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

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ABSTRACT

The NEHRP Recommended Seismic Provisions for New Buildings and Other Structures (NEHRP Provisions) serves as the consensus resource document for US seismic codes and standards. The NEHRP Provisions are developed by the Building Seismic Safety Council (BSSC) through a five-year project sponsored by the Federal Emergency Management Agency (FEMA). The Provisions are developed for the BSSC by its Provisions Update Committee (PUC). The PUC, supported by subcommittees called Issue Teams, develops technical proposals that are intended to advance the current state of seismic design practice. The proposals are in the form of changes to ASCE/SEI 7-16 and Commentary, which provide the platform from which Provisions updates are made. This paper provides an overview of the key topics being considered for the 2020 NEHRP Provisions, including important updates on developing the next generation of seismic design value maps. The authors serves as Chair of the PUC in the 2020 NEHRP Provisions cycle and project manager of BSSC, respectively, and present this work as part of FEMA and BSSC’s commitment to ongoing outreach to the engineering community.

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Progress on the 2020 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures

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Introduction
The NEHRP Recommended Provisions for New Buildings and Other Structures (NEHRP Provisions, the Provisions) serve as a platform for advancing seismic analysis and design concepts that exist in the current edition of ASCE/SEI 7 Minimum Design Loads for Buildings and Other Structures based on recent research and experience, and for and introducing new seismic concepts prior to their introduction to ASCE/SEI 7. The Provisions are developed through a consensus process involving a Provisions Update Committee (PUC) consisting of a group of experts selected to cover the range of seismic concepts contained in the Provisions. The PUC selects relevant topics it considers most appropriate for development within the five-year update cycle. Topics are then assigned to Issue Teams, which include both PUC members and others with expertise in the issues being considered. The 2020 edition of the NEHRP Provisions is being developed by the Building Seismic Safety Council (BSSC) through a five-year contract sponsored by the Federal Emergency Management Agency (FEMA), which will mark the 10th publication since its first edition in 1985.

Prior to the 2009 edition, the NEHRP Provisions were code-language documents that were broadly adopted by some regional model building codes and by national standards, such as ASCE 7. Notably, the 2000 and 2003 editions of the International Building Code adopted requirements in concept from the 1997 and 2000 NEHRP Provisions into Chapter 16 of the code, together with

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modifications to the materials standards, adopted in Chapters 17 through 22 of the code.

Starting with the 2009 edition, in recognition of the fact that the codes and standards arena operates differently than it did during previous editions of the Provisions, the Provisions Update Committee (PUC) of the BSSC began adopting the ASCE 7 Standard as the reference for developing the Provisions seismic design requirements, then made substantive recommendations for modification and improvement of the standard based on recent research and improvements in knowledge. In this manner, the PUC process and the NEHRP Provisions became a technology resource and proving ground for new requirements that are offered for adoption into the ASCE Standard and the International Building Code. Almost all the major changes related to seismic design, analysis, and new seismic-force resisting systems are first vetted and approved by PUC, then be considered by ASCE 7 Seismic Subcommittee. The 2009, 2015, and the 2020 NEHRP Provisions currently under development, include three parts: Part I Provisions for recommended new changes and modifications to the adopted ASCE/SEI 7; Part II, the full ASCE 7 commentary that incorporates changes based on Part I; and Part III, resource papers, covering new concepts and methods for trial use and other supporting materials for design professionals.\textsuperscript{[1,2]}

This publication is occurring at approximately the mid-point of the 2020 Provisions update cycle, so the intent to introduce some of the key technical proposals under consideration, with the understanding that final development of these and other proposals will occur over the next two years.

**Primary Topics Addressed by the PUC and Issue Teams**

**Seismic Performance Objectives (IT1)**

The primary intent of the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures is to prevent, for ordinary buildings and structures, serious injury and life loss caused by damage from earthquake ground shaking and ground failure. Since most earthquake injuries and deaths are caused by structural collapse, the Provisions target performance such that the probability of collapse of a significant portion or all of an ordinary use structure does not exceed 10% under the occurrence of maximum considered earthquake shaking.\textsuperscript{[2]} Using the statistical and assumed uncertainty associated with the collapse probability, on average, there would be approximately a 1% chance of experiencing earthquake collapse over a 50-year period. The reliability or collapse risk for structures in higher risk categories, such as those housing a function essential to community response following a disastrous event, are adjusted and specified based on Risk Category in the Provisions. While the structure performance is quantitatively specified by the collapse risk, there are only qualitative descriptions, and no quantitative requirements, for nonstructural safety, release of hazardous materials, preservation of egress, and function protection in current Provisions. Some significant changes were made in the Intent statement of the 2015 Provisions on performance-based design, including reliability tables that were shown in the Provisions instead of the commentary, explicit preservation of function requirements for Risk Category IV facilities, and overarching serviceability requirements to be modified based on project design criteria. The issue team is evaluating the adequacy of the qualitative performance objectives in Section 1.1 of the 2015 NEHRP Provisions to determine if they are sufficient for the design of
buildings and other structures.

The ongoing effort considers collapse risk in parallel with functionality protection and economic loss protection. The topics include the reevaluation of the current collapse risk of 1% in 50 year (which is a joint effort with Project 17 that is discussed later in this paper); performance objectives for nonstructural components; design level earthquake for non-structural components; function goals for “critical” facilities of different risk categories, hazard intensity, and reliability; reconsideration of the definition of seismic design category (SDC), including SDC boundaries, and SDC stability; and resilience in seismic design.

**Seismic Force Resisting Systems and Design Coefficients (IT 2)**

During the development of the 2015 NEHRP Provisions, the need for system irregularity provisions in future Provisions was identified. Specifically, 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 been fully supported on a technical basis. Furthermore, a torsional irregularity (or extreme torsional irregularity) can be triggered by the geometry of the building rather than the performance of the lateral force resistance system (i.e. rectangular shaped buildings are penalized by the current equations, even when displacements due to torsional deformations are minimal). This issue team is working closely with ATC-123, *Improving Seismic Design of Buildings with Configuration Irregularities* funded by FEMA and working on code change proposals on configurational irregularities. The issue team is also looking at the relationship between $C_d$ and $R$, bearing wall definition, height limits, and directional combination. Proposals related to the scope of application for increased collector and diaphragm connector force, horizontal irregularity Type 2 And 3 triggers, elimination of weight (mass) irregularity, $C_d = R$ for building separation and deformation compatibility are being considered.

**Modification of Existing Modal Response Spectrum Method (IT3)**

During the 2015 NEHRP Provisions cycle, several changes were made to the Chapter 12 requirements for modal response spectrum (MRS) analysis. The largest change was the addition of a sub-section on linear response history analysis. This analysis method is offered as an alternate to the MRS method and has the advantage of preserving signs (e.g. positive-negative bending moments, tension-compression brace forces), where these are lost in the SRSS and CQC combination in the MRS method. Other changes made for the 2015 Provisions included clearer definition of the modes of vibration to be included in the analysis, and changes to rules for scaling of forces and drifts. Based on numerous FEMA P-695 studies that showed better collapse performance for archetypes designed to the ELF method compared to the MRS method, the scaling of the modal base shear was set to 100% of the ELF base shear, eliminating the traditional 0.85 scaling requirement, which was set based on the judgment that dynamic analysis provided inherently better results than the ELF method.

At the end of the 2015 cycle several issues related to MRS analysis were identified for further study in this cycle. These include possible adjustment of $C_S$ in the short period range by the square root of $(2R/\Omega_o – 1)$; reduction by $R$ only in the first mode (assuming higher modes are elastic);
triggers for dynamic analysis and consideration of ongoing studies associated with ATC 123 Improvement of Design Requirements for Buildings with Configurational Irregularities.

**Shear Wall Design (IT4)**

This IT is considering the need for an effort to improve the seismic design of reinforced concrete shear walls, especially to distinguish between ductile and less ductile walls, between squat and slender walls, and, very importantly, to recognize the characteristics and performance of coupled shear walls. Seismic force-resisting systems incorporating coupled shear walls are highly suitable for multistory reinforced concrete buildings. Yet, they are not recognized as distinct entities in Table 12.2-1 of ASCE/SEI 7-16. The shear wall design issue team is considering the effects of external loads (gravity as well as lateral) on shear walls of concrete, steel, masonry, and wood, and examining the possible failure modes resulting from those load effects or internal forces. A determination of the failure modes that are critical in design could lead to possible areas of improvement in current design practice.

The issue team includes experts in shear wall design covering all major construction materials, including concrete, steel, wood, and masonry. Issues, needs of improvements, latest findings, and challenges for each type of shear wall are being evaluated. The team members have agreed that the team will develop a part III resource paper covering the basics of shear wall design for all of the most common materials, include concrete, steel, wood, masonry, and coupled concrete, steel, or composite shear walls. Another major focus of the issue team is on coupled shear walls. Coupled shear walls are efficient systems for earthquake resistance and are recognized as distinct from isolated shear wall systems in Canadian and New Zealand codes, and are accorded higher response modification factors in view of their superior seismic performance. A proposal to add ductile coupled concrete shear wall to ASCE/SEI 7-16 Table 12.2-1 is being developed by the team and other types of coupled shear walls, like coupled steel shear walls and coupled composite walls are being examined.

**Nonstructural Components (IT5)**

Nonstructural seismic design provisions were first included in the 1927 *Uniform Building Code* and have evolved over the last 90 years. The seismic requirements for nonstructural components are currently covered in Chapter 13 of ASCE/SEI 7-16, which apply to components supported within a structure, and also commonly applied to many ground-supported components. However, issues have been identified that significantly influence the performance of nonstructural components, but are not adequately covered in the current Provisions. The performance goals of nonstructural systems are being considered, refined, and modified as necessary to produce the desired simplification.

Issue team 5 on nonstructural components will incorporate information and recommendations from latest research and field investigations to develop proposals reflecting the most current knowledge on nonstructural design. The goals of this work will include: (1) redefined/updated nonstructural component performance objective, which has been cooperated with IT 1 on Seismic Performance Objectives; (2) guideline to determine the boundary between nonstructural components and nonbuilding structures, which is being coordinated with IT 6 on nonbuilding structures; (3)
development of a design philosophy for nonstructural components that identifies desirable post-yield and failure mechanisms for components, supports and attachments, and a method for producing generic floor spectra for design of nonstructural components; and (4) development of proposals for updating the force equations and nonstructural anchorage to concrete and masonry, and proposals to update the \( R_p \) factor. Many of the efforts are being coordinated with the NIST funded ongoing ATC 120 project on *Seismic Analysis, Design, and Installation of Nonstructural Components and Systems* (ATC-120).

**Nonbuilding Structures (IT6)**

The issue team is charged with identifying seismic design issues unique to non-building structures. While coordinated closely with the nonstructural components issue team in the development of guidelines to differentiate between nonstructural components and nonbuilding structures, the team is working on a few specific items, including: (1) corrugated steel liquid storage tanks that are not addressed in current seismic design provisions; (2) new seismic design coefficients for fiber glass cooling towers; (3) design of large bore piping systems, where the pipe provides significant stiffness relative to the supporting structure; (4) anchorage to concrete, including resistance mechanisms, and load combinations; (5) \( R \) value for large concrete machine foundation similar to structures, including “table top” type machine foundations that are similar to concrete moment frames; and (6) Lattice column structures.

**Soil-Foundation Interaction (IT7)**

During the development of the 2015 NEHRP Provisions, considerable attention was given to Chapter 19 on Soil-Structure Interaction (SSI). The chapter was rewritten to address three types of SSI effects: Foundation Deformations (addressing modeling of the foundation and underlying geologic media), Inertial Interaction Effects (energy dissipation due to wave propagation away from the foundation and hysteretic soil damping), and Kinematic Effects (the deviation of stiff foundation elements from free field motion due to base slab averaging and embedment effects). Analytical procedures for calculating each of these effects are now included in Chapter 19 and limits are placed on the types of analysis permitted, and the amount of base shear reduction associated with each SSI effect. In the current cycle, the foundation-interaction issue team is considering the following scope:

- Consider modifications to the 2015 provisions related to the limitations on damping and base shear reduction, the relationship between foundation damping to superstructure damping, and effects of base slab stiffness.
- Review proposed changes to ASCE 41-17, *Seismic Evaluation and Retrofit of Existing Buildings* and bring forward pertinent modifications as appropriate.
- Consider development of provisions relating to seismic earth pressure on basement walls.
- Consider development of provisions related to rocking in flexible-base foundation modeling.
- Consider load factors on soil and hydrostatic pressure.
Diaphragm Issues – RWFD and Alternative Diaphragm Design Provisions (IT9)

During the development of the 2015 NEHRP Provisions, an alternative design method for rigid-wall flexible diaphragm buildings was initially developed. Discussion of this methodology is provided in Resource Paper 5: One-Story, Flexible Diaphragm Buildings with Stiff Vertical Elements in Volume II in Part 3 of the Provisions. A more complete presentation is provided in FEMA P-1026, Seismic Design of Rigid Wall-Flexible Diaphragm Buildings: An Alternative Procedure. The methodology described in these publications is currently only applicable to very simple building configurations. Effort is underway by Issue Team 9 to better define and expand the scope of the buildings to which the provisions apply. Part 1 code change proposals on RWFD Seismic Design are being developed with the aim of being incorporated into ASCE/SEI 7-22.

This issue team intends to further develop the alternate diaphragm design force methodology introduced in the 2015 NEHRP Provisions Volume I, Part 1 (NEHRP Provisions, 2015). While the diaphragm provisions in ASCE 7-10 and previous editions used an elastic design approach for diaphragm elements, basing the forces on a multiple of floor force calculated using the Equivalent Lateral Force (ELF) procedure, the 2015 Provisions proposed an alternative force level for seismic design of diaphragms, which contain new equations for force demands (yielding larger design force) and adjust the limited elastic capacities of the diaphragm. However, to use this alternate method beyond the limited systems currently described, further development of the new diaphragm design equation is needed. The ongoing effort is to develop a methodology for determination of diaphragm force reduction factors, $R$. In addition, the team is working closely with a project team that is currently conducting steel deck diaphragm research and looking at the possibility of incorporating it into the work of this issue team.

Seismic Design Value Maps addressed by Project 17 and Work Groups

Approximately once every 10 years, FEMA/BSSC and USGS collaborate to re-examine the rules and the basis for developing seismic design values maps. The joint committee is called Project 17 in this 2020 cycle, and was called Project 07 and Project 97 in the previously cycles. The work of the committee could result in major changes to seismic design value maps and design procedures. For example, the Project 97 adopted a seismic design basis for ordinary structures that sought avoidance of collapse for a major foreseeable earthquake event, termed Maximum Considered Earthquake (MCE), targeted MCE with a uniform hazard having 2475 year return period (with exception in regions proximate to major active faults where MCE were limited by deterministic caps), developed design procedures using a standard acceleration response spectrum, and introduced the concept of the Seismic Design Categories (SDCs). Project 07 transformed from uniform hazard of 2,475 year return period to uniform risk of 1% in 50 year collapse risk.

Following the similar goals of Project 97 and Project 07 of re-examining the rules and the basis for developing seismic design values maps, Project 17 was initiated in 2015 and aims to be complete by the end of 2018. Five Work Groups (WG) were established, addressing issues on: (1) Acceptable Risk WG on selection of an appropriate risk basis for the design value maps; (2) Multi-Period Spectral Parameters WG to correct the representation of spectral shape for soft soil site with motions dominated by large magnitude earthquakes; (3) Precision and Uncertainty WG, with the intent of stabilizing the mapped values of motion over time to minimize changes to practice; (4)
Seismic Design Category WG, with goal of minimizing the fluctuations that impact design requirements; and (5) Deterministic Cap WG, to develop specification of the deterministic event on which seismic hazards are based on sites close to major active faults. At the time of this writing, some important process has been made by Project 17 and issues are still under consideration.

Acceptable Risk

Project 97 adopted seismic design values maps portraying parameters having a 2,475-year return period (2% probability of exceedance in 50 years), with deterministic caps in some regions, because it was felt necessary to go to this exceedance probability in order to capture large events in the eastern U.S. that had occurred in historic times, such as the 1811-1812 New Madrid series of events and the 1886 Charleston earthquake. The deterministic caps were necessary to limit design ground motions in areas close to major active faults, such as some sites in Los Angeles, Salt Lake City and San Francisco to credible values approximating those that had been actually recorded. Project 07 adopted a revised basis for the MCE maps consisting of ground motions that would result in a 1% collapse risk in 50 years for buildings having a fragility with a 10% probability of collapse given the occurrence of MCE motion. Generally, the exceedance probability remains at approximately 2% in 50 years and deterministic caps were retained. However, it is clear that the “uniform-risk” maps do not provide completely uniform risk. For most of the U.S., they provide building design with a notional 1% in 50 year collapse risk. At sites located within a few kilometers of major active faults, where the ground motions are capped by characteristic events, the collapse risk can be much higher, on the order of 2% to 3% in 50 years.

In this Project 17 cycle, consideration was given to the notion that exceedance probabilities on the order of 5% in 50 years may adequately capture recurrence of the New Madrid events. It was judged that if this 5% in 50 year exceedance probability had been selected originally, it may have avoided the need to adopt deterministic caps, and may have had the benefit of developing “real” uniform hazard or uniform risk across the nation and may have simplified seismic design (no deterministic cap). Many options, including retain current 1% in 50 year collapse risk, or stay with risk based but with different risk target level, or return to uniform hazard with a shorter return period, were been discussed and debated within the P17 groups and among the seismic community through a P17 workshop held on April 11, 2017 (P17 Workshop) [5]. Based on that, it was decided that, without compelling reasons to change, the 2020 cycle will stay with current practice of 1% in 50 year collapse risk with continuing effort to update deterministic cap procedures.

Multi-Period Spectra

The national seismic design maps provided in ASCE/SEI 7-16 provide values for four design parameters: peak ground acceleration, $PGA$; the short period and 1-second period spectral values, $S_3$ and $S_1$; and the constant displacement transition period, $T_L$. Late in the 2015 NEHRP Provisions Update cycle it was found that the traditional three-domain design spectrum (constant response acceleration, velocity and displacement) derived from these parameters does not adequately address ground motion demands for sites on soft soils that are dominated by large magnitude events. For such sites, it was found that the spectral demands could be significantly underestimated at periods greater than 1-second, and could be overestimated at short periods. Ideally, for such
sites, the design spectral shape would be defined by a multi-period spectrum covering a full range of periods. However, due to time constraints, it was not possible to implement such a revision in the last cycle. Instead it was determined that an acceptable approach would be to require a site-specific spectrum for longer period structures on soft soil sites. That approach is used in the 2015 Provisions and ASCE/SEI 7-16.

In the 2020 Provisions cycle, the multi-period spectrum issue is being addressed through Project 17, which is developing proposals for the PUC. The plan is for the USGS to provide a database of spectral response parameters for a range of periods between 0.2 second and 10 seconds covering a range of site classes. Engineers will be able to obtain design values for sites by inputting site location (latitude and longitude) and site class. The spectral design values would directly incorporate site effects and spectral shape adjustment without the need for a site-specific analysis on soft soil sites.

From a code standpoint, the multi-period spectra would be included in ASCE/SEI 7 Chapter 21 (Site Specific Procedures) requirements for determining the Design Response Spectrum. In Chapter 11, the short and long-period site coefficient tables would be eliminated, as site effects would be incorporated into the USGS spectral parameters. In the Chapter 12 Equivalent Lateral Force and Modal Response Spectrum analysis procedures, the three-domain spectrum would be retained, but with the spectral response acceleration parameters based on Chapter 11 $S_{MS}$ and $S_{MI}$ values derived from the USGS database. It is also expected that additional site classes will be added in Chapter 20 (Site Classification Procedure), for example at BC, CD and DE boundaries to add more precision to the definition of site effects.

**Precision & Uncertainty and Seismic Design Category**

USGS updates the seismic design values once every three years to reflect the latest advancement in seismology research on location, length, and activity rate of faults and other seismic sources, as well as new development of hazard models. With each USGS update, the ground motions in regions can potentially go up and down. More significantly, in regions close to Seismic Design Category (SDC) boundaries, these oscillations may result in shifting in SDC’s, which significantly affects design and construction requirements that are associated with SDC’s. The design and construction within different SDC’s may favor different structural systems, affecting the cost of construction. This oscillation may create challenges in practice, and in code adoption and enforcement, as both designers and public officials work to justify the new provisions, and contractors adjust to build as required by the code and individual designs.

The Committee considered a wide range of solutions to these issues, including averaging ground motion values, incrementally changing ground motions across multiple map editions to avoid sudden significant change, reducing the number of significant figures in mapped values, creating an SDC map that relies on geographical and geological factors, etc. The most compelling discussion in the committee is that changes to design ground motions between map editions might be less problematic if the Seismic Design Categories remained more stable during relatively modest changes. The current consensus decision within the SDC work group is to allow SDCs to remain responsive to major scientific changes in the USGS Hazard Model without being overly sensitive to modest numerical changes in the latest USGS Hazard Model, and to let the seismic design values reflect the latest understanding of seismology science. Rules to develop future SDC
Concluding Remarks

The 2020 NEHRP Provisions are intended to serve as a nationally applicable resource document including Part 1 charging language based on and modifying ASCE/SEI 7-16, Part 2 detailed commentary also consistent with ASCE/SEI 7-16, and Part 3 introducing of new technologies. This paper provides an overview of the work underway in the Provisions update project, and is intended to contribute to the FEMA goal of outreach to the engineering community. The material in the Provisions represents the state of the art for many topics within earthquake engineering and was developed by committed volunteers with specialties ranging across the technical spectrum of the practice. The updates to these topics represent a net progression towards reducing the earthquake hazard facing the public.

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References


