various judgments made when attempting to apply the methodology to light-frame shear wall systems. These include consideration of how to characterize model quality, attributes of the archetypical designs as well as the number of them, and guidelines on how to characterize data quality and design method quality. Guidance also is needed for those reporting results of a FEMA P-695 study so that readers understand the important judgments made on all of the above as well as on more detailed aspects of the design basis such that "efficiency."

   d. Identify key variables to address in a "sensitivity" study of methods defined in FEMA P-695 as it pertains to light-frame shear wall systems. This study should document expected results due to changes in system ductility, drift capacity, and overstrength. The results would have many uses including identifying critical aspects of system behavior that contribute significantly to reducing collapse margin ratio as well as providing an authoritative source of information for eventual users and product approval bodies.

9. Use of mid-rise light-frame construction is increasing rapidly in the United States and Canada. For mid-rise light-frame construction, the adequacy of formulas for fundamental period should be evaluated and corrected if necessary and accurate procedures for calculating deflections due to seismic loads should be developed. It is believed that the formulas developed for low-rise construction are not representative for mid-rise construction.

10. Evaluate the effects of soft stories on the performance of light-frame construction and develop design guidance to ensure performance of buildings prone to soft stories.

11. Evaluate cost-effective methods of seismic retrofit for existing buildings with soft and weak first stories.

12. Evaluate performance of light-frame shear walls as a function of the uplift deflection permitted at tie-down devices. Develop criteria for uplift limitations as required to ensure shear wall performance.

13. Evaluate the seismic performance of retrofits for cripple wall and hillside buildings. Consider both the adequacy of currently used retrofit methods and potential new systems for building configurations not addressed by current methods (tall cripple walls, higher load walls, hillside conditions).

14. Provide testing and analysis to further development of capacity-based design procedures for wood and light-frame structures.

NONBUILDING STRUCTURES AND NONSTRUCTURAL COMPONENTS

1. Research is needed to improve the ACI 318 Appendix D requirements for cast-in-place anchors. The testing program needs to be based on reinforced concrete sections typically used in the foundations of nonbuilding structures and use of large diameter anchor bolts (greater than 2 inches in diameter). The goal of the research would be to justify the elimination of anchor reinforcement.

2. Research is needed to determine the vulnerability of nonbuilding structures to vertical ground motions.

3. Research is needed to fully determine the dynamic behavior of a boiler building (large isolated masses suspended from the roof structure) and its support structure using a combined model.

4. Enhanced performance requirements need to be developed for nonbuilding structures used in critical applications where post-earthquake performance is important.

5. There is a need to develop specific seismic requirements for floating floors. These floors can be supported on fiberglass blocks 2 to 4 inches thick and 12 inches on center (where tear-out is a concern) with natural frequencies in the range of 6 to 12 Hz) or on neoprene or natural rubber pads 24 inches on center with natural frequencies in the range of 4 to 12 Hz. Floating floors also can be supported on springs up to 60 inches on center (48 inches is normal) with natural frequencies of 2 to 4 Hz as standard. A floating floor can cover the entire building floor. These floors generally are 4 inches thick but they can be as thick as 12 inches and as thin as 3 inches. Floating floors are used to reduce sound and vibration (e.g., from HVAC and electrical equipment, in areas such as gymnasiums, music rooms, running tracks and

basketball/tennis/racquetball courts, and even in roof slabs for aircraft noise). These floors are very vulnerable to horizontal seismic inputs. The best way to provide seismic protection for these floors is by properly anchored curbs. Guidelines for the design of these seismic curbs are needed. Anchor bolt requirements, resilient curb impact surfaces, internal seismic stops, and uplift conditions when tall heavy equipment is supported on the floor must be addressed. Local slab tear-out is a concern when high CG equipment is attached. More than 200 floating floors are installed in the United States annually, many of which are in high to moderate seismic zones. These floors should not be treated as equipment or nonbuilding structures so a new *Provisions* section may be needed.

6. Research is needed on the seismic capacities (accelerations and relative displacement) of the most common nonstructural components currently found in buildings designed using ASCE 7 seismic loads and detailing. This is a major effort because of the very wide variety of nonstructural components and the lack of research in this area. Damage to nonstructural components accounts for well over half the building damage and downtime caused by recent earthquakes in the United States. This is particularly relevant given the importance of quantifying the behavior of nonstructural components in performance-based seismic design.

7. Improved procedures are needed for determining the demands on nonstructural components considering in-structure motions, component dynamic amplifications, and component inelastic deformations.

8. Mixed structural systems should be investigated to determine the interaction of materials and form. Calculations for structural systems with dissimilar materials are typically simplified to account for the stronger material response and the weaker and often more brittle materials are ignored to allow calculations to be completed in a simple form. However, the stiff weak materials often dictate the displacement patterns and concentrated demands on the designated structural system that result in premature failures. Also, if two structural forms are placed in the same line of action, the current methods dictate that the system with the lower R factor controls and the entire system is designed accordingly. However, the combined system may actually perform more as a composite system and better understanding of this issue would improve the design methods for additions and mixed systems.

9. Although several editions of the *Provisions* have required that the seismic performance of designated seismic systems be certified by the manufacturer, fulfilling this requirement is very problematic. The primary problem is that everything in an essential building is deemed to be a designated seismic system since it has an $I_p = 1.5$, but this is not the intent. Designated seismic systems should have some special attributes that make their superior performance necessary to meet the performance goal of the structure. Needed is a comprehensive approach that will allow a designer, owner, or building official to determine which nonstructural components are actually

required to function to meet the performance objectives of the Seismic Use Group. This might entail development of fault trees for typical nonstructural systems and fragility analysis of common nonstructural components. Only those components that are truly essential and cannot be shown to be sufficiently "robust" should be required to have special seismic qualification testing.

10. The ASCE 7-05 tables for nonstructural systems and equipment have undergone substantial revision. Components are now grouped and classified in a more consistent and rational manner. However, with minor exceptions, the actual design values for the coefficients have not been updated. A similar revision of the table for architectural components and systems should be undertaken. Assuming that the revised table is incorporated into the next edition of the *Provisions*, the design coefficients should be reviewed and modified to more closely reflect the expected behavior of the different components. Consideration should be given to developing design coefficients based on the nature of the component or system. For example, exterior nonstructural wall elements and connections all have the same design coefficients whether they are precast concrete, stucco on metal studs, or an aluminum curtain wall system. Each of these systems performs differently and has different seismic response characteristics.

11. Needed is a literature search that will identify and summarize the extent and type of damage (and lack of damage) to nonbuilding structures with building-like systems in moderate and large earthquakes.

12. Impulsive and convective load distribution in elevated water tanks has become an important topic for the American Waterworks Association standard development committees. Needed is shake table testing and finite element modeling of different tank configurations and styles to correlate the distributions now being assumed with limited background work. A Housner distribution model currently is used and a conservative lower limit is set.

13. There is a need to study the R factor basis for tanks. The study should address cylindrical welded steel, bolted steel, reinforced concrete, prestressed concrete, rectangular concrete, and different base joints used in concrete tanks (fixed, hinged, and free).

14. Needed are improved procedures for determining code-level sloshing heights in large diameter storage tanks.

15. Needed are improved procedures for determining the correct code-level design forces for connections for structures supported by other structures.

16. Needed are improved procedures for determining the proper seismic design forces and detailing for the anchorage of tall vertical vessels where nonlinear behavior occurs primarily in the anchorage.

17. Needed is testing of palletized steel storage racks with typical contents for near-field ground motions to determine the seismic safety of these structures and the adequacy of current content-securing approaches.

MODELING

Regional growth modeling and resilience modeling should be pursued as an offshoot of recent research in GIS-based regional loss modeling for seismic hazards. These modeling efforts should focus on:

1. The resilience of urban regions and their infrastructure (fitting work on seismic hazards with multihazard resilience, resilience against regional economic loss [due to issues beyond structural-related hazards], etc.);

2. Decision strategies for cost-effective infrastructure renewal in seismic zones; and

3. Optimization strategies for cost-effective infrastructure growth within a seismic region, tying all such analyses back to the structural systems used, construction cost, etc.