# FUTURE ISSUES AND RESEARCH NEEDS

IDENTIFIED DURING DEVELOPMENT OF

## THE 2020 NEHRP RECOMMENDED SEISMIC PROVISIONS FOR NEW BUILDINGS AND OTHER STRUCTURES

## (DRAFT)


developed by

National Institute of Building Sciences
Building Seismic Safety Council
Provisions Update Committee


for

the Federal Emergency Management Agency (FEMA)

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The Building Seismic Safety Council (BSSC) was established in 1979 under the auspices of the National Institute of Building Sciences as a forum-based mechanism for dealing with the complex regulatory, technical, social, and economic issues involved in developing and promulgating building earthquake hazard mitigation regulatory provisions that are national in scope. By bringing together in the BSSC all of the needed expertise and all relevant public and private interests, it was believed that issues related to the seismic safety of the built environment could be resolved and jurisdictional problems could be overcome through authoritative guidance and assistance backed by a broad consensus.

The BSSC is an independent, voluntary membership body representing a wide variety of building community interests. Its fundamental purpose is to enhance public safety by providing a national forum that fosters improved seismic safety provisions for use by the building community in the planning, design, construction, regulation, and utilization of buildings. This report was prepared under Contract HSFE60-15-D-0022 between the Federal Emergency Management Agency and the National Institute of Building Sciences.

For further information on Building Seismic Safety Council activities and products, see the Council's website (https://www.nibs.org/page/bssc) or contact Jiqiu (JQ) Yuan at the Building Seismic Safety Council, National Institute of Building Sciences, 1090 Vermont, Avenue, N.W., Suite 700, Washington, D.C. 20005; phone 202-289-7800; fax 202-289-1092; e-mail jyuan@nibs.org.

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# 1. INTRODUCTION

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 and recommend issues to be addressed and 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 2020 edition of the *Provisions*, the various Issue Teams and Study Groups that assisted with the development of proposals for the Provisions Update Committee (PUC) and Member Organization ballots identified specific items that were beyond the scope of the 2020 *Provisions* update. These were assembled and edited by an Oversight Committee led by PUC members Kelly Cobeen and S.K. Ghosh. The resulting list of recommendations is presented in two groups: "Future Provisions Issues" and "Research Needs" for the following categories. In some instances, items presented as future provisions issues will also require research, and items noted as research needs will have implications for future provisions.

NEHRP Chapter 1 - General
ASCE 7 Chapter 11- Seismic Design Criteria
ASCE 7 Chapter 12 - Seismic Design Requirements for Building Structures
ASCE 7 Chapter 13 - Seismic Design Requirements for Nonstructural Components
ASCE 7 Chapter 14 - Material Specific Seismic Design and Detailing Requirements
  14.1 Steel
  14.2 Concrete
  14.4 Masonry
  14.5 Wood
ASCE 7 Chapter 15 - Seismic Design Requirements for Nonbuilding Structures
ASCE 7 Chapter 19 - Soil-Structure Interaction for Seismic Design
ASCE 7 Chapter 20 - Site Classification
ASCE 7 Chapter 21 - Site-Specific Ground Motion Procedures for Seismic Design
ASCE 7 Chapter 22 – Seismic Ground Motion and Long-Period Transition Maps
Quality Assurance Provisions
FEMA P-695 and P-795

The Issue Team and Study Group members who contributed recommendations for each category also are listed. No prioritization is intended by the order of either the recommendations or their categories.

The recommendations herein are intended for review by the broad seismic community. Please direct any feedback regarding these issues and research needs to: Jiqiu (JQ) Yuan, Executive Director of BSSC, at jyuan@nibs.org.

# 2. OVERARCHING ITEMS

The following are recommendations related to future development of the NEHRP Provisions that are general or over-arching:

## 2.1. FUTURE PROVISIONS ISSUES:

1. Outreach and engagement of wider involvement in the code development process. Knowledgeable, experienced practicing professionals have been commenting with increasing frequency over the last few years that the code development process and its outcomes are not serving the community well. This goes beyond the traditional request for the code to be simpler and something that is not obviously broken should not be changed. The Provisions Update Committee (PUC), the Building Seismic Safety Council (BSSC), and the Federal Emergency Management Agency (FEMA) need to think more deeply about how to improve engagement and education so that the code development process targets what the wider community really wants and needs. [Lizundia]
2. The disparity of seismic design results coming from users of ASCE 7 need to be reduced. A nationwide study should be funded for researchers to actively gather feedback on ASCE 7 seismic design provisions from practitioners, code officials, and educators to determine which parts of the provision are most prone to being misinterpreted, misunderstood, misused or where fundamental disagreements with the provisions occur. This is a significant, pervasive complaint. This was one of the most vocal, and widely agreed upon issues brought up in the first meeting of the ASCE 7 Seismic Subcommittee (SSC), and little progress is likely to be made without a comprehensive study. [Gebelein]
3. Cumulative Effects of Current Cycle Changes. Review of cumulative effects of seismic design force changes to determine effects on common structure types and adjust if needed. This study would include the combination of design force changes generated from mapping changes as well as those due to changes in design rules, determine the combined affects, and reconfirm that the combination is consistent with the design intent. [Cobeen]
4. Specific performance objectives and associated design criteria for performance beyond current code. There exists a default performance objective in ASCE 41-17 for new buildings, which is the BPON. When an owner/design team want to go beyond that objective, they currently have little guidance or standard choices. Every project becomes a one-off effort in developing enhanced design strategies. The interest in functional recovery and its potential associated building code provisions may help this, but needed are specific criteria not generalities. For example, if an engineer were to do a damped moment frame, what would be a desirable amount of damping? What provisions should be associated with a better-than-code concrete

shear wall? If there were standardized details or standardized performance levels, this may simplify and incentivize actual implementation and thus improved resilience. [Lizundia]

5. Develop targets for functional recovery, including ground motion levels and desired performance. In order to start the process of introducing something more than the code minimum design provisions for functional recovery, the targets for performance must first be identified. The 2020 NEHRP *Provisions* resource paper titled *Resilience-Based Design and the* NEHRP *Provisions* provides some initial thoughts on how this topic might be pursued. [Cobeen]
6. Functional recovery for utilities and lifelines. In all of the discussion on functional recovery, a key component is missing or overlooked. The lifelines/utilities connecting the community together such as power distribution, water distribution, wastewater removal, transportation (e.g. streets/highways/bridges), and communication systems. If the functions provided by these systems are not maintained or quickly restored, then however resilient our buildings might be, they will be no more than attractive caves after a major seismic or other major environmental event. The longer the functions provided by these systems are down, the greater the misery experienced by the affected population. Therefore, the NEHRP Provisions should be expanded to include these lifeline/utility systems with regard to functional recovery. The expansion needs to consist of the following:

    a. Include power distribution and communication systems in the Provisions. These systems have not been part of the Provisions in the past.
    b. Coordinate/influence codes and standards covering water distribution, wastewater removal, and transportation (e.g. streets/highways/bridges) systems to introduce the concepts of functional recovery.
    c. Develop public policy recommendations (beyond the adoption of a building code) on a local, state, and federal level) on functional recovery.

7. Strategies to spur engineering creativity. There are some who argue that despite the large number of systems currently defined in the building code, there are still too many limitations on what a responsible structural engineer can do. From this point of view, one really just has moment frames, braced frames and shear walls, each of which comes with many prescriptive requirements. How can we encourage creativity and maintain safety, but not trigger a full alternative means of compliance and peer review when something a bit different is desired? [Lizundia]

## 2.2. RESEARCH NEEDS:

1. Testing protocol for development of functional recovery targets and design provisions. In order to move forward to establish performance targets and derived design requirements for

functional recovery, there will need to be both physical testing and numerical modeling, used to judge the viability of targets and the design methods required to achieve them. Numerical studies will be greatly reliant on physical testing and collection of performance data from that testing. Existing testing protocol will need to be revisited and revised with the functional recovery performance objectives in mind. [Cobeen]

# 3. NEHRP PROVISIONS CHAPTER 1 – GENERAL

## 3.1. FUTURE PROVISIONS ISSUES:

1. Risk Category IV structures are designated as essential facilities, such as hospitals or fire stations, that are intended to remain operational in the event of extreme loading. However, the current IBC Table 1613.3.5 treats all Risk Category structures the same for the lowest seismic hazard areas defined by Seismic Design Category (SDC) A. Damaging earthquakes are a possibility even in these low seismic hazard areas. A recent example of this is the Mineral Virginia earthquake which, while not centered in the lowest seismic hazard area, still resulted in damage to SDC A structures. There are no seismic design requirements for Seismic Design Category A. Given the critical post-disaster needs of Risk Category IV structures, the minimal seismic design requirements contained in SDC B would at least provide some level of protection for these critical facilities. For this reason, the following changes should be considered for the next cycle of the Provisions: For short period (0.2 second) response acceleration, $S_{DS}$ < 0.167g and Risk Category IV, Seismic Design Category A should change to B. For one second period response acceleration, $S_{DS}$ < 0.067g and Risk Category IV, Seismic Design Category A should change to B. [Hooper]
2. The *provisions* state that Risk Category IV structures provide protection against loss of essential function in the design earthquake. The current provisions are very qualitative, but there has not been a comprehensive study on what the quantitative target should be. One suggestion was setting a reliability target of a 10% chance of loss of function in the design earthquake. [Pekelnicky]

## 3.2. RESEARCH NEEDS:

1. Investigation of whether the design earthquake is the right hazard intensity to provide loss of function protection for Risk Category IV structures. With the new USGS hazard maps incorporating effects that are magnitude dependent, tying the design earthquake to an explicit ratio of the $MCE_R$ has led the return period of the design earthquake to be around 1,000 year in most of the country. This is much higher than what many engineers believe the hazard to be, around 500 years. A study which applies risk targeting to loss of function to determine what an appropriate absolute risk of function loss should be would help towards making an informed decision. [Pekelnicky]
2. Design of structural systems and their components has explicit reliability targets in the *provisions*. Design of nonstructural components and their anchorage does not. The ATC 120 project showed that demands on nonstructural components are highly variable and subject to

the same ground motion sensitivity and material variability as structural systems. Research is needed to quantify what reliability of failure the current *provisions* is providing, whether that is acceptable or overly conservative, and what the target should be. This will allow for determination of design forces (and possibly a different design earthquake) in a scientific manner, as opposed to the judgement-based method currently employed. [Pekelnicky]

3. Research is needed to evaluate the impact of the $I_e$-factor on design and determine whether it is improving seismic performance, and to what extent [Lehman]
4. There is some evidence that the conditional probabilities of failure of Tables 1.3-2 and 1.3-3, which are based on nonlinear response history analyses, underestimate the safety of code-designed buildings, based on limited data from past earthquakes. Although updating these conditional probabilities is unlikely to significantly change the $MCE_R$ ground motions that are mostly calibrated to previous MCE ground motions, the current probabilities are being used by some to argue that the safety of code-designed buildings is inadequate. Additional research is needed to accurately quantify the conditional probabilities of failure. [Luco]

# 4. ASCE 7 CHAPTER 11 – SEISMIC DESIGN CRITERIA

## 4.1. FUTURE PROVISIONS ISSUES:

1. In developing the 2020 NEHRP Provisions, the current approach of deriving ground motions for design directly from scientific estimates of seismic hazard was reviewed, in light of constantly evolving seismic hazard models and their inherent uncertainties. The importance of stability in the design ground motions was considered, in addition to the appropriateness of the degree of precision (i.e., number of decimal places) required by current design provisions, such as those related to the definition of seismic design categories. No changes were made, except to the precision of the design ground motions themselves. Stability, or at least thorough explanation of changes, will continue to be an important issue. [Luco, Rezaeian, Crouse, Kasali, Stewart]
2. As part of the 2020 NEHRP Provisions, V/H models to predict vertical ground motions have been updated, but they are only applicable to sites in the Western United States. By the time of the next PUC, V/H models are expected to be available for subduction zones and central and eastern portions of the US. Such results could be used to modify the recently updated Section 11.9, which is based on models applicable to tectonically active regions like California. [Stewart, Kasali, Rezaeian, Luco, Crouse]
3. Resource Paper 12: Evaluation of Geologic Hazards and Determination of Seismic Lateral Earth Pressures in Part 3 of the 2009 NEHRP Provisions addresses a number of issues that are not covered in the Provisions and Commentary, including various forms of ground failure (liquefaction, etc.) and seismic earth pressures. Only the seismic lateral pressure issue is addressed in Part 3 of the 2020 NEHRP Provisions. The remaining portions of Resource Paper 12 should be revisited to evaluate the need to provide updated information to the profession. This issue team could survey the state of knowledge, and if needed, draft a new Part 3 paper. [Stewart, Kasali, Luco, Rezaeian, Crouse]
4. The original six Seismic Design Categories (SDCs) were intended to preserve seismic design practices in different regions of the U.S. Since there have been few significant earthquakes in regions of low seismicity, the parsing of seismic design criteria between high seismic design categories and lower ones was based on engineering judgment, influenced by historic practice in different regions. In some cases, such as height limits for structural systems assigned to various SDCs, the requirements were and continue to be quite arbitrary. The differences in requirements between the various Seismic Design Categories are often not that significant. In

the 2015 NEHRP Provisions, the difference in design criteria between SDC B and C are not that great; for SDCs D through F, the only differences consist of somewhat arbitrary height limits and system exclusions. During the 2020 PUC cycle, the possibility of simplifying Seismic Design Categories was studied, and two proposals were considered. The first proposal would have replaced the original six Seismic Design Categories (A through F) with 3 Categories: low, medium and high, generally grouping the requirements for categories D through F in the High Category and preserving those for C in the Moderate Category. While the concept of simplifying the Seismic Design Categories had broad support in the PUC, a consensus on a method for determining the boundaries between the low and medium categories could not be reached. A less ambitious editorial proposal to consolidate Seismic Design Categories D, E and F into a single SDC D was prepared. This proposal was hoped to provide a platform for simplifying the Seismic Design Categories and facilitate review of the various system-specific restrictions. It was approved by the PUC. However, the proposal was withdrawn based on reservations voiced by some member organizations about adopting an editorial proposal that made sweeping changes to the nomenclature used to categorize structures requiring seismic design. The need to revise Seismic Design Categories has become more pressing. SDC E and F are assigned for structures located on sites where the 1-s period, $S_{1,}$ is greater than or equal to 0.75. Changes made to Chapter 11 in the 2020 NEHRP *Provisions* including multi-period $MCE_R$ response spectra and revision of the site classes have resulted in sites where $S_1$ exceeds 0.75 that are not near-field. It is unclear whether the current requirements for SDC E and F are appropriate at sites that are not near-field. [Gillengerten]

## 4.2. RESEARCH NEEDS:

1. The Project 17 Planning Committee identified damping levels (other than the conventional 5%) as an important issue, albeit outside of the limited number of priorities for the 2020 NEHRP Provisions. Ground motion models for different damping levels are, in effect, available and could be incorporated into the USGS National Seismic Hazard Model with additional research. [Rezaeian, Luco, Crouse, Kasali, Stewart]
2. In the 2020 NEHRP Provisions, Chapter 11 makes use of multi-period response spectra computed by the USGS for eight site classes defined in Chapter 20 (with Vs30 values specified by Project '17) but does not explicitly allow for user-specified Vs30 values, except through site-specific analysis. Research is needed to explore potential benefits of allowing continuous Vs30 values in addition to (or in place of) discrete site classes, as done in the latest Canadian code, with due consideration of Vs30 uncertainties. [Luco, Rezaeian]

# 5. ASCE 7 CHAPTER 12 – SEISMIC DESIGN REQUIREMENTS FOR BUILDING STRUCTURES

## *5.1.* FUTURE PROVISIONS ISSUES: [WHY DOES THE NUMBERING START WITH 5?]

1. Design guidance on rocking structures. Design guidance is needed across construction materials for structures specifically designed to rock. These are currently being designed on a case by case basis, but there should be enough information available from designs to date to set basic design guidance. [ Malley]
2. Work is needed to account for rocking in foundation design as a means of limiting force input into a building. [Kasali, Luco, Rezeaian, Crouse, Stewart]
3. Integration of foundation and superstructure design. Right now, one can design a lateral system with the presumption it will yield and dissipate energy in a certain way with no regard for what the foundation will do and whether it will yield first or prevent the intended mechanism from occurring. Some AHJs (like OSHPD) require the foundation to develop the superstructure, but this may not be practical or desirable in some cases. Can provisions be developed that look more holistically at how the entire structure will and should behave? [Lizundia]
4. Past analytical studies suggest that the collapse probability of short-period buildings is significantly larger than that of buildings with longer periods and in some cases exceeds the ASCE 7 collapse safety objective of 10% given $MCE_R$ ground motions. Observations of short-period building damage in recent earthquakes do not support this finding. Research is currently underway in the Applied Technology Council (ATC) ATC-116 Project to investigate and resolve the short-period building "paradox" and to develop recommended improvements to short-period building design requirements, if justified. The research results should be reviewed and incorporated into the *Provisions* as appropriate. Clarification of what constitutes a short-period structure should be provided as part of this effort. It is recommended that as a minimum discussion of the results of the ATC-116 project be brought into the *Provisions* commentary. [Hooper]
5. With the addition of the rigid wall-flexible diaphragm design method in the 2020 NEHRP Provisions, there are now three methods for derivation of seismic design forces for diaphragms. Combining of the alternative design methods into a single method should be investigated. [IT9]
6. With the recent addition of two methods for determining design seismic forces for diaphragms based on diaphragm ductility and displacement capacity, the potential future removal of the basic method in Section 12.10.1 and 12.10.2 should be considered, because it does not take diaphragm properties into consideration. Additional development of diaphragm design force

reduction factors, overstrength factors and deflection amplification factors may be required prior to removal of Section 12.101. and 12.10.2 provisions. [IT9]

7. During the 2020 NEHRP *Provisions* update cycle, provisions for special seismic detailing of bare steel deck diaphragms were introduced simultaneously in IT9 proposals to PUC and AISI standard committee proposals. These provisions were adopted as mandatory in the IT9 proposals for Section 12.10.3 alternative diaphragm design provisions and Section 12.10.4 rigid wall-flexible diaphragm provisions. IT9 delayed similar mandatory application to the diaphragm design method in Sections 12.10.1 and 12.10.2 because research was still underway at that time. Consideration should be given to making the special seismic detailing provisions mandatory when using Section 12.10.1 and 12.10.2. [IT9]
8. At the end of the 2020 update cycle, research regarding $R_s$ factors for concrete topped metal deck diaphragms had not yet been completed. Available information was included in a NEHRP Provisions Part 3 Resource Paper. During the next update cycle, the $R_s$ factors for these diaphragms should be brought into the NEHRP Provisions. Include other materials if design parameters are being developed that draw from the IT9-8 resource paper. [IT9]
9. Diaphragm Deflection Calculations. Design guidance is needed for appropriate calculation, amplification, and combination of diaphragm deflections, paralleling the provisions already available for vertical systems. This will draw from the IT9-10 Resource Paper "Calculation of Diaphragm Deflections Under Seismic Loading." Also look at Lawson papers addressing calculation of deflection for wood systems and some of the implications for period, force and deflection prediction. Possible upper and lower bounds on deflections should be considered. Review use of diaphragm deflections in various Chapter 12 provisions for consistency. [IT9]
10. $R$ vs. $R_s$ Interaction. During the course of the 2020 NEHRP update, Ben Schafer and Matt Eatherton and other colleagues have been investigating the interaction between ductility provided in the vertical elements and that available in the horizontal components of the seismic force-resisting system. What are the performance consequences of design choices - ductility in vertical versus horizontal system? (Publications from Schafer and Eatherton should be available as a starting point). It should be determined whether there are any limits required on combinations of vertical and horizontal system ductility. [IT9]
11. Flexible diaphragm building period. Evaluate whether it is of benefit to develop a code formula for period for structures with flexible diaphragm to allow design engineers to better estimate force level before applying an $R$-factor. This is already implemented in the Canadian code. Might need limited numerical studies. [IT9]
12. Develop initial design provisions based on selected functional recovery targets. Once performance targets are identified, design provisions that are thought to achieve the targets can be developed. While developing the design provisions will be a long-term activity, initial

work should be undertaken if possible. The 2020 NEHRP Provisions resource paper titled *Resilience-Based Design and the* NEHRP *Provisions* provides some initial thoughts on how this topic might be pursued. [Cobeen]

13. There are identified needs in high seismic areas to have structures designed for strength rather than ductility. This is the subject of a proposal in ASCE 7 seismic subcommittee for miscellaneous structures of small footprint. An effort is needed to identify vertical systems for which this an acceptable approach, and the design approaches for diaphragms and nonstructural components that are needed to address the anticipated increase in seismic demand. [Cobeen]
14. The following set of questions has been identified during discussion at the ASCE 7 seismic subcommittee meetings. These reflect an expanding use of the two-stage analysis procedure for larger buildings and for a wider variety of building systems. Systematic consideration of these issues relative to the Chapter 12 provisions is needed.

    a. Where is the structural height (Table 12.2-1) of the upper portion measured from? Are there any instances where it would not be acceptable to allow the full tabulated building height for both the upper and lower structure?
    b. How are the stiffnesses of the upper and lower portion measured? Story stiffness or full portion stiffness?
    c. Is use of this analysis procedure expanding to systems and combinations of systems not used in the past? Does this create concerns that need to be studied?
    d. When such seismic force resisting systems are used, can the lower portion use an $R$ for design lower than the $R$ of the upper system?
    e. What dynamic interaction of lower portion and upper portion is likely to occur, and does the two-stage procedure adequately capture resulting demands?
    f. When designing for podium diaphragm transfer forces, is it necessary to combine the ratios of $R$ and $\rho$ and the $\Omega_0$ for diaphragm transfer forces (added in ASCE 7-16)?
    g. When designing the vertical force load path under discontinued vertical elements (shear walls discontinued at the podium level, etc.), is it necessary to combine the ratios of $R$ and $\rho$ and the $\Omega_0$?
    h. Is it necessary to use semi-rigid modeling of the podium diaphragm per Section 12.3.1.2 (Rigid Diaphragm Condition) due to out-of-plane offset irregularity?
    i. Wood structures on podiums often use open-front systems. SDPWS now requires use of rigid or semi-rigid diaphragm modeling for this configuration. Confirm that the reduction of omega-not, permitted for structures with flexible diaphragms by footnote

b to Table 12.2-1, can no longer be used. ASCE 7 permits diaphragm idealization as flexible based on Section 12.3.1.3 calculated method.

j. SDPWS and IBC permit diaphragm designation as rigid based on inverse calculation. Should SDPWS criteria for rigid designation be brought into ASCE 7? Is there need to study these criteria? Is there need to designate circumstances when semi-rigid is required (beyond current irregularity trigger)?

k. Requirements for Two-stage Analysis Procedure: ASCE 7-16 in Section 12.2.3.2 allows podium type buildings to be designed with a two-stage analysis procedure provided.

    i. Stiffness of the lower portion is at least 10 times the stiffness of the upper portion.
    ii. Period of the entire structure is not greater than 1.1 times the period of the upper portion considered as a separate structure supported at the transition from the lower to the top structure.

    ASCE 7-16 is not explicit about ways in which the stiffness of the two structures are computed. For a multistory structure, this can be interpreted as global stiffness, story stiffness etc. Additionally, for wood framed podium structures, engineers typically do not model the upper portion in an analysis program. Thus, it is not clear how period or stiffness for wood framed buildings are to be computed. This study will aim at producing consolidated recommendations for Two Stage Analysis especially for wood framed buildings over concrete podium. [IT3, Cobeen]

15. Further Study on Investigation of Triggers for MRSA: A resource Paper authored by BSSC Issue Team 3 has concluded that the requirements for MRSA can be substantially relaxed from what is currently required by ASCE 7-16 in Table 12.6-1. However, a more exhaustive evaluation needs to be conducted especially for buildings with significant horizontal irregularity so that the use of the Equivalent Lateral Force procedure (ELF) can be extended further. [IT3]
16. Investigation of Explicit Triggers for Vertical Ground Motion Analysis: ASCE 7-16 in Section 12.4.2.2 requires that vertical ground motion effects be included through the use of $E_v$ (=$0.2S_{DS}D$). This is generally adequate for normal building structures as they are inherently stiff in the vertical direction. Additionally, the use of 1.2 Dead + 1.6 Live load combination for the gravity case provides a margin of safety for the seismic load cases since the live load is typically halved in the latter. However, this may not be the case for long span flexible structures where the incorporation of vertical seismic ground motion can add significant demands to the structural elements. There is a need for identifying buildings and setting triggers where vertical

direction analysis (through MRSA or Time History Analysis) needs to be explicitly conducted so that such structures are not under-designed. [IT3]

17. Requirement for Foundations of Risk Category IV Buildings to be designed for Overstrength Load Combinations: Per ASCE 7-16, Risk Category IV buildings are currently designed for $Ie$ = 1.5 with no requirement for foundations be designed for Overstrength Load Combination. Chapters A of the 2019 California Building Code overwrites the minimum requirements of ASCE 7-16 requiring foundations for hospitals to be designed for Overstrength Load Combination. This study will investigate whether it is appropriate for foundations of Risk Category IV buildings be continued to be designed for non- $\Omega_o$ forces. If $\Omega_o$ forces are indeed necessary, then is their application necessary for all actions or could they be limited to critical force-controlled actions such as shear and relaxed for ductile actions such as flexure? [IT3]
18. Requirements for Analysis and Modeling for Buildings with Subterranean Levels: There is currently no explicit requirements for modeling and analysis of buildings with subterranean levels. The typical practice is to use the height of the building from the ground level (assumed as the Base) in the calculation of the approximate period per Equation (12.8-7), although 11.2 defines $h_n$ as the height from the base (defined as the level in which the seismic ground motions are imparted into the system). Basements, when not assumed as a rigid substructure, are often modeled in three-dimensional computer models as massless entities with only stiffness represented. There is a need for setting requirements for subterranean elements including proper earth pressures (at rest under no earthquake, active plus seismic increment under earthquake) to be used for their design. [IT3]
19. Evaluate further limitation of the reduction of overturning moment at the foundation to soil interface allowed by ASCE Section 12.13.4. This reduction in overturning moment is not consistent with the understood overstrength of the vertical elements of the SFRS and should be limited to use on systems where the R-factor is less than five. This is based on a change proposal submitted by a member of the public to ASCE 7 [Howard Hill].

## 5.2. RESEARCH NEEDS:

1. Envisioned is a simplification of ASCE/SEI 7-10 Table 12.2-1 that would be more generically based on an anticipated level of ductility (ordinary, intermediate, and special) for all material types. For example, 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 would be verified, e.g., to determine whether seismic design objectives are best categorized as "life safety" or "collapse prevention". FEMA P-695 and NIST GCD 12-917-20 provide tools for use in verification. The performance goals of nonstructural

systems also need to be considered, refined, and modified as necessary to produce the desired simplification. The determination of structural performance goals should be based, at least in part, on these research efforts. [Hooper]

2. Expanding on the ATC-123 project, further research is needed to see if soft story requirements can be eliminated. Research is needed to see if current provisions go far enough in penalizing weak stories, such that probabilities of collapse are similar to buildings without weak stories. Structures that can form story mechanisms were not directly considered as part of the original ATC-123 study, and should be included in a follow-on effort. IT-2 envisions using a system independent process to directly study the degree of "weakness" and modify the code triggers accordingly. [Hohener, IT2]
3. Introducing Height Limits for Moment Frames and Dual Systems Solely Proportioned with Linear Analysis in SDC D and above – during the 2018 Cycle, IT-2 explored the possibility of modifying the high limits within Table 12.2-1. Specifically, IT-2 considered following the example of the City of Seattle and adopting the 240-foot height limit on Moment Frames and Dual Systems. While there is certainly anecdotal evidence of linear designs being insufficient for the design of tall buildings, there has not been a major research effort devoted exclusively to the subject. Consequently, there was not the analytical support required to adopt this change during this cycle. Given that many major coastal jurisdictions are considering adopting policies similar to the City of Seattle, we recommend funding and implementing a research effort devoted to determining whether or not non-linear analysis for structures above 240-feet is necessary to proportion designs that meet the performance objective of the standard. [Hoehner, IT2]
4. Harmonization of Torsional Amplification Factor between ASCE 7-16 and PEER TBI: Currently the trigger for identifying torsional irregularity in ASCE 7 is based on the calculation of a torsional amplification factor $A_x$ defined as the ratio of the maximum story drift at the two ends of the structure divided by the average story drift. Guidance documents, such as the PEER TBI, set the requirement for inclusion of accidental torsion through the use of a torsional index $A_x$* defined as the ratio of maximum displacement at any level including effects of inherent plus accidental torsion divided by the maximum displacement using inherent torsion only. This study will harmonize the requirements between the two requirements taking into account the recommendations of ATC 123. [IT3]
5. Research is needed to set criteria for determining required deformation capacity of systems not part of the SFRS, and to set deformation capacity requirements when such systems are considered to contribute post-peak residual capacity to the overall structure. [Lehman]
6. Duration and energy-based design. These topics have long been brought up, but little has been done. Is it time to think about whether the duration of shaking matters? Are there limits

on the amount of energy that can/should be dissipated? Are there any practical techniques that can be implemented or developed? [Lizundia]

7. Recent research activities on short- and long-period buildings have identified that the approximate period relationship in ASCE 7, Section 12.8.2 needs to be revisited. First, some structural systems have data to support their derivation and for locations in specific regions of the U.S., while others have been continued through the years without specific technical support or locality adjustment. Research is required to address the approximate period relationship for systems other than steel or concrete moment frames and concrete or masonry structural walls, as well as regional adjustments. Second, a review of the buildings used to derive the approximate period relationships has indicated that they were not designed using an importance factor, $I_e$ (i.e., assigned to current Risk Category III or IV). Therefore, the influence of the importance factor on the approximate period has not been quantified nor addressed in design. Research should advance the approximate period formulation by explicitly including vibration characteristics of buildings designed with an importance and/or redundancy factor or by an implicit approach. The effects of capacity design and other design provisions implemented after UBC 1994 on the design period can also be explored. [Harris (Jay)]
8. Deformation Compatibility of Components Not Part of the Seismic Force-Resisting System. The ATC-116 Project analytical studies have identified that drift ratios experienced by short-period archetypes (1-story, 2-story and 4-story light-frame wood, steel special concentrically braced frame, and reinforced masonry shear wall) prior to collapse can be significantly larger than those currently used for ASCE 7 checks of deformation compatibility for components not part of the seismic force-resisting system. This is of possible concern because the collapse probabilities determined by the ATC-116 project, which generally achieve the 10 percent collapse safety objective of ASCE/SEI 7 for high seismic criteria (i.e., $S_{MS}$ = 1.5g), are only valid if the gravity system can maintain gravity load out to the drift at incipient collapse. Otherwise they are overly optimistic. A study is recommended to determine whether current ASCE/SEI 7 provisions for deformation compatibility checks are adequate given the new drift information available from this project. [ATC-116]
9. Very High Seismic Collapse Potential. The ATC-116 Project analytical studies of collapse probabilities of 2-story and 4-story archetypes of light-frame wood and steel special concentrically braced frame buildings designed and evaluated for very high seismic loads (i.e., $S_{MS}$ = 2.25g) exceed the 10 percent collapse safety objective of ASCE/SEI 7 for Risk Category II structures, often by a substantial amount. Collapse performance for all studied archetypes (including 1-story buildings, as well as reinforced masonry shear walls buildings) is substantially worse for an archetype designed and evaluated for very high seismic criteria as compared to the same archetype designed and evaluated for high seismic criteria (i.e., $S_{MS}$ = 1.5g). This

trend is due largely to the influence of nonstructural wall finishes on strength of wood buildings, which is not in proportion to seismic design loads (i.e., with an increase in seismic design loads, structural walls are proportionally stronger while nonstructural walls remain the same). For other reasons, an increase in the probability of collapse given $MCE_R$ ground motions was observed in the ATC-116 short-period building studies of steel concentrically braced frame buildings and reinforced masonry shear wall buildings, as well as in the prior collapse analyses of reinforced concrete buildings (i.e., see Appendix A of FEMA P-695). A study is recommended to quantify the potential increase in the conditional probability of collapse given $MCE_R$ ground motions (i.e., above the 10 percent target of ASCE/SEI -7 for Risk Category II structures) and the associated increase in collapse risk (i.e., annual probability of collapse) of building archetypes of common seismic force-resisting systems for sites located in very high seismic regions. [ATC-116]

10. Redundancy Factor: The ATC-116 Project analytical study of redundancy for a 2-story steel SCBF archetype found that the redundancy design requirements of Section 12.3.4 of ASCE/SEI 7-10 (and ASCE/SEI 7-16) do not affect comparable collapse performance of a "non-redundant" steel SCBF building designed for seismic loads factored by the redundancy factor, $\boldsymbol{\rho}$ = 1.3, with a "redundant" steel SCBF building designed for un-factored seismic loads (i.e., rho = 1.0). Contrary to the intent of the design requirements, the strength of the "non-redundant" steel SCBF archetype was less than that of the "redundant" steel SCBF archetype, which adversely affected collapse performance. Further study is recommended to determine if there might be a collapse safety issue for steel SCBF buildings due to potential short comings of current redundancy requirements and, if so, to develop appropriate code changes to remedy the potential collapse safety deficiency. [ATC-116]
11. Risk Category III and IV structures are assigned importance factors of 1.25 and 1.5, respectively. This design approach provides for a lower probability of collapse, given risk-targeted, maximum considered earthquake ($MCE_R$) ground shaking at the site, for critical and essential facilities relative to ordinary structures. Yet, it is not clear whether the factors are appropriate for the intended functionality of these structures. Resource Paper 5: New Performance Basis for the *Provisions* in Volume II: Part 3 of the 2015 NEHRP *Provisions* outlines a potential framework for defining and implementing functionality. This work needs to be taken to a conclusion. Consideration might also be given to the following: 1) Splitting Risk Category III and IV buildings to allow development of separate performance objectives and design requirements; 2) Determining whether nonstructural scoping and exceptions by SDC are appropriate for nonstructural components. (Currently, many nonstructural considerations are waived for RC II and RC III, with no difference existing between the two RC's.); 3) Determining whether drift limits are more appropriately specified by the RC or the SDC; and, 4) Working out

the probability of collapse in a more useful way before asserting that RC III or IV reduces the 1% in 50 years probability to some other arbitrary level. Even if it is the best metric, the probability of collapse is not uniform at 1% in 50 years in places where it matters most, such as in Coastal California or anywhere in the deterministic parts of the map. [Hooper]

12. Review and potential modifications of dual system requirements and associated design coefficients are needed. 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 collapse given $MCE_R$ ground shaking at the site. The methodology outlined in FEMA P-695 could be used to assess these requirements. Similar consideration could be given to vertical combinations of systems in buildings, including, but not limited to, podium slab buildings. [Hooper]
13. FEMA P-695 studies are needed to address the current structural systems listed in ASCE/SEI 7-10 Table 12.2-1, especially those systems permitted for buildings assigned to Seismic Design Category C. These studies should cover 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), with the objective of verifying that performance objectives are being met for these systems as currently designed (not with the addition of detailing requirements). The studies should include appropriate component and system testing to support the analytical evaluations. [Hooper]
14. Research is needed to determine whether any changes to the *Provisions* drift analysis requirements of the *Provisions* are warranted given the adoption of the $MCE_R$ ground motions associated with a 1% probability of collapse in 50 years. This is especially important for drift-controlled systems such as steel and concrete moment frames. In addition, a review is needed to determine whether scaling to $R/C_d$ is correct for drift determination. The $C_d$ values need to be revisited. [Hooper]
15. The minimum base shear requirements control the design of many tall buildings and are based on historic precedents with limited verification. A future study would be useful to further investigate the minimum base shear requirements, and how they relate to the collapse safety goals of ASCE/SEI 7 for various structural systems. Such a study also could utilize recent earthquake data to revisit the near-source basis of ASCE/SEI 7-10 Equation 12.8-6. [Hooper]
16. The current orthogonal load requirements for elements of non-planar frames and walls do not adequately address potential bi-directional post-yield response. Research is needed to determine the appropriate level of post-yield response for the following cases:

- Strong-column/weak-beam requirements for special moment frames;
- Axial forces on braced-frame columns; and
- Flange forces in walls. [Hooper]

17. Research is needed to evaluate and improve the accuracy of parameter $C_d$ in estimating expected drift. During the 2020 NEHRP Update there was extensive discussion of whether it was appropriate to set $C_d$ equal to $R$. In the end it was decided that there is not currently sufficient information to determine for what systems $C_d$ should be changed. The discussion and issues were documented in a Part 3 Resource Paper entitled "Seismic Design Story Drift Provisions: Current Questions and Needed Studies." Research is needed to gather available experimental and analytical study building drift information and compare these to the estimates of building drift generated in accordance with Chapter 12 provisions and the applicable material design standards. See the Resource Paper for details of the recommended research. [Cobeen, Lehman]
18. Research is needed in support of developing functional recovery design provisions. As functional recovery design targets are developed, research will be necessary to identify design provisions required to meet the functional recovery targets.

# 6. ASCE 7 CHAPTER 13 – SEISMIC DESIGN REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS

During the development of the 2020 NEHRP Provisions, significant revisions were made to the nonstructural seismic design force equations, based on equations and underlying research developed in the Applied Technology Council ATC-120 project. The ATC-120 project resulted in NIST GCR 17-917-44 Seismic Analysis, Design, and Installation of Nonstructural Components and Systems – Background and Recommendations for Future Work (NIST, 2017) and NIST GCR 18-917-43 Recommendations for Improved Seismic Performance of Nonstructural Components (NIST, 2018), which are included as references to the proposal.

The goal of the ATC-120 effort was to develop equations that have a more rigorous scientific basis and that capture the key parameters that influence nonstructural component response, and yet remain appropriate for use in design by practicing engineers. While many factors contribute to this condition, NIST (2018) identified the influence of the supporting structure on component response to be a very significant factor, and it is not considered in design procedures then in use. It was noted that given an input ground motion and dynamic response characteristic for a specific structure, the distribution of peak floor acceleration demands along the height of structures is significantly influenced by:

a. Modal periods, especially the initial fundamental period of vibration, of the supporting structure;

b. The type of lateral load resisting system or the lateral stiffness ratio (a parameter that quantifies the degree of participation of the global flexural and global shear deformations of the structure, and hence, defines the shape of lateral response) of the supporting structure; and

c. The level of inelastic behavior of the supporting structure.

The revisions to the nonstructural component lateral force procedures adopted in the 2020 NEHRP Provisions now account for the influence of the supporting building or nonbuilding structure on the seismic demands experienced by the component. However, the properties of the nonstructural component itself, component ductility and likelihood of being in resonance with the supporting structure, continue to be determined chiefly using engineering judgement, backed by limited analysis and testing, a process followed in all prior editions of the NEHRP Provisions.

## 6.1. FUTURE PROVISIONS ISSUES:

1. A more rigorous basis for determining the design coefficients for the component resonance ductility factor, CAR, the component strength factor, $R_{po}$, and anchorage overstrength factor $\Omega_{0p}$. [Gillengerten]
2. Displacement demands for nonstructural components and systems should be reviewed. In the current Provisions, drift-controlled components are required to "accommodate" story drift, but there is little guidance on the meaning of this term. For example, how much inelastic behavior (damage) to the component is acceptable? Performance requirements for essential (Risk Category IV) versus other types of structure also should be studied. [Gillengerten]
3. Design requirements for piping systems should be reviewed, including studying nozzle loads, and reconciling mechanical and structural design requirements. $R_p$ values for piping systems (e.g., ASME B31 and ASCE/SEI 7-16) should also be reviewed. [Gillengerten]
4. Provisions should be further developed to address 1) Potential adverse interactions between nonstructural components and other portions of the structure; 2) Determination of generic relative displacement between points of attachment for distributed systems such as piping, and 3) Enhancement, as necessary, of requirements to preclude inadvertent sprinkler activation and/or wet system pipe rupture during earthquakes. [Gillengerten]
5. Available records for shake table testing of nonstructural components and systems should be examined and recommendations developed to improve design based on the tests. [Gillengerten]
6. Performance expectations should be developed for nonstructural components at several levels of earthquake motion. Performance levels provided by the current Provisions at different shaking intensities should be assessed to determine whether changes are needed to meet performance objectives. [Gillengerten]
7. Design of structural systems and their components have explicit reliability targets in the provisions. Nonstructural components and their anchorage do not. The ATC 120 project showed that demands on nonstructural components are highly variable and subject to the same ground motion sensitivity and material variability as structural systems. Research is needed to quantify what the reliability of failure the current provisions are providing, whether that is acceptable or overly conservative, and what the target is. This will allow for determination of design forces (and possibly a different design earthquake) in a scientific manner, as opposed to the current judgement-based method currently employed. [Pekelnicky]

## 6.2. RESEARCH NEEDS:

1. Experimental investigation of content falling hazard posed by palletized rack systems, such as those found in big-box stores, should be conducted. [Soules, Carrato, IT6]
2. Recent instrumented building records from strong earthquakes should be examined for a comparison of recorded nonstructural component response to response predicted by the Provisions. [Soules, Carrato, IT6]
3. Provisions for preservation of means of egress, including requirements for doors and ceilings, should be established, which might involve studying the response of exit components, such as doors to transient and residual story drift, and development of egress system components that will remain operable following a strong earthquake, while meeting fire protection and security requirements. [Gillengerten]
4. Research is needed on the performance during seismic events of large-bore (diameter) piping systems used in industrial facilities to connect various structures. Large-bore piping systems common in refineries and chemical plants are currently treated as nonstructural components. But, such systems have significant stiffness and behave as structural systems spanning between adjacent structures. A study should include the interaction between these piping systems and the structures to which they are connected. [Gillengerten]
5. Overstrength and displacement demand requirements for anchorage should be reviewed, including anchorage response/degradation that might be much more influential than the component response itself. This is necessary to create rational seismic cyclic testing requirements and consistent simplified nonstructural equations for relative displacement demands. [Gillengerten]

# 7. ASCE 7 CHAPTER 14 – MATERIAL SPECIFIC SEISMIC DESIGN AND DETAILING REQUIREMENTS

## 7.1. STEEL

### 7.1.1. Future Provisions Issues:

### 7.1.2. Research Needs:

1. Design for Rocking Response of Braced Frames on a Flexible Foundation. The ATC-116 Project analytical study of foundation flexibility and SSI effects on 2-story and 4-story archetypes found collapse performance of steel SCBF building archetypes to be governed by large lateral displacements due to rocking of braced frames on flexible foundations (i.e., where rocking occurs before braced frames reach their strength capacity). Observed rocking response behavior was not found to adversely affect collapse performance for the limited number of steel SCBF archetypes investigated in this study, but it represents an entirely different collapse failure mode from that due to brace failure, the failure mode assumed by seismic design codes and standards that develop seismic loads and design requirements for steel SCBF buildings. Further study is recommended to first determine if there might be a collapse safety issue due to rocking (i.e., identify steel SCBF configurations, if any, for which collapse performance could be made worse due to rocking) and if so, develop appropriate code changes to remedy the potential collapse safety deficiency. Second, it is recommended that additional study investigate and determine feasible code changes that would explicitly incorporate rocking response in the design of the steel SCBF buildings. New design methods for rocking response would likely need to apply to all seismic force resisting systems, not just steel SCBFs. [ATC-116] [Editorial note: While this topic was identified for SCBF systems by the ATC116 project, the same behavior is potentially applicable to a number of SFRSs and materials.]

## 7.2. CONCRETE

### 7.2.1. Future Provisions Issues:

1. Shear friction capacity for reinforcement grades higher than Grade 60. [Taylor]
2. Clarify what portion of gravity reinforcement can be used as seismic shear reinforcement in concrete diaphragms. [Taylor]

### 7.2.2. Research Needs:

1. Behavior of Grade 100 Reinforcement in Special Concrete Moment Frames: In ACI 318-19, Grade 100 flexural reinforcement is allowed in special structural walls but not in special moment frames. This is because at the time the 2019 provision was written, there was insufficient research to support Grade 100 for special moment frames. [Taylor]
2. Behavior of Grade 120 Reinforcement in Special Structural Walls and Special Concrete Moment Frames: Permission to use Grade 120 reinforcement would push the limits of reinforcement strength for special seismic systems. It would actually be beneficial if available research established if there is an upper bound on reinforcement grade. Then the limitations on steel grades for special seismic systems would be known, and attention could focus on an improved understanding of the performance of reinforcement of grades below that maximum. Currently there is a perception that it may be possible to push reinforcement grades ever higher, but in reality there may be some point at which steel grades should be capped. [Taylor]
3. Biaxial bending interaction in slab-column joints hasn't been studied sufficiently. Typically one designs for uniaxial bending only, whereas biaxial moments exist in most practical situations. Neglecting biaxial bending effects may result in under-estimation of punching shear at slab-column joints. [Taylor]
4. The influence of top bars to inhibit punching shear failure in slab-column joints: During the last two ACI 318 cycles, there was significant debate on the need to further extend top bars away from the joints out into the slab. The argument was that these bars would help inhibit punching shear failure. It is difficult to understand the mechanics of this, however, as it appears that horizontal top bars in the slab would not be very effective at intersecting punching shear cracks or inhibiting punching shear failure. These bars may simply pull up through the top concrete cover of the slab. The effectiveness of these top bars needs to be studied further. [Taylor]
5. Study new methods for confinement of concrete in boundary elements of special structural walls and columns of special moment frames: Recent changes in confinement requirements for boundary elements (e.g. cross ties with seismic hooks at both ends and overlapping, closed hoops) have made it increasingly difficult, and less economical, to construct special lateral force-resisting systems with reinforced concrete. Perhaps there could be some additional testing, to verify the findings of recent research indicating that cross ties with 90 degree/135 degree hooks are not very effective, that cross ties with 135 degree hooks at both ends are only a little more effective, and that non-overlapping, long hoops, are also not very effective, even with cross ties. Also, additional research could be performed to investigate fabrication methods for confining reinforcement in highly congested regions. [Taylor]

6. The use of very-high-strength reinforcing steel for chord reinforcement, and drag struts, in diaphragms. The use of high-strength threaded bars in diaphragms is not uncommon. There may be limits on the grade of reinforcement that should be permitted in diaphragms. Bond and development lengths are also uncertain for these types of bars. [Taylor]
7. Breakout of headed diagonal reinforcement in coupling beams that are close to a corner of a concrete core. Non-symmetric openings in shear walls can create narrow “wall piers” on one side of the openings. If the stacking of these openings creates coupling beams, and the coupling beams are diagonally reinforced with bars terminating in heads, then there is the possibility of group breakout of the headed bars within the narrow “wall piers.” This condition is fairly common, but ACI 318 is silent on how to design the termination of diagonal reinforcement in narrow wall piers. [Taylor]
8. ACI 318 is lacking in provisions for reinforcement of coupling beams for coupled walls in SDC C or lower. This opens up the possibility of designers detailing coupling beams as ORDINARY moment frame beams in SDC C, which does not seem appropriate. [Taylor]
9. 3D printing of concrete structures is a topic that comes up often. There are no code provisions for 3D-printed structures. A major concern is the continuity between layers of extruded concrete. Current methods rely only on adhesion between layers. Could methods be developed for incorporating fibers or other elements that would link layers to one another? [Taylor]
10. No test results on cast-in-place concrete diaphragms under pseudo-dynamic (or even static) loading is currently available. This is in stark contrast to precast concrete diaphragms, wood diaphragms, and steel deck diaphragms. In order to put the design of cast-in-place reinforced concrete diaphragms using the alternative diaphragm design force level of ASCE 7-16 Section 12.10.3 on a solid footing, such testing is urgently needed. Design provisions for anchorage in concrete consist of fairly simplistic approximations of complex material behavior that were developed over two decades ago and were linked with safety concepts that predate modern codes. The proliferation of mechanically anchored reinforcing in structures and the use of reinforcing as anchorage, whether wittingly or unwittingly, has spurred general interest in this arena, but the topic of anchorage is most critical in the case of earthquake demands on structures, since failure to comprehend governing failure modes in critical parts of the load path could have far-reaching consequences for both structural and nonstructural elements. Study should focus on:
    a. Harmonization of design concepts for all anchorage-related parts of the code
    b. Improvement of prediction models for concrete failure modes related to anchorage, including interaction of discrete anchors and proximate reinforcing

c. Establishment of a rational safety factor concept that is detail- and/or application-specific (e.g., bar cutoffs vs. collector anchorage) as opposed to element-specific ("anchor, rebar") [Silva]

## 7.3. MASONRY

### 7.3.1. Future Provisions Issues:

1. Perforated shear walls. Most perforated shear walls are analyzed and designed using simple approximations, often modeling them as solid piers and ignoring the masonry above and below openings that connect the piers. This can result in uneconomical construction, as well as potential unintended detrimental behavior. The recently developed limit design method (Appendix C of TMS 402) needs to be expanded so that it does not just apply to special reinforced shear walls. {This may not really be a research need. Needed is education, perhaps through a NEHRP Seismic Design Technical Brief, so that engineers start using the limit design method. It is a powerful method, but rarely, if ever, used.} [Bennett]
2. Systems that behave essentially elastically. There is a fundamental issue with the code that is most commonly brought to light in the design of masonry structures and perhaps concrete tilt-up structures – structures where there is significantly more length of wall than is needed structurally to satisfy seismic design requirements. Based on the SDC, we may be required to use intermediate or special systems that have $R$ values consistent with inelastic behavior. The actual behavior of those walls is, however, elastic. This leads to two observations:

   a. The demands on some systems like diaphragms may be significantly underestimated. Attempts are being made to get some commentary into TMS 402 to at least get designers to think about this issue which is outside of the purview of TMS 402 to address.
   b. The required detailing for the high $R$ systems is a waste of resources as the demands on the walls will never be such that the detailing will matter.

   The preferred solution might be to allow the design of essentially elastic systems (perhaps even require it, if the system will not experience the assumed inelastic behavior.) This would offer at least a tradeoff where fewer resources could be put into the walls where it does not improve performance and more into the diaphragms where performance could be improved. The New Zealand code apparently allows elastic systems, but exactly how that is done has not been examined. [Bennett]

### 7.3.2. Research Needs:

1. Boundary elements for masonry shear walls. The current TMS 402 provisions for boundary elements require testing to determine ductility and curvature capacity of boundary elements. Hence boundary elements are never used. Recent research in Canada has provided some information, but it is not yet to the point of being ready to be codified. There are also potential architectural and construction issues with boundary elements of larger thickness than the wall. Additional research, both experimental and analytical, is needed to identify boundary element detailing requirements that would not result in excessive construction costs so that boundary elements become a viable means of masonry construction. [Bennett]
2. Detailing methods for shear walls, particularly partially grouted shear walls, to improve ductility and seismic behavior. Recent research has shown the benefit of double grouted vertical cells and joint reinforcement on the ductility and energy absorption ability of partially grouted shear walls. This research needs to be expanded to identify moderate changes in construction practices that would cause little increase in cost but have the potential to significantly increase ductility of partially grouted shear walls. [Bennett]

## 7.4. WOOD

It is noted that some of the items listed below concerning wood light-frame construction may be equally applicable to cold-formed steel light-frame construction.

### 7.4.1. Future Provisions Issues:

1. The performance of wood light-frame shear walls as a function of the uplift deflection permitted at tie-down devices should be evaluated. Criteria should be developed for uplift limitations, as required, to ensure shear wall performance. [Line]
2. The recent work leading to the FEMA P-1100 publication included numerical modeling of hillside dwellings and identified the need for these structures to be treated differently from other dwellings for purposes of analysis and detailing. Work is needed to integrate into ASCE 7 and SDPWS provisions for analysis, design and detailing of hillside structures. [Line]
3. Use of mid-rise wood light-frame construction continues to be prevalent in the United States and Canada. For this construction type, the adequacy of formulas for the fundamental period should be re-evaluated and corrected if necessary. Comparison of shear wall load-deflection response by standard calculation to building level load-deflection response is needed. [Line]

### 7.4.2. Research Needs:

1. Quantification of seismic performance and design coefficients is needed for heavy timber systems, such as timber braced frames. [Line]
2. Improving Collapse Performance. The ATC-116 Project analytical studies of 1-story, 2-story, and 4-story light-frame wood archetypes found in all cases that collapse occurred due to side-sway failure of first-story walls. Increasing the strength and/or stiffness of first-story walls could significantly improve the collapse performance of wood light-frame buildings, in particular collapse performance of multi-story configurations, which in some cases were found to have $MCE_R$ collapse probabilities exceeding the collapse safety objectives of ASCE/SEI 7-10. A study is recommended to develop code changes (e.g., revising the vertical distribution of seismic design loads, and/or incorporating nonstructural wall finishes, etc.) that would reduce the susceptibility of first-story failure and improve collapse performance of the multi-story wood light-frame buildings. [ATC-116]
3. Irregularity due to Nonstructural Wall Finishes. The ATC-116 Project analytical studies of 1-story, 2-story, and 4-story light-frame wood archetypes found nonstructural wall finishes (e.g., above the first story) can precipitate premature failure of first-story walls and adversely affect the collapse performance of certain configurations of wood light-frame buildings. A study is recommended to develop code or standard changes that would require checking for and mitigating the potential adverse effects of building irregularity due to nonstructural wall finishes. [ATC-116]
4. Research is needed to determine detailing requirements to achieve the intended seismic performance for light-frame shear walls. Resource Paper 11, Shear Wall Load-Deflection Parameters and Performance Expectations, in Part 3 of the 2009 NEHRP Provisions defined the load-deflection parameters and performance expectations for wood structural panel sheathed shear walls with wood framing to guide development of detailing recommendations. A conflict currently exists between the philosophies 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. Focused research is needed to determine whether current detailing practice can consistently provide adequate performance. The research should consider the range of wall configurations and sheathing materials permitted under current design standards, experimental boundary conditions such as testing with and without applied vertical loading, and implications for both single-story and multi-story walls. Detailing considerations should consider both forces and deformations. [Line]
5. Performance-based seismic design procedures are needed for light-frame buildings that take into account the effect of nonstructural interior and exterior wall finishes. The CUREE (Consortium of Universities for Research in Earthquake Engineering) and NEES Wood (Network

for Earthquake Engineering Simulation) projects and FEMA P-695 indicate that finish materials significantly influence the seismic performance of wood 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 NEHRP Provisions, FEMA P-750.) Testing of non-structural interior and exterior wall finishes alone and in combination with structural sheathing under appropriate boundary conditions will facilitate an understanding of the extent to which they improve strength and stiffness over the structural system alone. [Line]

6. Research is needed to provide more guidance to designers on distribution of forces in the design of light-frame buildings. Prior to its 2010 edition, ASCE 7 seismic provisions required semi-rigid diaphragm analysis, which was impractical as a default assumption. In ASCE 7-10 this changed to allow most light-frame construction to be designed using flexible diaphragm idealization. Guidance needs to be based on building performance resulting from practical analysis techniques. Research is needed to quantify performance. [Line]
7. Research is needed to assess the performance of and develop design guidance for open-front light-frame construction. Significant performance issues were seen with open-front light-frame construction in both the Loma Prieta and Northridge earthquakes. While current seismic requirements still permit construction of this building configuration when certain conditions are met, research is needed to quantify at what point this configuration becomes vulnerable when designed in accordance with existing requirements and limitations, and evaluating whether alternative design approaches are needed to reduce the vulnerability or if relaxation of current design limitations is warranted. [Line]
8. Continuation of current 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 buildings; and
    c. Identify key variables to address in "sensitivity" study methods defined in FEMA P-695 as they pertain 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. [Line]

9. Using FEMA P-695, the effects of soft/ weak stories on the performance of light-frame construction should be evaluated, and design guidance to ensure performance of buildings prone to soft/weak stories should be developed, which will require research. [Line]
10. Seismic force and ductility demands on wood-frame diaphragms and adequacy of design methods need to be better understood. 2015 NEHRP *Provisions* Issue Team No. 6 (IT06), which addressed diaphragm issues, investigated anticipated seismic demands for diaphragms ranging from near elastic to inelastic behavior. As a part of this effort, a limited analytical study was conducted, which showed that the significant displacement capacity of wood diaphragms, along with associated overstrength, tended to greatly reduce forces from those anticipated with near elastic diaphragm response. However, more rigorous studies are needed. To support such studies, additional cyclic testing of full-scale diaphragms would be of benefit to verify hysteretic behavior, and validate analysis models, since most test data currently available are monotonic, and do not necessarily capture peak strength and deformation capacity. This further information would allow more rigorous analytical verification of the alternative diaphragm design methodology and diaphragm design force reduction factor included in Part 1 of the 2015 NEHRP Provisions. [Line]

# 8. ASCE 7 CHAPTER 15 – SEISMIC DESIGN REQUIREMENTS FOR NONBUILDING STRUCTURES

## 8.1. FUTURE PROVISIONS ISSUES:

1. The performance of "pedestal" type systems typically used for coker structures in refineries should be studied, and a specific entry for this system in ASCE 7-10 Table 15.4-2 should be developed. A typical coker structure will have 2, 4, 6, or more coke drums supported on a very thick slab supported on legs. Currently, this system is treated as an ordinary moment frame, but generally behaves significantly better than an ordinary concrete moment frame in seismic events. Please note that the ASCE 7-22 Seismic Subcommittee has taken this task on. While the proposed provision is technically sound, it is based on extrapolating performance of cantilever column systems. The proposal may not pass the ASCE 7 SSC or Main Committee without a PUC/P-695 review. Therefore, this would become a topic for an Issue Team during the next cycle. [Soules, Carrato, IT6]

## 8.2. RESEARCH NEEDS:

1. Research is needed on the performance of floating roofs in tanks during seismic events. Floating roofs are used to cover volatile petroleum products to reduce the possibility of fire. No specific design procedures exist for floating roofs under seismic loads. Some floating roofs perform well, while others sink usually followed by fire. This topic is well beyond what an Issue Team can handle, It will likely require extensive finite element and CFD analyses [Soules, Carrato, IT6]
2. If instrumented nonbuilding structures are found, it will be worthwhile comparing their recorded response with response predicted by the *Provisions*. [Soules, Carrato, IT6]

# 9. ASCE 7 CHAPTER 16 – NONLINEAR RESPONSE HISTORY ANALYSIS

## 9.1. FUTURE PROVISIONS ISSUES:

## 9.2. RESEARCH NEEDS:

1. While substantial progress has been made in Chapter 16 on response history procedures to link acceptance criteria more directly to the collapse safety goals of ASCE/SEI 7, further development and research could refine the calibration of the satisfaction of the collapse safety goals implicit in Chapter 16 with more explicit methods. Additionally, drift acceptance criteria in ASCE/SEI 7 have remained unchanged for many years, and were simply adjusted for use in Chapter 16. Both topics could be advanced through future study. [Hooper]
2. The acceptance criteria of Chapter 16 are developed by individually calibrating each acceptance criterion to the collapse safety goals. Since collapse generally involves multiple components simultaneously, a future effort should look at how the collapse probability of a building is affected by the interaction between multiple individual element acceptance criteria. As part of this work, consideration should be given to grouping of similar elements (e.g. those due to symmetry), a requirement not explicitly included in Chapter 16. [Hooper]
3. When developing the acceptance criteria for force- and deformation-controlled actions, assumptions were made to address the probability of total or partial collapse conditioned on the exceedance of a single component (such as 100% for critical force-controlled actions, and 40% for critical deformation-controlled actions with an alternate load path). Future work should study in greater depth the consequences of failure and potentially refine the *Provisions*. The topic of this study would overlap with that presented under "structure of acceptance criteria" under Chapter 12 and the two recommendations. [Hooper]
4. It is widely acknowledged that the uniform-hazard shape of the design and maximum considered earthquake spectra 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 efforts have led to the use of a conditional mean spectrum as an acceptable target spectrum. Further research on more appropriate selection/modification criteria and a better justified number of acceleration histories also might be warranted. [Kasali, Luco, Rezaeian, Crouse Stewart]

# 10. ASCE 7 CHAPTER 19 – SOIL-STRUCTURE INTERACTION FOR SEISMIC DESIGN

## 10.1. FUTURE PROVISIONS ISSUES:

1. A recent ATC project led by Bret Lizundia has identified a series of issues that is limiting the application of soil-structure interaction procedures in current design practice. His team will be putting forward recommendations to increase utilization. An Issue Team could be formed to review these recommendations and develop proposals for revision of Chapter 19. [Stewart, Luco, Rezaeian, Crouse, Kasali]
2. Work is needed to extend the inertial interaction provisions in Chapter 19 to deep foundations. [Kasali, Luco, Rezaeian, Stewart, Crouse]
3. Reduction of Equivalent Lateral Force (ELF) Base Shear for SSI. The ATC-116 Project analytical study of foundation flexibility and SSI effects found that collapse performance was essentially the same for 1-story, 2-story, and 4-story wood light-frame building archetypes on a rigid base as those archetypes modeled with a flexible foundation and nonlinear soil springs. The provisions of Section 19.2.1 of ASCE/SEI 7-16 permit a reduction in the equivalent lateral force (ELF) procedure base shear to account for the soil damping effects of SSI. Seismic code committees should consider prohibiting this reduction for short-period wood light-frame structures. This recommendation is based on wood light-frame building collapse performance but may apply to other short-period buildings that make use of significant ductility in resisting earthquake ground motions. [ATC-116]

## 10.2. RESEARCH NEEDS:

1. Procedures for analysis of kinematic interaction, particularly base slab averaging, are based on a ground motion database that will be more than 20 years old at the time of the next NEHRP *Provisions* cycle. These procedures should be revisited based on an updated database, which could potentially look into the following additional topics: (a) variations in kinematic interaction for different site conditions (including hard rock sites); (b) variations in kinematic interaction for sites in different parts of the U.S. (California, Cascadia, Central and Eastern North America); (c) kinematic effects on the vertical component of ground motion. [Stewart, Kasali]
2. SSI effects are always present, whether for elastic or yielding structures. However, because such effects can be more significant for stiff structures than for flexible structures, the change in SSI that accompanies period elongation from yielding has generated interpretations suggesting that fixed-base models are preferred for certain classes of structures. Such interpretations are anecdotal and do not reflect underlying physics, but do highlight potential problems in the

ways in which SSI effects are currently derived using elastic properties. To address this issue, research is needed to allow a rational adjustment to the SSI effects applied in equivalent lateral force and response spectrum procedures to account for variable amounts of structural yielding. [Stewart, Kasali]

# 11. ASCE 7 CHAPTER 20 – SITE CLASSIFICATION PROCEDURE FOR SEISMIC DESIGN

## 11.1. FUTURE PROVISIONS ISSUES:

1. Currently, unless the 0.5 second-period exception in Chapter 20 applies, sites with potentially liquefiable soils are classified as Site Class F irrespective of the severity of the liquefaction potential. It would appear that the severity of the liquefaction potential could affect the response of the site. Definition of Site Class F needs to be further refined to address this issue. [Kasali, Luco, Rezaeian, Crouse, Stewart]

## 11.2. RESEARCH NEEDS:

# 12. ASCE 7 CHAPTER 21 – SITE-SPECIFIC GROUND MOTION PROCEDURES FOR SEISMIC DESIGN

## 12.1. FUTURE PROVISIONS ISSUES:

1. An Issue Team should re-examine procedures in Section 21.1 for deriving site-specific ground motions. There has been substantial evolution in site characterization methods and site response analysis procedures that should be reflected in an updated version of this section. One benefit of such a re-write of Section 21.1 could be that it would articulate why site-specific analysis is still useful, with the recent changes in how $MCE_R$ ground motions are developed. [Stewart, Luco, Rezaeian, Crouse, Kasali]
2. As part of the efforts associated with the 2020 NEHRP Provisions, the current definition of the deterministic ground motions that cap $MCE_R$ values near very active faults was reviewed and modified. This effort stemmed from the move away from the concept of "characteristic" earthquakes in the Uniform California Earthquake Rupture Forecast (UCERF) that is used for both the 2020 and 2015 NEHRP Provisions. This also led to the development of a Part 3 paper documenting two alternative procedures for eliminating deterministic caps. Consensus could not be reached on either of the two alternative procedures, but the paper is anticipated to serve as a resource paper for future code cycles. This deterministic cap issue needs to be revisited in the next code cycle in the larger context of establishing appropriate design ground motions. An Issue Team should be formed to consider the alternatives for specifying collapse risk that would avoid large, uncontrolled spatial variability in risk as we have now. The team would evaluate alternate means by which deterministic caps could be removed while maintaining appropriate design ground motions in different parts of the U.S. A potential additional task for this team is to reconsider portions of the ground motion characterization process that might systematically bias risk from target levels. Two such examples are the use of maximum-component ground motions and the 2/3 factor. [Stewart, Luco, Kasali, Rezaeian, Crouse]

## 12.2. RESEARCH NEEDS:

# 13. ASCE 7 CHAPTER 22 – SEISMIC GROUND MOTION AND LONG-PERIOD TRANSITION MAPS

## 13.1. FUTURE PROVISIONS ISSUES:

1. For the 2020 NEHRP Provisions, multi-period response spectra were calculated by the USGS on evenly-spaced grid points. Preliminary computations were done to increase the resolution of the grids behind the maps in select locations with deep basins, but this was not incorporated in the 2020 NEHRP design maps. More study of the sensitivity of design ground motions to the grid resolution for deep basins as well as for locations near faults is needed to improve estimates of ground motions. [Luco, Rezaeian]

## 13.2. RESEARCH NEEDS:

1. Multi-period $MCE_R$ response spectra have been developed for each grid point in the USGS national seismic hazard model as part of the 2020 NEHRP Provisions. One of the primary goals of that effort was to directly include the effects of various local geologies from rock (Site Class A and B) to soft soil (Site Class E) as well as deep basins in urban areas such as Los Angeles, the San Francisco Bay Area, Seattle, and Salt Lake City. However, due to the paucity of data for, in particular, (i) the longest periods (e.g., 10 seconds), (ii) the hardest and softest soils (e.g., Site Classes A and E), and (iii) factors controlling site response in basins of different sizes and of different geologic origins, significant research needs still remain. [Luco, Kasali, Rezaeian, Crouse, Stewart]
2. The USGS is working toward a 2023 update of its National Seismic Hazard Model, for not only the conterminous US but also Hawaii and Alaska, and potentially the other US territories, depending on funding. Outside of the conterminous US, the multi-period spectra in the 2020 NEHRP Provisions are approximations that await the new USGS models. Research in the 2023 USGS update should include evaluation and incorporation of (i) new empirical ground motion models for magnitude 8-9+ subduction-zone earthquakes, (ii) incorporation of physics-based simulations of ground motions where available, (iii) updated earthquake rupture forecasts, among others. Research on the impacts of this USGS update on design and $MCE_R$ ground motions will also be needed. [Rezaeian, Luco, Kasali, Crouse, Stewart]

# 14. QUALITY ASSURANCE PROVISIONS

## 14.1. FUTURE PROVISIONS ISSUES:

1. Improved quality assurance provisions. Needed is an investigation and potential rethinking of the way quality assurance is handled. Changes over the last few years have made the situation more confusing. For example, steel observation and inspection is now governed by AISC standards, and uses language different from that traditionally used in the building codes. The NEHRP *Provisions* and ASCE 7 should actively engage in defining what is required and what is appropriate. It will also be desirable to have provisions about enhanced levels of quality assurance to go with enhanced performance objectives. [Lizundia]

## 14.2. RESEARCH NEEDS:

# 15. FEMA P-695 AND P-795

## 15.1. FUTURE PROVISIONS ISSUES:

1. Following ten years of working experience with FEMA P-695, work related to P-695 studies of R-factors for shear wall systems is needed to provide guidelines to P-695 users on the judgements made when attempting to apply the methodology to wood light-frame shear wall systems. These guidelines should include consideration of attributes of the archetypical designs, as well as the number of them, and how to characterize model, data, and design method quality. Guidance is also needed for those reporting results of a FEMA P-695 study, so that readers understand the important judgements made on all of the above, and on more detailed aspects of the design basis. [Line]

## 15.2. RESEARCH NEEDS:

1. Either update FEMA P-695 and P-795 or create similar documents to address development of seismic design parameters for diaphragms, including $R_s$, $C_d$ and $\Omega_0$ factors. This could draw on the IT9-9 resource paper. Consideration should be given to the best methods to develop the $R_s$ factor, given multiple methods have been documented. [Describe need, open questions for problem focused studies]. [IT9]
2. FEMA P-695 Seismic Criteria Update. A study is recommended to determine what if any updates to FEMA P695 should be made to (1) incorporate current ASCE/SEI 7-16 (ASCE/SEI 7-22) ground motion criteria and (2) address the apparent discrepancy between the acceptance criteria of FEMA P695 and those of Section 12.2.1.1 of ASCE/SEI 7-16.

   The seismic criteria of FEMA P695 are based on the "Zone 4" seismic criteria of the 1994 UBC, as embodied in the deterministic lower limit (DLL) seismic criteria of Section 21.2.2 of ASCE/SEI 7-05. The seismic criteria of FEMA P695 are out-of-date with respect to the current seismic criteria of ASCE/SEI 7-16 and ASCE/SEI 7-22, as proposed. At short periods (i.e., the acceleration domain), the seismic criteria of FEMA P695 are either the same as the DLL of ASCE/SEI 7-16 or only about 10 percent less than those proposed for ASCE/SEI 7-22. In the velocity domain (i.e., periods greater than 1.0 second for Site Class D site conditions) the seismic criteria of FEMA P695 are only about 60 percent of those of ASCE/SEI 7-16 (and somewhat less for ASCE/SEI 7-22). Updating the seismic criteria of P695 would not significantly affect the collapse evaluation of short-period building archetypes (and the findings of this study of wood light-frame buildings), but could be of importance to the collapse evaluation of taller building archetypes with longer periods.

As per the original "Zone 4" approach of FEMA P695, all of the ground motions, described above, represent "far-field" sites and purposely ignore higher levels of ground shaking typical of sites closer to the fault(s) governing site seismic hazard. Accordingly, FEMA P695 implicitly permits $MCE_R$ collapse probabilities greater than 10 percent for structures at sites where ground motions are greater than those of the "far-field" SDC $D_{max}$ seismic criteria; whereas, the 10 percent collapse objective of Section 1.3.1.3 (Performance-Based Procedures) and Section 12.2.1.1 (Alternate Structural Systems) of ASCE/SEI 7-16 applies to all sites, regardless of their proximity to fault rupture, noting that the commentary to Section 12.2.1.1 identifies FEMA P695 as the preferred methodology for verifying compliance with the 10 percent collapse objective. As shown by comparison of the collapse performance of high seismic and very high seismic baseline archetype models of this study [which study?], very different conclusions could be reached if the $MCE_R$ ground motions greater than those of the "far-field" SDC $D_{max}$ of FEMA P695 were required for collapse evaluation. The fundamental question is simply – does the 10 percent collapse safety of ASCE/SEI 7-16 apply to buildings at all possible sites, or only to those sites that are not "near-source"? [ATC-116]