Proposed Multi-Period Response Spectra and Ground Motion Requirements of the *2020 NEHRP Recommended Provisions* and *ASCE 7-22*

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Abstract

This paper summarizes a comprehensive set of proposals to the Provisions Update Committee of the Building Seismic Safety Council that would incorporate multi-period response spectra (MPRS) in the 2020 edition of the *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures* (*2020 NEHRP Provisions*) and related proposals to the ASCE 7-22 Seismic Subcommittee of the American Society of Civil Engineers for incorporation of MPRS in the ASCE Standard, *ASCE/SEI 7-22*, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE 7-22).* Ultimately, the intent is that the proposed MPRS and related design requirements of *ASCE 7-22* would be adopted, by reference, as part of the *2024 International Building Code*.

Introduction

The multi-period response spectra (MPRS) proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* would define MCE_R ground motions at 22 response periods (from PGA to 10 seconds) for the site class of interest. The MPRS proposals would primarily affect the seismic design criteria of Chapter 11, the site classification requirements of Chapter 20, the site-specific ground motions procedures of Chapter 21, and the seismic ground motion maps of Chapter 22. The proposed changes to MCE_R ground motions (Chapter 11 and 22) incorporate the most recent (2018) update of the United States Geological Survey (USGS) National Seismic Hazard Model (NSHM) (Petersen et al., 2019).

The proposed changes would collectively improve the accuracy of the frequency content of earthquake design ground motions and enhance the reliability of the seismic design parameters derived from these ground motions by defining earthquake design ground motions in terms of MPRS. Such changes would make better use of the available earth science which has, in general, sufficiently advanced to accurately define spectral response for different site conditions over a broad range of periods. Three new site classes would be added to better describe site effects.

The proposed changes would eliminate the need for site-specific hazard analysis now required by *ASCE 7-16* for certain (soft soil) sites. The proposed changes would directly incorporate site amplification and other site (and source) dependent effects in the design parameters S_{DS} and S_{D1} (two-thirds of S_{MS} and S_{M1}) eliminating the need for site coefficients. Site-specific values of design parameters (and corresponding MPRS) would be available online at a USGS web site and presumably other related web sites (e.g., SEAOC, ASCE and ATC web sites) for user-specified values of site location and site class. Traditional design methods (e.g., ELF procedure) familiar to and commonly used by engineering practitioners for building design would not change.

The following sections provide background on recent seismic code development work relevant to the MPRS proposals, an overview of the seismic design criteria and site-specific requirements of *ASCE 7-16*, a summary of the proposals to incorporate MPRS in Chapters 11, 20, 21 and 22 of the *2020 NEHRP Provisions* and *ASCE 7-22*, an overview of the 2018 update of the USGS NSHM, which forms the basis of the new MCE_R ground motions of the conterminous United States, a summary of the methods used by the USGS to calculate MCE_R ground motions proposed for non-conterminous United States sites, and examples comparing multi-period design spectra proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* with the design spectra of *ASCE 7-10* and *ASCE 7-16* for selected conterminous and non-conterminous United States sites.

Background

During the closing months of the *2015 NEHRP Provisions* cycle, a study, referred to herein as the ELF Study (Kircher & Associates, 2015), was undertaken on behalf of the Provisions Update Committee (PUC) of the Building Seismic Safety Council (BSSC) to investigate the compatibility of current Site Class coefficients, F_a and F_v, with the ground motion models (GMMs) used by USGS to produce the design maps. In the course of this study, it was discovered that the standard three-domain spectral shape defined by the short-period response spectral acceleration parameter, S_{DS}, the 1-second response spectral acceleration parameter, S_{D1}, and long-period transition period, T_L, is not appropriate for soft soil sites (Site Class D or softer), in particular where ground motion hazard is dominated by large magnitude events. Specifically, on such sites, the standard spectral shape substantially understates spectral response for moderately long period structures.

The 2015 NEHRP PUC initiated a proposal to move to specification of spectral acceleration values over a range of periods, abandoning the present three-domain format, as this would provide better definition of likely ground motion demands. However, this proposal was ultimately not adopted due to both the complexity of implementing such a revision in the design procedure and time constraints. Instead, the PUC adopted a proposal prohibiting the general use of the three-parameter spectrum, and instead requiring site-specific hazard determination, for longer period structures on soft soil sites.

Subsequently, *Project 17*, a joint committee of BSSC volunteers and USGS representatives, was charged with formulating rules by which the next-generation seismic design value maps would be developed (NIBS, 2019). This included re-evaluating the use of multi-period spectra as a replacement or supplement to the present three-domain (two-period) spectral definition, and consideration of how the basic design procedures embedded in *ASCE 7-16* should be modified for compatibility with the multi-period spectra. As a result, *Project 17* developed (and unanimously approved) a comprehensive multi-period response spectra (MPRS) proposal, in four parts, for consideration by the 2020 NEHRP PUC. The four parts separately address MPRS-related changes to Chapters 11, 20, 21 and 22, respectively, and form the basis of the MPRS proposals for the *2020 NEHRP Provisions* and *ASCE 7-22*.

Overview of *ASCE 7-16* Seismic Design Criteria

ASCE 7-16 includes Chapter 11 which provides seismic design criteria based on site class, Chapter 20 which defines site classes, Chapter 21 which describes site-specific earthquake ground motion procedures and Chapter 22 which provides maps of risk-adjusted maximum considered earthquake (MCE_R) earthquake ground motion parameters (S_s and S_1) and the long-period transition period parameter (T_L). Chapter 12 prescribes seismic design requirements for buildings and Section 12.6 defines the applicability of permitted analytical procedures that include the equivalent lateral force (ELF) procedure of Section 12.8, the modal response spectrum analysis (MRSA) methods of Section 12.9 and the seismic response history procedures of Chapter 16.

Section 11.4.4 provides equations for determining values of the MCE_R spectral response acceleration parameters at short periods (S_{MS}) and at 1.0 s (S_{M1}) adjusted for site class effects. Section 11.4.5 defines the design earthquake spectral acceleration parameter at short periods (S_{DS}) and at a period of 1.0 s (S_{D1}) as 2/3 of the parameters S_{MS} and S_{D1}, respectively. Section 11.4.6 defines the frequency content of design ground motions using Figure 11.4-1 with domains of constant acceleration (S_{DS}), constant velocity (S_{D1}/T) and constant displacement ($S_{D1}T_L/T^2$), as shown in Figure 1. The parameters S_{DS} and S_{D1} are used in Section 12.8 to determine seismic base shear of the ELF design procedure and the design response spectrum of Figure 11.4-1 is used in Section 12.9 for MRSA.

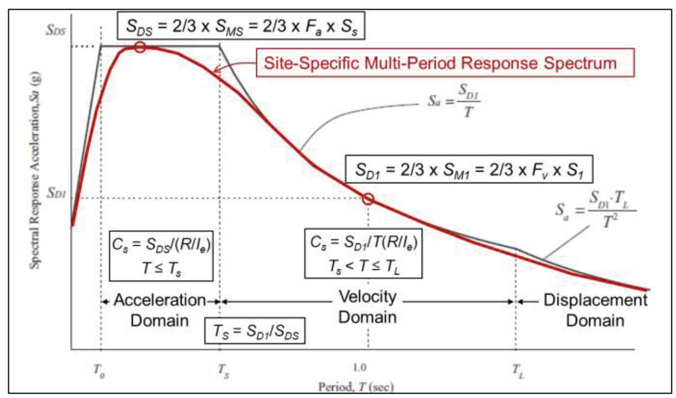

Figure 1. Design response spectrum (copy of Figure 11.4-1, *ASCE 7-16*) anchored to corresponding site-specific multi-period response spectrum with annotation showing domains of constant acceleration, velocity and displacement and associated design parameters).

The ELF procedure is permitted for design of all SDC B and C structures and for design of SDC D, E, F structures of regular configuration that are less than 160 feet in height, or which have a design period $T < 3.5\ T_s$, or which are less than 160 feet and do not have severe irregularity (Table 12.6-1), where the transition period, T_s, is defined by the ratio of the design spectral acceleration parameters, $T_s = S_{D1}/S_{DS}$. MRSA is permitted for all structures, regardless of configuration or design period, using the design response spectrum shape of Figure 11.4-1, unless site-specific ground motion procedures are required to define response spectral accelerations (Section

11.4.8). The vast majority of all buildings are designed for seismic loads using either the ELF procedure or MRSA methods and the design spectrum of Figure 11.4-1.

Site-Specific Requirements of *ASCE 7-16*

Significant changes were made to the requirements of Section 11.4.8 requiring site-specific hazard analysis of Chapter 21 to be used for design of:

(1) Structures on Site Class E with values of S_S greater than or equal to 1.0 g, and

(2) Structures on Site Class D or Site Class E for values of S_1 greater than or equal to 0.2 g.

The site-specific requirements of ASCE 7-16 could significantly impact the use of practical ELF (and MRSA) design methods, of particular importance for design of a building at a Site Class D site which is quite common. To minimize the impact of proposed changes on design practice, the site-specific requirements include three exceptions permitting the use of reasonably conservative values of seismic design parameters, in lieu of performing a site-specific ground motion analysis. The three exceptions permitting ELF (or MRSA) design without performing a site-specific ground motion analysis are given below for:

(1) Structures on Site Class E sites with S_S greater than or equal to 1.0, provided the site coefficient F_a is taken as equal to that of Site Class C.

(2) Structures on Site Class D sites with S_1 greater than or equal to 0.2, provided the value of the seismic response coefficient C_s is determined by Eq. (12.8-2) for values of $T \leq 1.5T_s$ and taken as equal to 1.5 times the value computed in accordance with either Eq. (12.8-3) for $T_L \geq T > 1.5T_s$ or Eq. (12.8-4) for $T > T_L$.

(3) Structures on Site Class E sites with S_1 greater than or equal to 0.2, provided that T is less than or equal to T_s and the equivalent static force procedure is used for design.

The first exception permits use of the value of the site coefficient F_a of Site Class C (F_a = 1.2) for Site Class E sites (for values of S_S greater than or equal to 1.0 g) in lieu of site-specific hazard analysis. The ELF study (Kircher & Associates, 2015) found that while values of the site coefficient (F_a) tend to decrease with intensity for softer sites, the shape of the spectrum tends to offset this reduction such that the net effect is approximately the same amplitude of MCE_R ground motions for Site Classes C, D and E where MCE_R ground motions are strong (i.e., $S_{MS} \geq 1.0$). Site Class C was found to not require spectrum shape adjustment and the value of site coefficient F_a for Site Class C (F_a = 1.2) is large enough to represent both site amplification and spectrum shape effects for Site Class E.

The second exception permits both ELF (and MRSA) design of structures at Site Class D sites for values of S_1 greater than or equal to 0.2 g, provided that the value of the seismic response coefficient C_s is calculated using Eq. 12.8-2 for $T \leq 1.5T_s$ and using 1.5 times the value computed in accordance with either Eq. 12.8-3 for $T_L \geq T > 1.5T_s$ or Eq. 12.8-4 for $T > T_L$. This exception presumes that structures would be designed conservatively for response spectral accelerations defined by the domain of constant acceleration (S_{DS}) or by a 50 percent increase in the value of seismic response coefficient C_s for structures with longer periods ($T \geq 1.5T_s$). The underlying presumption of this exception for MRSA design of structures is that the shape of the design response spectrum (Figure 11.4-1) is sufficiently representative of the frequency content of Site Class D ground motions to permit use of MRSA methods and that the potential underestimation of fundamental-mode response using the design response spectrum shape of Figure 11.4-1 is accounted for by scaling MRSA design values (Section 12.9.4) with a reasonably conservative value of the seismic response coefficient C_s.

The third exception permits ELF design of short-period structures ($T \leq T_s$) at Site Class E sites for values of S_S greater than or equal to 0.2 g. This exception recognizes that short-period structures are conservatively designed using the ELF procedure for values of seismic response coefficient C_s based on the domain of constant acceleration (S_{DS}) which is, in all cases, greater than or equal to response spectral accelerations of the domain of constant velocity. In general, the shape of the design response spectrum (Figure 11.4-1) is not representative of the frequency content of Site Class E ground motions and MRSA is not permitted for design unless the design spectrum is calculated using the site-specific procedures of Section 21.2.

The three exceptions effectively limit mandatory site-specific analysis to taller buildings (i.e., buildings with a design period, $T \geq T_s$) located at Site Class E sites. However, based on the exceptions of Section 11.4.8, the value of the seismic response coefficient (C_s) of *ASCE 7-16* could be as much as 70 percent greater than that of *ASCE 7-10* for mid-period buildings at Site Class D sites. This very significant increase in the value of C_s applies to most United States sites of higher seismicity (i.e., Site Class D sites with S_1 greater than or equal to 0.2).

Key changes to the Seismic Design Criteria of Chapter 11 proposed for the *2020 NEHRP Provisions* and *ASCE 7-22*

Proposed changes to seismic design criteria of Chapter 11 would incorporate values of seismic design parameters S_{MS} and S_{M1} (and S_{DS} and S_{D1}) derived from MPRS of the site of interest that include site amplification, spectrum shape, and other site (and source) effects. Users would obtain values of these and other ground motion data from a USGS web service for user-specific values of the location (i.e., latitude and longitude) and site conditions (i.e., site class) of the site of interest.

Values of seismic design parameters S_{MS} and S_{M1} (and S_{DS} and S_{D1}), provided by the USGS web service, preclude the need to define earthquake ground motions for "reference site" conditions (Site Class BC) and site amplification factors for determining earthquake ground motions for other site conditions. Accordingly, proposed changes to Chapter 11 would eliminate the tables of site coefficients, F_a and F_v.

The definition of seismic design parameters S_{DS} and S_{D1} (two-thirds of S_{MS} and S_{M1}) and their use in Chapter 12 and other chapters of *ASCE 7-22* to define seismic loads for ELF design, etc., would remain the same as that of *ASCE 7-16* (and other prior editions of that standard). Traditional methods familiar to and commonly used by engineering practitioners for building design would not change. Figure 2 is an annotated copy of the traditional two-period design spectrum proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* illustrating the relationship of seismic design parameters S_{DS} and S_{D1}, the underlying site-specific multi-period design spectrum, and the ELF seismic design coefficient, C_s.

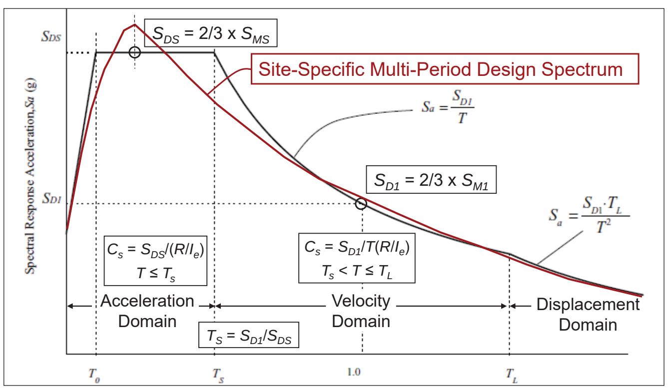

Figure 2. Annotated copy of the traditional two-period design spectrum proposed for the *2020 NEHRP Provisions* (and *ASCE 7-22*); essentially the same as the design spectrum of *ASCE 7-16*.

As a preferred alternative to the traditional two-period design spectrum, proposed changes to Chapter 11 incorporate site-specific MPRS in the seismic ground motion criteria (e.g., site-specific multi-period design spectrum shown in Figure 2). Like parameters S_{MS} and S_{M1} (and S_{DS} and S_{D1}), users would obtain values of site-specific MPRS from a USGS web service for specific values of the location (i.e., latitude and longitude) and site conditions (i.e., site class) of the site of interest. Site-specific MPRS provide a more refined description of the frequency content of the ground motions that would be suitable for multi-mode response spectrum analysis and the selection and scaling ground motion records for nonlinear response history analysis.

Proposed values of seismic design parameters S_{DS} and S_{D1} (and S_{MS} = 1.5 S_{DS} and S_{M1} = 1.5 S_{D1}) would be developed by the USGS from the multi-period design spectrum for the site class of interest in accordance with the proposed requirements of Section 21.4 of the *2020 NEHRP Provisions* and *ASCE 7-22*. Figure 3 illustrates the requirements of proposed Section 21.4 for a hypothetical high seismicity site with soft soil Site Class DE site conditions (V_{S30} = 600 fps). In this example, the value of S_{DS} is about 1.03 g (i.e., 0.9 x 1.14 g) and the value of S_{D1} is about 1.58 g (i.e., (3 s/1 s) x 0.53 g) with a corresponding transition period, T_S, of about 1.54 seconds. The frequency content of the design spectrum (i.e., two-thirds of the MCE_R spectrum) of this example reflects the combined effects of site amplification and spectral shape, both of which contribute significantly to the long-period frequency content for this soft soil site.

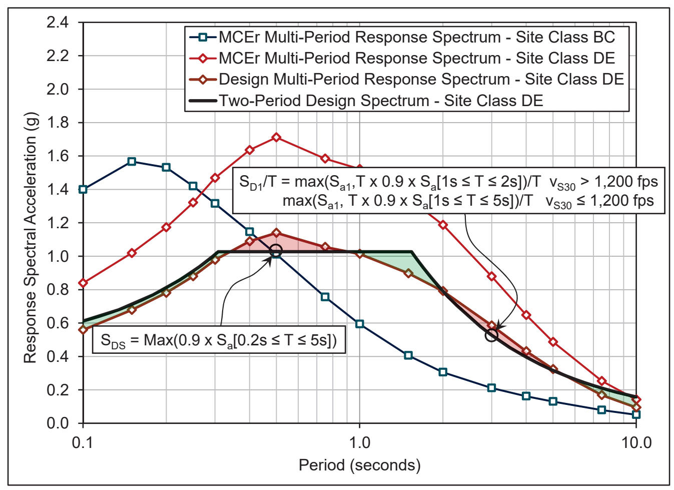

Figure 3. Example derivation of values of S_{DS} and S_{D1} from a multi-period site-specific design spectrum for a hypothetical high seismicity site with soft soil Site Class DE site conditions (V_{S30} = 600 fps).

Spectrum shape effects are not included in the site coefficients of *ASCE 7-16*, which necessitated requiring site-specific ground motion analysis for softer soil sites. The MPRS proposals would eliminate the need for such analyses, and proposed changes to Chapter 11 (of *ASCE 7-16*) for site-specific analysis would revert back to those of *ASCE 7-10* (e.g., site-specific analysis would only be required for Site Class F sites with very poor soil conditions prone to potential failure under seismic loading).

Proposed changes to Chapter 11 would add three new site classes (Site Class BC, CD and DE) to more accurately define the frequency content of earthquake ground motions, of particular importance to accurate characterization of ground motions of softer sites at longer periods of response. New site classes, including revised ranges of V_{s30} values and related site classification criteria, are proposed as changes to Chapter 20.

A new “Default” site class is proposed as the more critical spectral response of Site Class C, CD, and D, for design where soil properties are not known in sufficient detail to reliably determine the site class. This is, in concept, consistent with *ASCE 7-16,* which effectively requires the more critical of Site Class C and D to be used for design where soil properties are not known in sufficient detail to determine the site class.

Key changes to the Site Classification Criteria of Chapter 20 proposed for the *2020 NEHRP Provisions* and *ASCE 7-22*

As noted in the previous section, proposed changes to Chapter 20 would provide a more refined classification of site conditions and thereby improve the accuracy of site amplification and associated values of seismic design parameters at longer response periods, and define the “Default” site class in terms of the maximum site amplification of Site Class C (Very Dense Soil or Hard Clay), Site Class CD (Dense Sand or Very Stiff Clay) or Site Class D (Medium Dense Sand or Stiff Clay).

Proposed changes would add to Table 20.3-1 three new site classes, Site Class BC (Soft Rock), Site Class CD (Dense Sand or Very Stiff Clay) and Site Class DE (Loose Sand or Medium Stiff Clay), and the associated ranges of average shear wave velocity and other site classification criteria for these new site classes. The new site classes would be centered on existing site class boundaries (e.g., center of Site Class BC is 2,500 fps, center of Site Class CD is 1,200 fps, and center of Site Class DE is 600 fps). Table 1 describes the eight site classes proposed for Table 20.3-1; the upper-bound, lower-bound, and center values of shear wave velocity (V_{S30}) of each site class; and the rounded, center of range values of shear wave velocity used by the USGS to develop site-specific MPRS ground motions (i.e., proposed for Chapter 22).

Table 1. Site classes and associated values of shear wave velocity.

Site Class		Shear Wave Velocity, V_{s30} (fps)			USGS[2] V_{s30} (mps)
Name	Description	Lower Bound[1]	Upper Bound[1]	Center	
A	Hard rock	5,000			2,000
B	Medium hard rock	3,000	5,000	3,536	1,080
BC	Soft rock	2,100	3,000	2,500	760
C	Very dense soil or hard clay	1,450	2,100	1,732	530
CD	Dense sand or very stiff clay	1,000	1,450	1,200	365
D	Medium dense sand or stiff clay	700	1,000	849	260
DE	Loose sand or medium stiff clay	500	700	600	185
E	Very loose sand or soft clay		500		150

1. Upper and lower bounds, as proposed for Table 20.3-1.
2. Center of range (rounded) values used by USGS to develop MPRS.

Key changes to the Site-Specific Ground Motion Procedures of Chapter 21 proposed for the *2020 NEHRP Provisions* and *ASCE 7-22*

Proposed changes would incorporate the MPRS available from the USGS web service into the site-specific requirements of Chapter 21 by (i) permitting their use, in lieu of those determined by a traditional site-specific ground motion analysis, and (ii) by requiring that site-specific ground motions not be less than 80 percent of those from the USGS web service without peer review (i.e., to provide a lower-bound safety net for ground motions developed by a site-specific analysis).

Other proposed changes to Chapter 21 would eliminate the risk coefficient method for determining probabilistic (risk-targeted) MCE_R ground motions from uniform-hazard (2% in 50-year) ground motions, revise the period-dependent factors required for conversion of geometric mean (RotD50) ground motions to maximum direction (RotD100) ground motions, and revise deterministic MCE_R ground motion requirements. Each of these proposed changes are consistent with the methods used by the USGS to develop the updated values of seismic design parameters and MPRS provided by their web service (i.e., updated values of seismic ground motion maps proposed for Chapter 22).

The proposed elimination of the risk coefficient method would not affect the values of MPRS, which would be determined by iterative integration in accordance with the requirements of Section 21.2.1.2 (Method 2) of *ASCE 7-16* that would remain the same in *ASCE 7-22*. The proposed revision of the period-dependent factors used to convert geometric mean to maximum direction response would have a modest effect on the frequency content of the MPRS by factoring short-period (0.2-second, or less) response by 1.2, rather than 1.1, by factoring 1-second response by 1.25, rather than 1.3, and by factoring long-period (10-second) response by 1.3, rather than 1.5 at periods of 5 seconds or greater. The proposed factors are based on the analyses of Shahi & Baker (2014) and tend to increase short-period response and decrease long-period response from those required by *ASCE 7-16* (see Resource Paper 4 of the *2015 NEHRP Provisions*).

The proposed changes to deterministic MCE_R ground motion requirements include (1) replacing “characteristic earthquakes” with “scenario earthquakes” as the definition of deterministic events, where scenario earthquake magnitudes would now be determined by de-aggregation of the probabilistic spectral response acceleration at each period, (2) defining “active faults” in accordance with their hazard contributions from the de-aggregations, and (3) replacing the lower limit on the deterministic MCE_R spectrum (e.g., Figure 21.2-1 of *ASCE 7-16*) with a table of MPRS that define the lower limit deterministic MCE_R spectrum at all periods for the site class of interest.

The first proposed change was necessitated by the 2013 update of the Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3) (Field et al., 2013), which essentially eliminated the concept of "characteristic earthquakes". The second proposed change introduces a definition of "active faults" that ensures that all faults contributing significantly to the probabilistic ground motions, but only those faults, are considered. These problems were investigated by *Project 17* and the proposed changes reflect recommendations of *Project 17* to use probabilistically-defined scenario earthquake ground motions constrained such that they comply with the fundamental, 84th percentile definition of the deterministic MCE_R spectrum (Section 21.2.2 of *ASCE 7-16*).

The proposed change to replace the lower limit on the deterministic MCE_R response spectrum with a table of MPRS was necessitated by the elimination of the site coefficients (F_a and F_v) and the desire to replace the two-domain spectrum of *ASCE 7-16* with a more realistic multi-period characterization of the frequency content of lower limit ground motions. Figure 4 shows plots of the MPRS of proposed Table 21.2-1 illustrating the variation of the lower limit deterministic MCE_R response spectrum with site class.

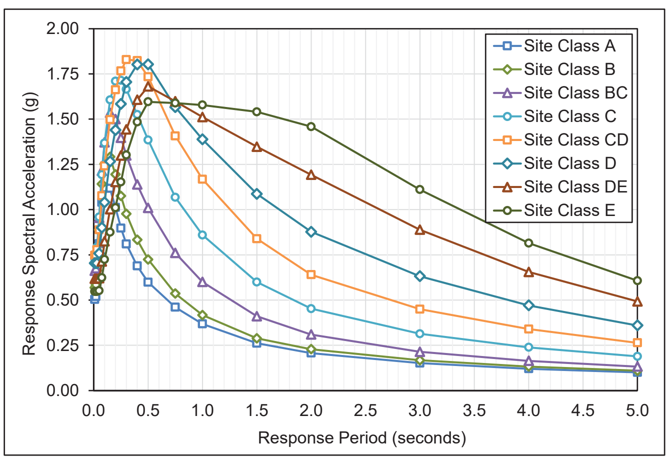

Figure 4. Plots of the MPRS (up to 5 seconds) proposed for the lower limit deterministic MCE_R response spectra of Table 21.2-1 (up to 5.0 seconds) of the *2020 NEHRP Provisions* and *ASCE 7-22*.

The values of lower limit deterministic MPRS of proposed Table 21.2-1 were developed as part of the MPRS study (ATC, 2019). The proposed MPRS are based on an assumed magnitude M8.0 WUS earthquake at a distance of about 12 km from fault rupture. A magnitude M8.0 earthquake represents the approximate magnitude typically found by de-aggregation of site hazard for sites near major fault systems (e.g., San Andreas Fault in the San Francisco Bay Area). A 12 km distance from the site to fault rupture is the approximate distance at which a magnitude M8.0 earthquake generates 0.2-second response of 1.5 g and 1-second response of 0.6 g for Site Class BC site conditions. The proposed deterministic lower limit MPRS are anchored to these values of 0.2-second and 1-second response for consistency with the deterministic lower limit on the MCE_R response spectrum of *ASCE 7-16* (i.e., Figure 21.2-1 of *ASCE 7-16*).

Where a site-specific hazard analysis is performed, the lower limit deterministic MCE_R response spectra of proposed Table 21.2-1 (shown in Figure 4) provide a convenient means of screening out sites not requiring calculation of the deterministic MCE_R response spectrum (Section 21.2.2). Where the probabilistic MCE_R response spectrum is less, at all periods, than the lower limit deterministic MCE_R response spectrum of the site class of interest, the probabilistic MCE_R response spectrum governs site hazard and the deterministic MCE_R response spectrum need not be calculated.

Key changes to the Seismic Ground Motion Maps of Chapter 22 proposed for the *2020 NEHRP Provisions* and *ASCE 7-22*

Proposed changes to Chapter 22 would (1) update figures of mapped values of parameters S_S (S_{MS}), S_1 (S_{M1}) and PGA (PGA_M) for Site Class BC site conditions, (2) reference a USGS web service for values of design parameters S_{MS}, S_{M1}, and PGA_M for any site condition of interest, and (3) delete figures of mapped values of the obsolete risk coefficients C_{RS} and C_{R1}.

All values of design parameters (and corresponding MPRS) would be obtained from the USGS web service for user-specific values of the site location (latitude and longitude) and site class (including Default site conditions). The proposed values are based on the 2018 update of the United States Geological Survey (USGS) National Seismic Hazard Model (NSHM).

Proposed MCE_R ground motions are developed from the USGS NSHM in accordance with the site-specific requirements of proposed Chapter 21 of the *2020 NEHRP Provisions* and *ASCE 7-22* for sites in the conterminous United States, and following the methods developed in "Procedures for Developing Multi-Period Response Spectra of Non-Conterminous United States Sites" (ATC, 2019) for sites outside of the conterminous United States (i.e., sites in Alaska, Hawaii, Guam and the Northern Mariana Islands, Puerto Rico and the United States Virgin Islands, and American Samoa). For descriptions of the calculation of MCE_R ground motions from the USGS NSHM, please see the commentaries of Chapters 21 (Section 21.2) and 22 proposed for the *2020 NEHRP Provisions* and *ASCE 7-22*.

Overview of the 2018 Update of the National Seismic Hazard Model

The 2014 USGS NSHM was used to calculate ground motion parameters for the *2015 NEHRP Provisions* and *ASCE 7-16*. The USGS updated this model in 2018-2019 (i.e., 2018 USGS NSHM). Whereas the 2014 USGS NSHM provided ground motion parameters at three spectral periods and one reference site class, the 2018 USGS NSHM provides ground motion parameters for all 22 spectral response periods and eight site classes needed to develop the MPRS. For details of the 2018 USGS NSHM, please see its documentation (Petersen et al., 2019) and a summary of the 2018 changes in "Updates to USGS National Seismic Hazard Model (NSHM) and Design Ground Motion Maps for 2020 NEHRP Recommended Provisions' (Rezaeian and Luco, 2019).

Proposed MCE_R ground motions for Sites Outside of the Continental United States

The modifications in the 2018 USGS NSHM are all for the conterminous United States. For the other states and territories outside of the conterminous United States, the 2018 NSHM has not been updated with respect to the 2014 USGS NSHM and cannot be used to develop MPRS. Regions outside of the conterminous United States of interest include sites in Alaska, Hawaii, Guam and the Northern Mariana Islands, Puerto Rico and the United States Virgin Islands, and American Samoa.

In general, for sites outside the conterminous United States, the 2014 (2018) USGS NSHM provides only values of PGA and response spectral accelerations, S_S and S_1, at two periods for reference site conditions (e.g., Site Class BC). Another available ground motion parameter is the long-period transition period, T_L, which is related to the earthquake magnitude governing MCE_R ground motions at the site of interest. As a consequence of this short-coming, a FEMA-funded study (referred to herein as the MPRS study) was conducted by the Applied Technology Council (ATC, 2019) to provide the technical basis and associated methods to develop MPRS and related ground motion parameters for the *2020 NEHRP Provisions* and *ASCE 7-22* at sites in non-conterminous United States regions for which seismic hazard analyses have not yet been updated by the USGS to fully define all periods and site classes of interest.

By reference, the MPRS study report accompanies the subject MPRS proposals and, with their adoption, would provide the basis for USGS to develop MPRS for the aforementioned regions. The intent is that the *2020 NEHRP Provisions* and *ASCE 7-22* define and provide values of MPRS and associated ground motion parameters in a consistent manner for all United States regions. In this sense, the methods of the MPRS study augment the site-specific ground motion procedures, proposed for Chapter 21 of the *2020 NEHRP Provisions* and *ASCE 7-22*.

The MPRS study developed methods that can be used to derive MPRS from three, currently available, ground motion parameters S_S, S_1, and T_L for all non-conterminous United States regions of interest. The methods include models that characterize the generic shapes of MCE_R ground motions as a function of these three parameters. For deriving MPRS that represent probabilistic MCE_R ground motions, the models are based on statistical analyses of large sample sets of probabilistic MCE_R response spectra for WUS and Cascadia sites in California, Oregon, Washington (including Puget Sound), Idaho, and Nevada. For deriving MPRS that represent deterministic MCE_R ground motions, the models are based on sets of deterministic MCE_R response spectra calculated using WUS shallow crustal ground motion models for earthquake magnitudes and shaking levels typical of sites governed by deterministic MCE_R ground motions.

The MPRS study validated its methods and models by comparison of derived MPRS with calculated MPRS (i.e., MPRS proposed for the *2020 NEHRP Provisions* and *ASCE 7-22)* for 34 sites in the conterminous WUS and CEUS. These comparisons show the study methods and models to be valid for deriving MPRS of tectonic regions that are similar to the WUS and Cascadia, including the regions of interest (Alaska, Hawaii, Guam and the Northern Mariana Islands, Puerto Rico and the United States Virgin Islands, and American Samoa), but would not be appropriate for deriving MPRS for regions tectonically similar to the CEUS.

Example Comparisons of Design Spectra proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* and those of ASCE 7-10 and ASCE 7-16

Figures 5 and 6 are plots of design spectra (2/3 of MCE_R spectra) for two WUS sites of the conterminous United States used in the MPRS study, Irvine (CA) and San Mateo (CA), comparing design spectra proposed for the 2020 NEHRP Provisions and *ASCE 7-22* with those of *ASCE 7-10* and *ASCE 7-16*. Five design spectra are shown in each figure:

(1) The two-period design spectrum of *ASCE 7-10* (ASCE 7-10 2PRS),
(2) The two-period design spectrum of *ASCE 7-16* (ASCE 7-16 2PRS),
(3) The two-period design spectrum proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* (ASCE 7-22 2PRS),
(4) The multi-period design spectrum proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* (ASCE 7-22 MPRS),
(5) The multi-period design spectrum derived from values of S_S, S_1, and T_L using the methods of the MPRS study (Derived MPRS).

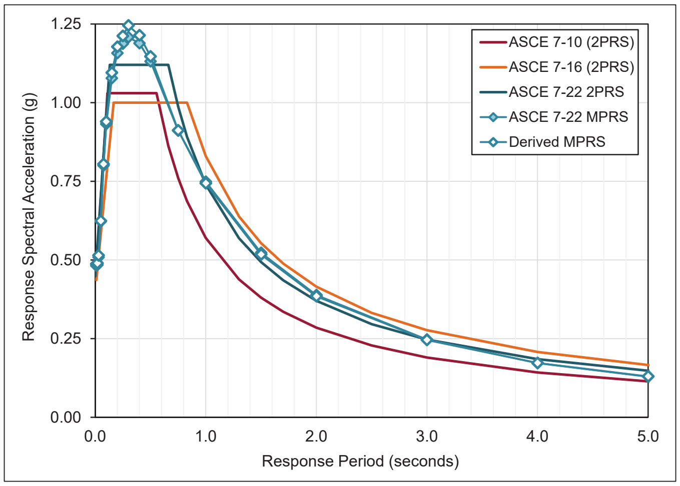

Figure 5. Comparison of two-period design response spectra (2PRS) of *ASCE 7-10*, *ASCE 7-16*, and *ASCE 7-22* (as proposed), multi-period design response spectra (MPRS) of *ASCE 7-22* (as proposed), and derived MPRS from *ASCE 7-22* values of S_S, S_1, and T_L using the methods of this study, for the Irvine site assuming default site conditions.

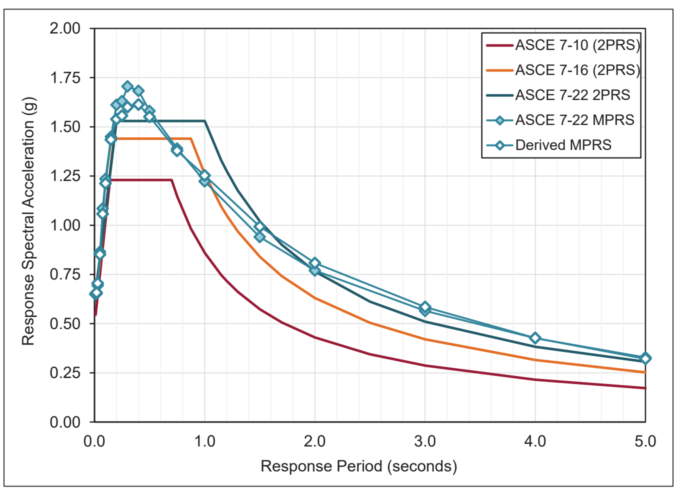

Figure 6. Comparison of two-period design response spectra (2PRS) of *ASCE 7-10*, *ASCE 7-16*, and *ASCE 7-22* (as proposed), multi-period design response spectra (MPRS) of *ASCE 7-22* (as proposed), and derived MPRS from *ASCE 7-22* values of S_S, S_1, and T_L using the methods of this study, for the San Mateo site assuming default site conditions.

In Figures 5 and 6, the design spectra are based on a hypothetical "default" site condition, as defined by the respective version of *ASCE 7*. Default site conditions of *ASCE 7-16* are the more critical of Site Class C and D site conditions and, as proposed for the *2020 NEHRP Provisions* and *ASCE 7-22*, would be the most critical of Site Class C, CD, and D site conditions. In all cases, response at longer periods is governed by Site Class D site conditions in Figures 5 and 6. The two-period design spectra of *ASCE 7-16* shown in these figures incorporate the 50 percent increase at longer periods that serves as an exception at Site Class D sites where site-specific analysis is not performed.

The design response spectra of the Irvine site are governed by probabilistic MCE_R ground motions (e.g., Section 21.2.1 of *ASCE 7*). The design response spectra of the San Mateo site are governed by deterministic MCE_R ground motions (e.g., Section 21.2.2 of *ASCE 7*). As shown in these figures, the multi-period design response spectra derived from values of S_S, S_1, and T_L (Derived MPRS) closely match the multi-period design response spectra proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* (ASCE 7-22 MPRS), indicative of the reliability of the methods of the MPRS study to replicate MPRS at all periods of interest for WUS sites. Note. Derived MPRS spectra shown in these figures are not proposed for the two WUS sites, rather to illustrate their similarity to ASCE 7-22 MPRS proposed spectra (i.e., derived spectra are only used to characterize design ground motions at sites in the non-conterminous United States where MPRS are not available).

Comparison of the two-period design spectra of *ASCE 7-10* with those of *ASCE 7-16* illustrates the short-coming discovered during the *2015 NEHRP Provisions* cycle that led to substantial changes to the site-specific requirements. The ground motions of *ASCE 7-10* substantially underrepresent ground motions for softer soil (default) site conditions at longer periods. Comparison of the design spectra of *ASCE 7-16* with those proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* shows mixed success of the 50 percent increase correcting the identified short-coming. For the Irvine site, where hazard is governed probabilistically by smaller magnitude earthquakes, the 50 percent increase in seismic demand of *ASCE 7-16* is sufficient to match the two-period (and multi-period) design spectra of *ASCE 7-22*.

For the San Mateo site, where ground motions are stronger and hazard is governed by very large magnitude (M8.0) earthquakes, the 50 percent increase in seismic demand of *ASCE 7-16* is not sufficient to match the two-period (and multi-period) design spectra of *ASCE 7-22* at longer response periods. In this case, and at other softer soil sites where hazard is governed by large magnitude earthquakes, the design spectra of *ASCE 7-22* better characterize the frequency content of the site-specific ground motions that would otherwise be underrepresented by the two-period design spectrum of *ASCE 7-16* at longer response periods. Likewise, derived multi-period design spectra that closely match those of *ASCE 7-22* (as proposed for WUS sites) are expected to more reliably represent the frequency content of ground motions at non-conterminous United States sites with comparable governing earthquake magnitudes, shaking levels, and site conditions.

To illustrate the above discussion, Figures 7, 8 and 9 show plots of design spectra (2/3 of MCE_R spectra) of three example sites of the non-conterminous United States, Honolulu (HI), Anchorage (AS) and Anderson AFB, Guam, comparing design spectra derived from values of S_S, S_1 and T_L with those of prior editions of *ASCE 7*. Four design spectra are shown in each figure:

(1) The two-period design spectrum of *ASCE 7-10* (ASCE 7-10 2PRS),
(2) The two-period design spectrum of *ASCE 7-16* (ASCE 7-16 2PRS),
(3) The two-period design spectrum proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* (ASCE 7-22 2PRS) and
(4) The multi-period design spectrum proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* (ASCE 7-22 MPRS).

In each figure, the two-period and multi-period design spectra proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* are derived from values of S_S, S_1, and T_L for the site of interest using the methods of this study. Like those shown previously in Figures 5 and 6, the design spectra of Figures 7, 8 and 9 are based on a hypothetical "default" site condition, as defined by the respective version of *ASCE 7* (see above for details). In all cases, response at longer periods is governed by Site Class D site conditions. The two-period design spectra of *ASCE 7-16* shown in these figures incorporate the 50 percent increase at longer periods required at Site Class D sites.

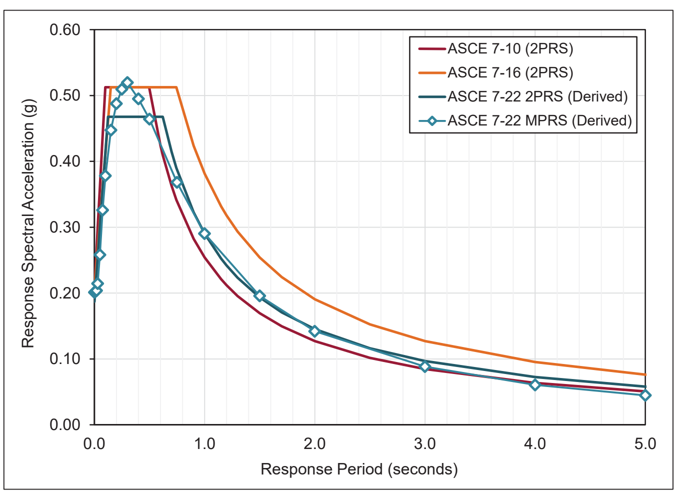

Figure 7. Comparison of two-period design response spectra (2PRS) of *ASCE 7-10*, *ASCE 7-16*, and *ASCE 7-22* (as proposed), and multi-period design response spectra (MPRS) of *ASCE 7-22* (as proposed) derived from values of S_S, S_1, and T_L using the methods of this study, for the Honolulu (HI) site assuming default site conditions.

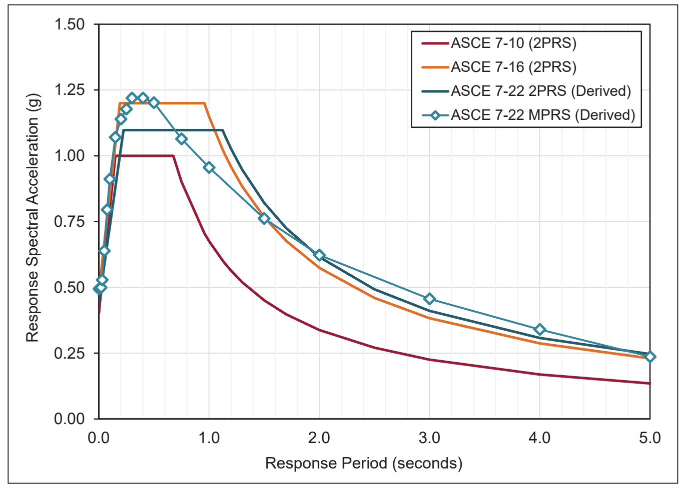

Figure 8. Comparison of two-period design response spectra (2PRS) of *ASCE 7-10*, *ASCE 7-16*, and *ASCE 7-22* (as proposed), and multi-period design response spectra (MPRS) of *ASCE 7-22* (as proposed) derived from values of S_S, S_1, and T_L using the methods of this study, for the Anchorage (AS) site assuming default site conditions.

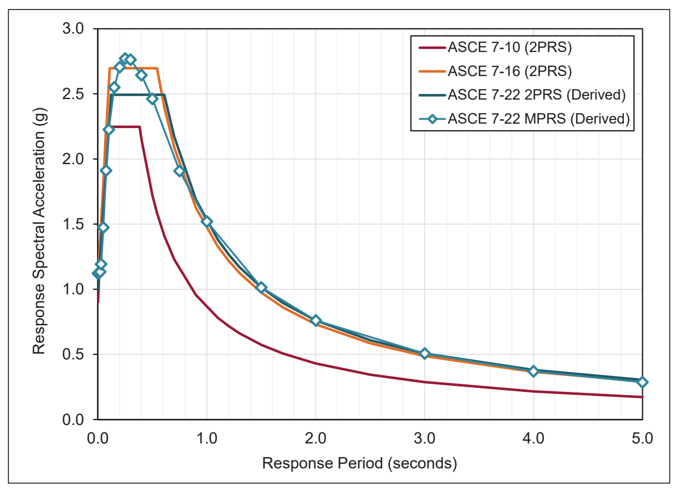

Figure 9. Comparison of two-period design response spectra (2PRS) of ASCE 7-10, ASCE 7-16, and ASCE 7-22 (as proposed), and multi-period design response spectra (MPRS) of ASCE 7-22 (as proposed) derived from values of SS, S1, and TL using the methods of this study, for the Anderson AFB, Guam, site assuming default site conditions.

The three non-conterminous sites represent a broad range of design ground motion levels from rather modest shaking at the Honolulu site (i.e., PGA ≈ 0.2 g) to extreme shaking at the Anderson AFB site (i.e., PGA ≈ 1.0 g). In all cases, the multi-period design spectrum proposed for the *2020 NEHRP Provisions* and *ASCE 7-22* (derived from values of S_S, S_1, and T_L) look reasonable and, except for the Honolulu site, the proposed two-period design spectra (ASCE 7-22 2PRS) look similar to those of *ASCE 7-16* (ASCE 7-16 2RS). For the Honolulu site, the proposed two-period design spectrum is somewhat less than that of *ASCE 7-16* at longer periods, reflecting a modest conservatism in the 50 percent increase required by *ASCE 7-16* at longer periods where ground motion levels are relatively low.

The flatter shape of the multi-period design spectrum of the Anchorage site (ASCE 7-22 MPRS), shown in Figure 8, reflects stronger shaking at longer periods expected for sites where ground motion hazard is governed by very large magnitude earthquakes. For comparison, Figure 6 shows a similar flatter shape to the multi-period design spectrum of the San Mateo site (ASCE 7-22 MPRS) which is also governed by large magnitude earthquakes.

Summary and Conclusion

The background, supporting studies, and key changes of a comprehensive set of proposals are described in this paper that would incorporate a multi-period response spectra (MPRS) characterization of MCE_R ground motions and related design requirements in the *2020 NEHRP Provisions* and *ASCE 7-22* and, by reference, *2024 International Building Code*. The proposed changes to MCE_R ground motions include the recent 2018 update of the USGS National Seismic Hazard Model.

The proposed changes would collectively improve the accuracy of the frequency content of earthquake design ground motions and enhance the reliability of the seismic design parameters derived from these ground motions by defining earthquake design ground motions in terms of MPRS. Of equal importance, the proposed changes would eliminate the need for site-specific hazard analysis now required by *ASCE 7-16* for certain (soft soil) sites, an interim solution to a deficiency with the seismic ground motion criteria of *ASCE 7-10*.

Traditional design methods (e.g., ELF procedure) familiar to and commonly used by engineering practitioners for building design would not change. Site-specific values of design parameters (and corresponding MPRS) would be available online at a USGS web site and presumably other related web sites (e.g., SEAOC, ASCE and ATC web sites) for user-specified values of site location and site class.

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