The 2020 NEHRP Recommended Seismic Provisions An Overview

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Abstract

The 2020 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures (2020 NEHRP Provisions) has been under development since 2016 by the Building Seismic Safety Council (BSSC) Provisions Update Committee (PUC) and is currently nearing completion. As with prior editions, this FEMA-sponsored state-of-the-art document will serve as a national resource for design professionals and the U.S. standards and code-development agencies. Most significant PUC proposals are adopted by ASCE/SEI-7, Minimum Design Loads for Buildings and Other Structures, followed by the International Building Code.

The PUC conducts its technical proposal development process through a group of technical committees called of Issue Teams, which focus on topics ranging from ground motions to structural system design. Issue Teams develop technical proposals aimed at advancing various sections of the ASCE/SEI-7 seismic provisions. These proposals are vetted through the PUC and eventually the BSSC member organizations.

This paper summarizes the major code change proposals that are considered to have wide ranging implications regarding future seismic design requirements for buildings. The work that forms the technical basis for some of the most significant proposals will be discussed in more detail separately in other papers in this convention session.

Introduction

The NEHRP Recommended Provisions for New Buildings and Other Structures (NEHRP Provisions, the Provisions) serve as the starting point in the process of U.S. seismic standards development. Major seismic analysis and design concepts included in the ASCE/SEI 7 Minimum Design Loads for Buildings and Other Structures originate in the Provisions, which are developed through a consensus process through a Provisions Update Committee formed by the Building Seismic Safety Council (BSSC) through funding provided by FEMA. The BSSC is a council of the National Institute of Building Sciences, which was founded by the U.S. Congress in 1974 to provide a national natural platform to solve complicated building sciences issues. Topics that are considered most relevant to the advancement of seismic provisions are selected by the PUC at the beginning of each five-year Provisions development cycle. The publication of this paper is occurring near the end of the current five-year cycle, when most key technical proposals have been developed, though some proposals have not been officially reviewed and approved by the BSSC member organizations. However, at this time most major change proposals are under consideration by the ASCE/SEI 7 Seismic Subcommittee relative to potential inclusion in ASCE/SEI 7-22.

The 2020 edition of the Provisions follows a process used in both the 2009 and 2015 editions (BSSC, 2009 and 2015), in which the most recent edition of ASCE/SEI 7 is adopted by the PUC as the reference standard and proposals for technical change are made relative to specific sections of the standard. Thus, the code change proposals that comprise the 2020 Provisions are developed as modifications to ASCE/SEI 7-16 (ASCE, 2016). In turn, the seismic provisions in ASCE 7-22 will be shaped substantially by the proposals that comprise the 2020 NEHRP Provisions. The Provisions are comprised of three sections as follows:

- Part 1 – the provisions themselves, representing proposed modifications to the ASCE 7-16 seismic requirements
- Part 2 – A fully contained commentary, addressing all sections of ASCE 7, whether modified in current Provisions or not.
- Part 3 – resource papers, covering new concepts and methods for trial use and other supporting materials for design professionals.

The rules for developing the seismic design maps contained in the Provisions are re-examined approximately every ten years through a FEMA-funded collaboration between BSSC and USGS. That effort occurred at the beginning of the 2020

Provisions cycle and was titled *Project 17, Development of Next Generation of Seismic Design Maps for the 2020 NEHRP Provisions* (BSSC, 2019). Similar projects occurred in 2007 (Project 07) and 1997 (Project 97) and formed the basis for the design maps contained in the building codes of the past twenty-plus years. Project 17 played an important role in setting the risk basis for the 2020 design maps and in the consideration of other significant aspects of the seismic design provisions.

Project 17 is described in more detail below. That is followed by two sections directly related to Project 17, seismic design ground motions and the multi-period design spectrum. Following that, summaries are provided of other major issues considered in this Provisions cycle that resulted in significant code change proposals.

Project 17

The United States Geologic Survey (USGS), under funding provided through the National Earthquake Hazards Reduction Program (NEHRP), develops national seismic design value maps for adoption in standards and building codes. The USGS develops these maps in a cooperative manner with the National Institute of Building Sciences' Building Seismic Safety Council's (BSSC) Provisions Update Committee (PUC), where USGS provides the science update on the seismic risk, known as the national seismic hazard model, and PUC provides the engineering input on the parameters to be used in seismic design and analysis. Project 17 was an important part on of the BSSC PUC process in this cycle, and provided recommendations for the rules by which 2020 NEHRP Provisions (and ASCE/SEI 7-22 and IBC-2024) seismic design value maps will be developed.

In the beginning of the 2020 NEHRP cycle, Project 17 was commissioned in response to issues identified in adopting the 2014 edition of the USGS national seismic hazard model and the design procedures that reference them for use, including the NEHRP Provisions, building codes and referenced standards. Specific issues included: the engineering profession's discontent with the fluctuating design values portrayed by successive map editions; discovery that the standard spectral shape referenced by the design provisions did not adequately represent ground motion amplitude and spectral character on some sites; and a change in seismologic characterization of the possible size of earthquakes originating on various faults and source zones. A Project 17 Committee was empaneled and four task subcommittees were formed, each charged with evaluating one of the key issues identified in the planning effort: stabilizing mapped values; definition of acceptable risk; development of multi-period spectral parameter data; and, definition of procedures for computing deterministic caps. A fifth task subcommittee was formed in 2017 to look at ways to stabilize the seismic design category as an extended effort to stabilize mapped values.

Project 17 delivered its final recommendations in a series of proposals to the PUC for final approval and adoption in the 2020 NEHRP Provisions. A detailed description of the Project 17 recommendations is documented in the Project 17 Final Report. This section summarizes the issues that were considered in the Project 17 process.

<u>Acceptable Risk:</u> the evolution of the risk basis for the seismic design maps can be briefly represented by the flow chart shown in figure 1 below. As shown, Project 97 introduced the definitions of maximum considered earthquake (MCE) for which mapped values would be provided and established the 2%-50 year exceedance probability for MCE shaking with deterministic limits near major active faults. In the Project 07 effort, the risk basis for the design maps was transformed from the 2%-50 year uniform hazard to the "uniform risk" of 1%-in-50-year collapse risk. The Project 07 recommendations resulted in a computed 1% probability of collapse in 50 years for buildings having typical fragilities with 10% probability of collapse given the occurrence of MCE motion. Note that the deterministic limits for sites near major faults sites were retained in Project 07, which resulted in somewhat different probabilities of exceedance for MCE and design ground motion across the U.S., with relatively high probability of exceedance for design ground motions in the Western U.S. compared to those in the Eastern U.S.

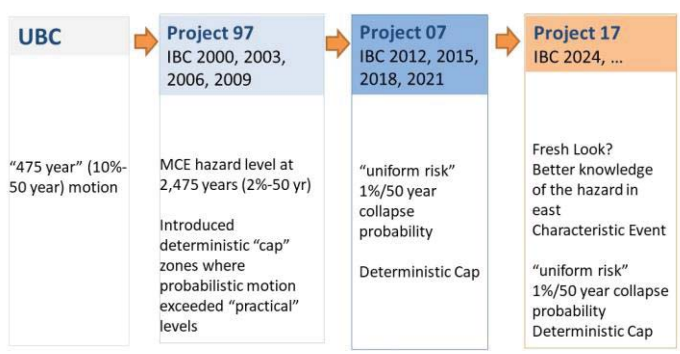

Figure 1 Evolution of Risk Basis for Seismic Design Maps

With advancements of earthquake science, a different understanding of likely recurrence intervals for large magnitude earthquakes in the New Madrid seismic zone and near Charleston SC, elimination of characteristic earthquake in the latest national seismic hazard models and the desire for a better uniform risk across the nation, Project 17 took a fresh look on the risk basis of the design maps. A Project 17 work group investigated options including using alternative collapse risk and return to a uniform-hazard with a shorter return period, which would both potentially eliminate the need for the deterministic limit and result in a more uniform risk basis for the entire nation. Alternative approaches including adopting reduced return periods for MCE shaking and grading the acceptable collapse risk on sites near major active faults as an alternative means of controlling the intensity of design shaking near these active sources were also discussed.

The Project 17 Committee recommended that national seismic design value maps continue to be developed on the basis developed by Project 07, as being ground motion that produces a 1% risk of collapse in 50 years for structures having 10% conditional probability of collapse given the occurrence of MCER shaking, except at those sites where such motion exceeds the deterministic lower limit, as defined in the 2015 NEHRP Provisions. The recommendation was later approved by the PUC.

Stabilizing Mapped Values: With successive editions of the ASCE 7 Standard and the International Building Code, engineers have occasionally noted specified ground motions in regions that go up, then down, then back up again. These oscillations, although theoretically justified, create a lack of confidence in the basis for design ground motions. More significantly, in regions close to Seismic Design Category boundaries, these oscillations occasionally result in shifting design and construction requirements as structures move from SDC B to C or C to D and back again with successive editions of the maps. Design and construction requirements can vary significantly between SDCs, favoring different structural systems and affecting the cost of construction. This oscillation creates considerable problems in practice, adoption, and enforcement as both designers and public officials work to justify the new provisions and contractors struggle to build as required by the code and individual designs.

A project team evaluated two primary means of stabilizing the design requirements: 1) using a weighted average of mapped values over several recent map editions; and, 2) assigning Seismic Design Categories using separate seismic zonation-like maps. The committee generally thought that the first option was a valid approach. Ultimately this approach was not adopted because the planned adoption of multi-point spectra, discussed in the next section of this paper, rendered the approach impractical to implement in this cycle. It may have applicability in future cycles as a means of providing stability.

The second alternative proposed that future editions of the NEHRP Provisions assign Seismic Design Category through reference to a Seismic Design Category Map constructed by USGS using the procedures for category assignment contained in the then current NEHRP Provisions, but assuming a default Site Class. A proposal was developed and forwarded to PUC, however, this recommendation was not supported by PUC mainly due to concerns that provisions based on such a map (default site class) would require some structures to be designed too conservatively, for a higher design category than would otherwise be permitted.

Multi-Period Spectral Values: During the 2015 NEHRP cycles, it was discovered that the standard spectral shape derived from the S_{DS}, S_{D1}, and T_L parameters does not adequately represent the spectra of real ground motions on soft soil sites (Site Class D, E, or F) produced by large magnitude events. As an interim solution to this problem, the 2015 NEHRP Provisions required a site-specific seismic hazards study for design of structures with S_1 values exceeding 0.2g located on sites classified as Site Class D or E, and for structures with S_S values exceeding 1.0g for structures on sites classified as Site Class E; with an exception that permitted the use of conservatively amplified spectra in some cases. A work group was formed under Project 17 for the 2020 NEHRP cycle to develop multi period response spectra. A series of multi-period response spectra (MPRS) proposals were developed, which are significant changes affecting chapters 11, 12, 15, 20, 21 and 22. The proposals and changes are summarized in the Multi Period Response Spectra section. At the time of the writing of this paper, USGS has developed the seismic design values with period from 0 to 10 seconds for all US domestic sites and the final revisions of the MPRS proposals are being balloted by PUC.

Deterministic Limits: As discussed earlier, Project 17 recommended the 1%-in-50-year collapse risk basis, with deterministic limits for near major fault sites. However, the latest national seismic hazard models adopted by USGS did not include the concept of characteristic earthquakes with limiting magnitudes on faults, and instead adopted a model that admitted to very large magnitude earthquakes on faults, albeit at low probability, resulting from simultaneous rupture in combination with other regional faults. Project 17 and its work group evaluated a few alternatives, including use of a graduated risk model near major active faults and selection of a characteristic earthquake magnitude through examination of the hazard disaggregation. After rounds of deliberation, the second option was recommended by Project 17. The proposals and seismic values incorporating the MRPS, the new deterministic limits, and other national seismic hazard model updates are being balloted by PUC.

Performance Basis - the Intent of the Provisions

The NEHRP Provisions Intent section describes the expected seismic performance that is judged to be inherent in the Provisions and ASCE 7. The section does not appear in ASCE 7. As noted above, the risk basis for the seismic design maps used in the Provisions was reassessed in Project 17 and it was decided to maintain the current practice of using design values maps that target a 1% risk of collapse in 50 years, and that ground motions be deterministically capped using updated procedures.

Consistent with this collapse risk target, the performance intent of the NEHRP Provisions 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 (MCE) shaking. 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. Many engineers involved in seismic code development believe that the 1% in 50-year collapse risk (and the 10% risk in MCE shaking) overstates the real risk associated with properly designed code-complying buildings, and that the common analytical approach to performance measurement (e.g. FEMA P-695) is inherently conservative.

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 structural 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.

Two performance-related issues originated in Project 17 and were later considered by the PUC. These are the concept of consolidation of Seismic Design Categories (SDC's) from the current six (A-F) to a lower number; and the stability of ground motion mapped values, and particularly stability of SDC's from one code cycle to the cycle. These are discussed in detail in the Project 17 summary above. As noted, neither of these proposed changes were accepted by the PUC in this cycle. Two Intent-related proposals were approved for Provisions Part 1 and one on functional recovery was approved as a Part 3 white paper. These are summarized below.

Essential Facility Reliability Targets: It is generally assumed that structures designed to Risk Category IV requirements will retain their pre-earthquake function. This proposal sets a target reliability in quantitative terms, suggesting a probability of loss of function of 10 percent or less for RC IV structures subjected to Design Level ground shaking.

Individual Member Reliability Targets: The intent of this proposal is to quantify the probability of failure of individual structural members in Risk Category II, III and IV structures subjected to Design Level and MCE Level shaking. For Design Earthquake shaking, failure probabilities are set at 10% for an RC II structure and 2.5% for an RC IV structure. In MCE shaking, values are set at 25% for RC II structures and 10% for RC IV structures. These values are consistent with the target reliabilities inherent in Chapter 16 NLRH analysis and in the general targets stated in ASCE 7-16 Chapter 1.

Functional Recovery: The consideration of post-earthquake function for buildings that are not designated as Risk Category IV has gained considerable attention at the national and state level. The 2018 NEHRP Reauthorization Act (U.S. Senate, 2018) contains language related to community resilience, as well as seismic risk. Specifically related to seismic standards, it requires recommendation of options for improving the built environment and critical infrastructure to reflect goals stated in terms of post-earthquake reoccupancy and functional recovery time. At the state level (California Legislature, 2019), there is legislature requiring the assembly of a functional recovery working group that will consider whether a functional recovery standard is warranted for some or all occupancies and to investigate the practical means of implementing such a standard. A NIST report titled *Community Resilience Planning Guide for Buildings and Infrastructure Systems* (NIST, 2016) outlines a planning process to help communities set priorities and allocate resources to improve their resilience.

The PUC discussed functional (and economic) level performance in the 2015 Provisions through a Part 3 Resource Paper that was built on the work by NIST. It provided hypothetical performance objectives at each risk category in terms of life safety, function and economic risk using multiple ground motion intensities. In the 2020 Provisions a more comprehensive resource paper has been developed that addresses the relationship between future NEHRP Provisions and resilience-based design. It recognizes the role to be played by building codes and standards in providing design criteria related to functional recovery time and discusses the possible transition of the NEHRP Provisions toward a standard that addresses functional recovery. It acknowledges that resilience involves not only safety but recovery of function, and therefore that the design standards would need to incorporate the element of time, which is not currently done.

Seismic Design Ground Motions

The updated seismic design maps for the 2020 Provisions are based on recommendations from Project 17 (discussed above) and the 2018 update to the USGS National Seismic Hazard Model (NSHM). Project 17 recommendations that transferred directly to the Provisions development effort this cycle include the reestablishment of the risk basis for the maps, the multi-period spectra development, discussed in detail below, and the procedures for computing deterministic caps. As noted above, consistent with current practice, the maps will target a 1% collapse in 50-year collapse risk and include deterministic caps for areas near major active faults.

Where deterministic caps are applied, the risk levels associated with the resulting ground motions are greater than the targets noted above. During Project 17 deliberations, alternative procedures were considered that would allow elimination of the caps. These involved considerations of alternative return period ground motions based on research conducted since the 2475-year return period was selected as appropriate in the nineties during Project 97. Although these alternative procedures were ultimately not adopted, it was agreed that they should be documented for consideration in future code cycles. This information is contained in a Part 3 resource paper titled *Risk Based Alternatives to Deterministic Ground Motion Caps*.

The 2018 NSHM includes incorporation of new ground motion models and soil amplification factors for the central and eastern U.S. (NGA-East), incorporation of basin effects in the western U.S. to provide better estimation of long-period amplifications in deep sedimentary basins in Los Angeles, San Francisco, Salt Lake City and Seattle, and minor adjustments to U.S. ground motion models. The consideration of basin effects represents a significant change from the prior model in which these effects were only represented generically by default values, and results in increases in predicted ground shaking for cities that are built over deep sedimentary basins. The new USGS model accounts directly for basin effects for the four regions listed above and uses default values elsewhere. The model does not recognize a reduction in predicted shaking (from default values) in shallow basin locations.

Another recent USGS seismic modeling update affecting ground motion requirements for this edition of the Provisions is the USGS Uniform California Fault Rupture model (UCERF3). This model differs from prior ones in that it does not include the identification of characteristic earthquakes with limiting magnitudes on faults, but instead uses combinations of regional faulting, potentially resulting in larger but less frequent events. This change resulted in the need to define a new procedure in Chapter 21 (Site Specific Ground Motion Procedures) for setting deterministic caps since prior ones used the characteristic event.

As described further below, the multi-period spectrum procedure will be facilitated through mapped values for ground motion parameters S_{MS} and S_{M1} for the default site class and spectral values for all classes and geographic locations through a USGS web service. Therefore, while the MCE_R spectral values were previously developed for each site class by adjusting the mapped ground motions S_S and S_1 by applying F_a and F_v factors, the provisions now provide S_{MS} and S_{M1} values directly for the USGS NSHM; and while the S_{MS} and S_{M1} values were previously linked to S_S and S_1 values taken at actual periods of 0.2 and 1.0 seconds, they now adhere to the definitions of S_{MS} and S_{M1} given in Chapter 21 which consider a range of periods (as described below).

A companion paper in this conference by Rezaeian and Luco titled *Updates to the USGS National Seismic Hazard Model (NSHM) and Design Ground Motions for 2020 NEHRP Recommended Provisions* provides a more detailed description of the updated USGS NSHM.

Multi-Period Response Spectra

Near the end of the 2015 NEHRP Provisions cycle, studies by Kircher (2015) showed that for many sites the two-parameter (S_S, S_1) spectrum used in combination with site factors (F_a and F_v) does not provide an accurate estimate of the spectral shape of ground motions, particularly at longer periods. This was shown to be the case for soft soil sites affected by major active faults. It was determined that at such sites, peak spectral response values may be significantly underestimated using the conventional design spectrum (defined by S_s and S_1), and instead should be determined based on response at other periods, suggesting the need for multi-period spectral values to be defined. Figure 2, taken from the Chapter 11 Commentary of the 2015 Provisions, shows the multi-period design spectrum compared to the standard three-domain ELF design spectrum for a Site Class D site. For this site, the multi-period spectral value at a period of 1 second exceeds the standard (1/T) design curve by more than 20 percent. This effect is significantly greater for a Site Class E site. Since there was not sufficient time for USGS to develop multi-period spectra in the 2015 cycle, the interim solution, now included in ASCE/SEI 7-16, was to require site-specific seismic studies for the design of structures on sites classified as Site Class D and E in areas of moderate and high seismic hazard unless conservative simplifying assumptions are made relative to design spectral values. In this cycle, the multi-period spectrum issue was addressed in a Project 17 work group and that work was transferred to the PUC.

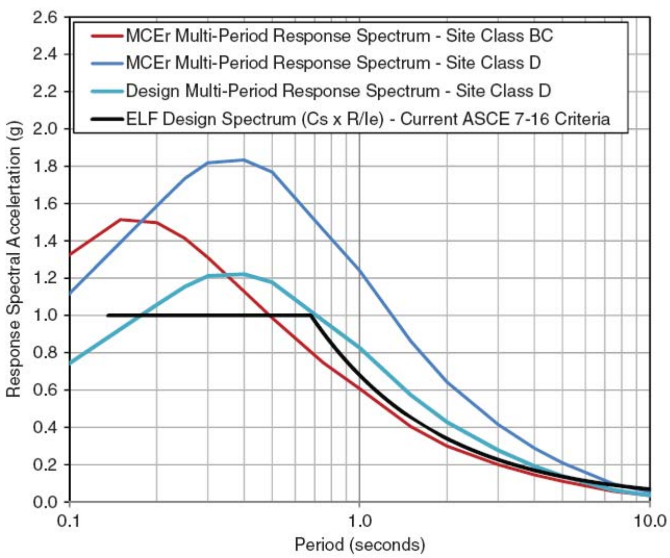

Figure 2 Comparison of ELF and Multi-Period Design Spectra – Site Class D Ground Motions ($v_{S,30}$ = 870 ft/s) from 2015 NEHRP Provisions Commentary

In the multi-period response spectrum (MPRS) approach, a database of MCE-level spectral acceleration values is provided by USGS for a geographic array of gridded data points for periods ranging from zero to 10 seconds for each site class. Consistent with current practice, Design Spectral Response values are taken as 2/3 of the MCE-level values. Spectral values for sites outside of the gridded values will be obtained by geographic interpolation. Since site class is integrated into the spectral values, the site coefficient tables are eliminated. This database will replace the maps of S_S and S_1 ground motion parameters that have been produced since the 1997 NEHRP Provisions. The amount of data required to represent the full spectral shape associated with the range of site classes and the full geographic grid makes it impractical to use maps to obtain spectral acceleration values.

Implementing the multi-period spectrum approach in the design requirements involves substantial changes to Chapters 11 (Seismic Design Criteria), Chapter 20 (Site Classification Procedure), Chapter 21 (Site-Specific Ground Motion Procedures), and Chapter 22 (Seismic Ground Motion Maps). The seismic design requirements for buildings in Chapter 12 and nonbuilding structures in Chapter 15 are also affected.

Chapter 11 allows either of two approaches to be used to determine design response parameters if a site-specific analysis per chapter 21 is not used: either the multiperiod spectrum discussed above, or a simplified two-period design response spectrum, representing the traditional three-domain design spectrum. Web applications, based on USGS-derived data, provide the multi-period spectral values, as well as the S_{MS} and S_{M1} values to create S_{DS} and S_{D1} values (for the two-period spectrum) based on user-provided values of site location and site class. The two-period spectrum is provided as an alternate to the multiperiod spectrum specifically for locations where multiperiod data is not available from the USGS web service.

In order to provide a better definition of the multi-period spectral shape on sites where it can vary significantly as a function of site class, intermediate site classes have been introduced. Site soil properties are now required to be classified as Site Class A, B, BC, C, CD, D, DE, E or F. The new BC (soft rock), CD (dense sand or very soft clay) and DE (loose sand or medium stiff clay) classes are introduced to provide the smoother transition between classes. The requirement to use the default site class (that producing highest spectral response accelerations) is maintained, and now incorporates the new Site Class CD, in addition to Classes C and D.

Chapter 12 and Chapter 15 provisions continue to be framed in terms of design earthquake ground motions S_{DS} and S_{D1} and only minor changes are required in the Equivalent Lateral Force Procedure.

Chapter 20 (Site Classification Procedure) provides revised definitions of site classes. The effort to add the three new site classes noted above led to a reassessment of the correlations between shear wave velocity, standard penetration resistance (blow count), and undrained shear strength, upon which the definitions in the Site Classifications Table are based. The site classification procedure has been revised to define site class strictly in terms of shear wave velocity, which is considered more accurate. For sites at which shear wave velocity is not measured, or where it is not measured to a 100 foot depth, approximate generalized correlations between shear wave velocity and the other geotechnical parameters may be used to obtain an estimated shear wave velocity.

Chapter 21 (Site Specific Ground Motion Procedures) defines probabilistic and deterministic MCE ground motions and allows spectral response accelerations to be taken as the lesser of the two. As noted above, changes in USGS modeling procedures have resulted in the need to redefine the deterministic ground motion. Where the deterministic value was previously defined based on a single-magnitude characteristic earthquake on faults, it is now based on a scenario earthquake, which is determined from hazard deaggregation of the probabilistic ground motions at the site. In this procedure the contribution of each active fault to the total hazard at a site is considered. Any fault that contributes less than 10% of the largest contributor at each period is ignored.

Section 21.4 defines the spectral response parameters S_{MS} and S_{M1} as 1.5 times the values S_{DS} and S_{D1}, which are defined as follows:

- S_{DS} is taken as 90% of the maximum value of the MCE_R spectral response accelerations between periods 0.2 and 5 seconds, inclusive.
- S_{D1}, for sites with values of $v_{S,30}$ greater than 1,200 ft/sec, is taken as 90% of the maximum value of TS_a for periods ranging from 1 to 2 seconds.
- S_{D1}, for sites with values of $v_{S,30}$ less than or equal to 1,200 ft/sec, is taken as the maximum value of TS_a for periods ranging from 1 to 5 seconds, but not less than 100% of the value of Sa at 1.0 second.

The $v_{S,30}$ value of 1,200 ft/sec corresponds to a CD site class (dense sand or very stiff clay). As noted above, the values S_{MS} and S_{M1} obtained from the USGS website are consistent with these definitions.

A companion paper in this conference by Charles Kircher titled *Proposed Multi-Period Response Spectra and Ground Motion Requirements of 2020 NEHRP Provisions and ASCE/SEI 7-22* provides a more detailed description of the multi-period spectrum.

Shear Walls

Two new ductile shear wall systems are being proposed for inclusion in ASCE/SEI 7 Table 12.2-1 – one of reinforced concrete, called a *Ductile Coupled Shear Wall*, and one of structural steel, called a *Composite Steel Plate Shear Wall with Coupling*. Both derive significant energy dissipation capacity through coupling beam yielding, with the resulting overall seismic behavior expected to be superior to the currently defined special shear wall systems, which do not specifically consider the configuration of internal wall elements. Both systems are considered particularly useful in mid-rise and high-rise construction, especially those utilizing a core wall system. In both cases, the research included FEMA P-695 studies intended to justify design coefficients and factors representing greater ductility, proposing Response Modification Coefficients, R equal to 8. A brief description of the two systems is given below.

The reinforced concrete ductile coupled wall system has been accepted by ACI 318-19, which defines a Ductile Coupled Wall as an assembly of walls with aspect ratio of total wall height to length greater than 2.0 which are linked by coupling beams having length to height aspect ratios between 2 and 5. The limit on wall aspect ratio is intended to ensure that wall behavior at the critical section is governed by flexural yielding prior to shear failure, while the limit on coupling beam aspect ratio is intended to assure that the overall inelastic energy dissipation is dominated by coupling beam yielding. Additional constraints are included to assure participation of a high percentage (at least 90%) of the coupling beams in the seismic system. This is done by requiring that participating coupling beams meet the specified aspect ratio range and that special reinforcing detailing requirements are met. FEMA P-695 studies show that this system is inherently superior to the special reinforced concrete shear wall system that is assigned an R-factor of 6. ACI 318-19 detailing requirements for this system will be referenced by the 2020 NEHRP Provisions and ASCE 7-22.

The composite steel plate system with coupling also involves a coupling-beam enhancement to a special shear wall system currently defined in ASCE 7-16. This system is comprised of composite wall panels and coupling beams with the wall panels constructed of a concrete core sandwiched between two steel faceplates. The faceplates are connected by tie bars, which are embedded in the concrete infill to form composite action. Inelastic deformation occurs first in the coupling beams, then in flexural yielding at the base of the individual wall sections. Similar to the concrete coupled wall system, configurational requirements are included to assure ductile behavior. The aspect ratios of coupling beam are required to be between 3 and 5 to assure flexural behavior. Also, all stories of the building are required to have coupling beams with aspect ratios greater than 3, and at least 90% of the stories are required to have aspect ratios less than 5. It is intended that design and detailing requirements for this system will be covered in the 2022 edition of AISC 341. In the interim, these requirements are described in the 2020 NEHRP Provisions and ASCE 7 Chapter 14.

A companion paper in this conference by S.K. Ghosh titled *Ductile Coupled Reinforced Concrete Shear Walls and Coupled Composite Steel Plate Shear Walls as Distinct Seismic Force-Resisting Systems* provides a more detailed description of the new shear wall systems.

Diaphragm Design

Alternative diaphragm design provisions were developed in the 2015 Provisions cycle and adopted in ASCE 7-16. These provisions, offered as an alternative to the traditional diaphragm design requirements, acknowledge results of recent analytical studies and large-scale testing, which show that actual forces imposed on diaphragms during strong ground shaking can be significantly higher than those predicted by traditional elastic design code requirements. The new provisions also acknowledge component testing results that show the ductility and capacity of most traditional systems generally exceeds allowable values. In short, it was concluded that demands inherent in traditional requirements have been underestimated but have been assessed against unrealistically low elastic capacities. The alternative provisions provide a new equation to calculate demands along the height of the building, not simply based on forces that are a multiple of floor forces from the ELF procedure and provide new diaphragm R-factors (R_S) for systems utilizing cast-in-place concrete, precast concrete, and wood sheathing. Diaphragm systems constructed of bare steel deck were omitted from the 2015 provisions due to a lack of available research.

Diaphragm studies conducted in the 2015 Provisions cycle also considered the specific performance of one-story rigid wall-flexible diaphragm (RWFD) buildings, that is, buildings for which response is dominated by dynamic response and inelastic action in the diaphragm. However, technical proposals did not evolve into code-language. A Part 3 Resource Paper titled *One-Story Flexible Diaphragm Buildings with Stiff Vertical Elements* is published the 2015 Provisions, based largely on FEMA P-1026, *Seismic Design of Rigid Wall-Flexible Diaphragm Buildings: An Alternate Procedure* (FEMA, 2015).

Since the last cycle, significant research has been conducted on bare metal deck diaphragms through the Steel Diaphragm Innovation Initiative, a collaboration involving industry-sponsored academic research. Within this initiative, research by Schafer (2019, Schafer) and others justified the inclusion of metal deck diaphragms in the alternative provisions discussed above, and in the new set of provisions related to one-story RWFD buildings discussed below. The research covers metal deck performance from the standpoint of overall diaphragm behavior as well as the deck connectivity level, considering fasteners at deck seams and from deck to framing.

In this cycle, specific provisions have been developed for one-story RWFD buildings, including a complete set of design requirements applicable to diaphragms utilizing both wood sheathing and bare metal deck, and a simplified two-stage analysis, akin to the two-stage procedure allowed in the code for podium structures (rigid base and flexible upper levels) has been added. A key concept inherent in the bare steel deck provisions is that ductile steel deck diaphragm response only occurs when special detailing requirements are met, addressing deck to deck and deck to framing connectivity. An interesting finding from the research is that steel deck that is mechanically fastened along deck section boundaries and to the underlying building frame performs well under high seismic demands, if properly detailed. However, steel deck that is welded, while having good strength and stiffness, is unable to develop the inelastic redistribution that is required in RWFD buildings. Diaphragm R_S factors have been proposed for bare steel deck systems, for both the one-story RWFD case and for the alternative diaphragm provisions.

A companion paper in this conference by Kelly Cobeen titled *New Provisions for Seismic Design of Diaphragms* provides a more detailed description of the new diaphragm design proposals.

Nonstructural Components:

Significant technical and organizational changes are proposed for Chapter 13 on Nonstructural Components. The technical basis for much of the proposed change is derived from ATC 120, a NIST-funded project titled *Recommendations for Improved Seismic Performance of Nonstructural Components*, (NIST, 2018) which had the goal of improving technical aspects of nonstructural design in areas that will have the greatest impact on public safety and economic welfare. ACT 120 acknowledged that nonstructural components and systems generally account for a significant percentage of the overall earthquake damage to a building, depending on occupancy and shaking intensity.

From a practice standpoint, the most significant proposed change to Chapter 13 is related to the horizontal force (F_p) equation, which has been in the provisions since 1997 and is based in part on an examination of instrumented building records. Criticisms of the current equation are related to the component amplification factor a_p and the amplification of accelerations over the height of the building. The a_p factor is currently capped at a value of 2.5, whereas analyses show that where the period of the component closely matches with any mode of the supporting structure, the mean amplification can significantly exceed that value. The floor accelerations of the building height are currently estimated by a triangular force distribution assumption, which in most cases overestimates floor accelerations, especially in flexible buildings, but in some cases underestimates them. In addition, ATC 120 studies show that the building structural system has a significant effect on component acceleration, which is not currently accounted for. For example, for a given building height, the ratio of peak component acceleration to peak ground acceleration (PCA/PGA) is higher for a stiffer lateral system than a more flexible one. In addition, studies show that component amplification is greater in buildings with low-ductility lateral systems than in buildings with higher ductility systems. While the primary emphasis of the proposed change is related to the influence of the supporting structure on response, the properties of the nonstructural components and the likelihood of resonance were also considered.

The proposed force equation is as follows:

$$F_p = 0.4S_{DS}I_pW_p\,(H_f/\,R_\mu)\,(C_{AR}/R_{p0})$$

In this formula, the factor H_f addresses peak floor acceleration relative to peak ground acceleration (PFA/PGA); the factor R_μ addresses structure ductility and overstrength; the factor C_{AR} addresses component resonance; and the factor R_{p0} addresses component strength. As in the current formula, $0.4S_{DS}$ addresses seismic hazard level and I_p addresses importance. The factors C_{AR} and R_{p0} are based largely on engineering judgment.

A companion paper in this conference by Bret Lizundia titled *Proposed Nonstructural Seismic Design Force Equations* provides a more detailed description of the new Chapter 13 proposals.

Other Proposed Changes to Seismic Design Criteria and Requirements

Configuration Irregularities: A FEMA-funded ATC project titled *ATC 123-3 Assessing Seismic Performance of Buildings with Configuration Irregularities: Calibrating Current Standards and Practice* (ATC 2018) provided useful information related to the effects of configurational irregularities on building seismic response and the effectiveness of the current provisions in improving performance. In that project, FEMA P-695 analysis was used to study collapse margin ratio of buildings with mass and configuration irregularities. Among other findings, the ATC 123 studies showed that collapse performance was not substantially affected by either the magnitude of a mass irregularity or whether a building was designed using the Equivalent Lateral Force (ELF) procedure of Modal Response Spectrum Analysis (MRSA). Based on this, a proposal was developed to eliminate the requirement for MRSA from the Vertical Structural Irregularities table. In addition, with respect to torsion-related provisions, ATC 123 analyses showed that current design provisions are generally conservative, with the exception of buildings that rely heavily on lines of resistance orthogonal to the earthquake force for torsional resistance. Accordingly, a proposal was developed to reduce unnecessary conservatism from current provisions, while adding provisions for building configurations that are not adequately addressed by current provisions.

Design Story Drift: The PUC considered the current requirements for story drift calculation and its application to protection against failure due to such actions as deformation compatibility and structural separation. An issue is whether design earthquake (2/3 MCE) story drifts should be amplified by the structural system (Table 12.2-1) R-factor rather than the C_d factor. This led to an effort to collect available information from nonlinear numerical studies and testing. It was determined that definitively answering this question required an effort that was beyond the scope of what could be achieved in this NEHRP cycle. However, several drift-related proposals were developed in this cycle. The first, addressing the general C_d vs. R issue, is a Part 3 resource paper that documents issues that arose in the studies undertaken and recommends steps that may be taken in the next PUC cycle or by separately funded research. Another proposal requires the amplification of design story drifts by the R-factor in the consideration of deformation compatibility. This was passed because it was judged have significant safety-related implications and is similar to a stopgap provision instituted in ASCE 7-10 related to members spanning between structures. A third drift-related proposal, not related to the C_d vs. R issue, creates definitions needed for the provisions to include diaphragm deformation in displacements related to deformation compatibility, structural separation and at supports of members spanning between structures.

System Selection: A proposal was developed related to the requirements in Section 12.2.1, which defines the seismic force resisting system selection and limitations, and the conditions under which exceptions can be made. It provides an exception that allows buildings with lateral force resisting systems conforming to the requirements of Table 12.2-1 to exceed the height limits prescribed in that table when the building is designed to the requirements of Chapter 16 on nonlinear response history analysis. It is based on the concept that the rules and acceptance criteria given in Chapter 16 provide adequate assurance of safety in such cases without the rigor associated with the FEMA P-695 methodology.

Seismic Lateral Earth Pressures: For structures assigned to Seismic Design Categories D, E and F, ASCE/SEI 7 Chapter 11 requires consideration of dynamic seismic earthquake pressures on basement and retaining walls, but the standard does not specify the methods for calculating these pressures. Conventional practice typically involves a pseudo-static acceleration applied to a mass of the retained soil assumed to be at a failure state. Recent research suggests that this classical approach is fundamentally flawed and generally results in an overestimation of earth pressures. A Part 3 resource paper presents an alternative method to account for the physical mechanisms that produce seismic earth pressures. The procedures pertain to the seismic increment of earth pressure, as opposed to the pre-seismic (static) pressure. The seismic increment is additive to the static pressure.

Cross Laminated Timber Shear Walls: This new lateral force resisting system was proposed late in the current provisions update cycle, and at the time of this publication, is under consideration by the PUC. From a timber industry perspective, an advantage of the CLT system is the speed with which it can be constructed. If accepted, it would result in a new system in Table 12.2-1 complete with design coefficients based on research involving testing and FEMA P 695 analysis. Two variants of the system are proposed: one utilizing high aspect ratio having a height to length ratio of 4, for which an R factor of 4 is proposed, and the other with ratios between 2 and 4, for which an R factor of 3 is proposed. In both cases, the height limit for all seismic design categories is 65 feet. The aspect ratios were selected based on the availability of test results. A key to the ductility of the CLT system is the top and bottom connection of panels, which consist of prescribed steel angles with bolts and nails.

Nonbuilding Structures Provisions Changes: Two provisions changes were developed related to Chapter 15 on Nonbuilding Structures. The first involves a modification of the *coupled analysis* provisions, affecting the analysis and design of a combined system including a structure supporting a large nonbuilding structure or nonstructural component (thus also affecting Chapter 13). The proposal changes the ratio of secondary weight to total weight that triggers a combined analysis from 25% to 20% and specifies design requirements in terms of R and R_p factors. The second change addresses the design of corrugated steel liquid storage tanks, which currently are not specifically addressed in the provisions. The new provisions address Chapter 15 design requirements and materials specifications. In addition, there was a general reorganization effort intended to clarify the scopes of Chapters 13 and 15.

Summary

The 2020 NEHRP Recommended Provisions for New Buildings and Other Structures will fulfill the stated FEMA and BSSC goal of developing a nationally applicable resource document that introduces new provisions and modifications to the seismic provisions in national standards and model building codes, provides a detailed commentary corresponding to that standard, and introduces new technologies for use by design professionals on a provisional basis. This paper, and the associated technical presentation session, contributes to the goal of outreach to the structural engineering community.

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