CHANGES IN SEISMIC DESIGN CRITERIA AND DESIGN GROUND MOTIONS IN IBC 2018 AND ASCE 7-16, AND RECOMMENDATIONS FOR SEISMIC DESIGN PRACTICE IN UTAH

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ABSTRACT

The 2018 International Building Code (IBC 2018), and by extension referenced provisions of ASCE 7-16, was adopted July 2019 by the State of Utah. ASCE 7-16 introduces significant changes to prescribed seismic forces for the design of structures when compared to IBC 2015 and ASCE 7-10. These changes include updated mapped B/C boundary seismic values S_s and S_1 as well as revised site coefficients (with the coefficients typically being larger). Most notable are new requirements to perform site-specific ground motion hazard analyses (GMHA, which is comprised of both deterministic seismic hazard analysis [DSHA] and probabilistic seismic hazard analysis [PSHA]) for areas of moderate to high seismicity and softer soil sites (Site Classes D and E). This site-specific study requirement is the result of deficiencies which are now more widely recognized in the shape and magnitude of the code-based ("standard") design response spectrum. In some cases, exceptions exist where an otherwise required GMHA may be omitted; however, these exceptions together with the other changes in ASCE 7-16 can increase design base shears by as much as 70%. In early 2019, a group of individuals from several professional societies formed an ad-hoc committee to develop a workshop whose purpose was to help inform fellow engineering and geological professionals in Utah about these changes. In preparing for the workshop, various design practice issues not explicitly addressed in IBC 2018 or ASCE 7-16 were discussed. The outcome of these discussions were consensus recommendations which are believed by committee members to represent good seismic design practices. This document presents several of those recommendations, including minimum qualifications for those performing site-specific seismic studies as well as the typical content of such reports.

INTRODUCTION AND BACKGROUND

With the recent adoption of IBC 2018 (and by extension the seismic design standards of ASCE 7-16) by the State of Utah, individuals experienced in seismic design procedures came together in an effort to help inform fellow engineering and geological professionals regarding changes in practice that this adoption entails. These individuals reached out to professional organizations and other pertinent parties to form an ad-hoc committee representing a wide spectrum of earthquake engineering design practitioners and affiliated parties to put on a workshop about the updated seismic ground motion provisions of these two code documents as well as to help create this follow-on document.

The workshop was held on June 10, 2019, in Sandy, Utah and consisted of three presentations and a panel-led discussion. The workshop was attended by over 150 individuals and received support from the following organizations: Utah Geo-Institute Chapter of the American Society of Civil Engineers (ASCE), Structural Engineers Association of Utah (SEAU), Utah Section of ASCE, Utah Chapter of the Earthquake Engineering Research Institute (EERI), Utah Chapter of the Structural Engineering Institute (SEI), Utah Geological Survey (UGS), and Utah Division of Facilities Construction Management (DFCM).

The intent of this document is to highlight changes in seismic design practices (relative to previous code documents IBC 2015 and ASCE 7-10) through items such as revised site coefficients and requirements for site-specific seismic studies. This document also presents the consensus thoughts of the ad-hoc committee and workshop panel members regarding certain issues not explicitly addressed by the code documents and, in the opinion of the group, represent good practices. These recommendations are presented in the second half of this document.

CODE CHANGES

Engineers regularly using the ASCE 7 standard have come to understand that changes in prescribed earthquake forces are to be expected within each cycle of this standard. Most common are subtle differences that do not result in significant changes to prescribed lateral forces or procedures used for the design of buildings and other structures. The 2016 Edition of the ASCE 7 standard is clearly an exception to this.

Changes in Mapped Spectral Acceleration Values in Utah

In the western US, provisions of ASCE 7-10 utilized spectral acceleration values developed from the Next Generation Attenuation (NGA) West effort. This multidisciplinary research program was coordinated by the Lifelines Program of the Pacific Earthquake Engineering Research Center and was concluded in 2008, culminating in the development of the 2008 United States Geological Survey (USGS) Seismic Hazard Maps. It was based upon sets of ground-motion attenuation models developed by independent, but interacting, teams. The NGA West 2 effort initiated in 2008 was a follow-up program to the original NGA West effort. The effort focused on developing a ground motion database that considers significantly more earthquakes, verification of the original NGA West models for recent events, scaling of ground motions via ground motion prediction equations (GMPEs) for different levels of damping, vertical effects, soil non-linearity/amplification and uncertainty. The new seismic parameters prescribed by ASCE 7-16 are the result of the NGA West 2 effort (which are included in the 2014 USGS Seismic Hazard Maps). Future code iterations will undoubtedly adopt even more of the findings of NGA West 2 as well as other future seismic research efforts.

While some provisions for prescribed earthquake forces changed significantly, mapped spectral acceleration values in Utah show changes for the ASCE 7-16 not unlike those witnessed for the last several code cycles. Tables 1 and 2 illustrate the differences in mapped spectral acceleration values for several Utah locations.

Table 1 – Generalized Short Period (S_s) Spectral Acceleration Values for Utah Sites

Site	ASCE 7-10	ASCE 7-16	Change	Percentage
Murray	1.556	1.488	-0.068	-4%
Logan	0.971	1.058	0.087	9%
Brigham City	1.467	1.372	-0.095	-6%
Ogden	1.373	1.362	-0.011	-1%
Provo	1.144	1.323	0.179	16%
Manti	0.638	0.635	-0.003	0%
Cedar City	0.702	0.777	0.075	11%
St. George	0.499	0.509	0.01	2%
Vernal	0.297	0.317	0.02	7%
Monticello	0.156	0.179	0.023	15%

Table 2 – Generalized Long Period (S_1) Spectral Acceleration Values for Utah Sites

Site	ASCE 7-10	ASCE 7-16	Change	Percentage
Murray	0.530	0.526	-0.004	-1%
Logan	0.311	0.353	0.042	14%
Brigham City	0.521	0.488	-0.033	-6%
Ogden	0.499	0.497	-0.002	0%
Provo	0.427	0.496	0.069	16%
Manti	0.186	0.199	0.013	7%
Cedar City	0.216	0.25	0.034	16%
St. George	0.153	0.165	0.012	8%
Vernal	0.091	0.082	-0.009	-10%
Monticello	0.054	0.057	0.003	6%

Changes in mapped spectral acceleration values for both long and short periods (S_s, S_1) are generally minor with noteworthy increases for short period and long period accelerations in the Provo and Southern Utah Areas. These accelerations are derived from the 2014 USGS National Seismic Hazard Maps, where preceding codes referenced the maps from 2008.

Changes in Site Coefficients and Quantification of Site Soil Effects

While design professionals should develop a general awareness of the changes in mapped spectral acceleration values, an understanding of the revised spectral response acceleration parameters (site coefficients) is essential. Prescriptive site coefficients (F_a and F_v) are intended to modify mapped spectral acceleration values for local site conditions and non-linear behavior. These values are based on soil site class and, because soil behaves non-linearly, mapped acceleration levels.

In common practice, seismic design forces are estimated using code-based seismic design parameters and/or the design response spectrum which are dependent on site coefficient values. In addition to this approach, there are two site-specific procedures that can more accurately determine spectral response than the response spectrum developed using site coefficients F_a and F_v and ASCE 7-16 Figure 11.4-1. Both of these procedures are described in ASCE 7-16 Chapter 21. The first procedure is a site response analysis (SRA; see Section 21.1). This analysis has been generally required for Site Class F soils for several ASCE 7 code cycles. This procedure uses a detailed soil model developed from site-specific data. Ground motions are transformed from a base layer (usually bedrock) through the soil profile to provide estimates of ground motions (and corresponding response spectrum) at the ground surface. A one-dimensional SRA with vertically propagating shear waves is sometimes colloquially referred to as a "SHAKE" analysis, stemming from the name of the predominant computer code originally used to conduct such analyses. However, SHAKE is an equivalent linear analysis, and many times (particularly for liquefiable soils), a nonlinear analysis is needed. If performed correctly, an SRA is generally considered a more accurate quantification of local site effects than reliance on simplified, code-based site coefficients. The base-rock response spectrum needed as input may be developed from ASCE 7's prescriptive / code-based method or from a site-specific ground motion hazard analysis. It should be noted that actual site response during an earthquake is a three-dimensional problem which we commonly try to quantify using one-dimensional site response tools. In many cases, one-dimensional site response analyses do not fully capture the true response, especially for structural periods larger than the site period.

The second procedure is a site-specific ground motion hazard analysis (GMHA; see Section 21.2). This procedure is typically comprised of 1) a deterministic seismic hazard analysis [DSHA] and 2) probabilistic seismic hazard analysis [PSHA]. In the DSHA, the ground shaking hazard is assessed by identifying specific earthquake seismic events ("event scenarios") – ones for which the combination of magnitude and distance (together with other pertinent source and site parameters) provide relatively large levels of ground shaking. This process typically consists of checking multiple, active faults at an 84th percentile of potential values (hence reflecting the uncertainty in acceleration given any particular, fixed set of input parameters) and using the peak acceleration response for each period to define the deterministic spectrum. In the PSHA, the ground shaking hazard is assessed in terms of statistical likelihood and reflects the combined effects of multiple potential seismic sources, including a background or gridded event, each with its own recurrence relationship. The PSHA also accounts for uncertainties in the size (magnitude), location (distance), and rate of occurrence of each seismic source in the area of influence, as well as the variation of the ground motions themselves given a specific earthquake magnitude and location. For structural design, the probabilistic spectrum is assessed such that the ground motions reflect the direction of maximum response as well as a level of shaking which would nominally result a one percent probability of structural collapse in 50 years. Both PSHA and DSHA consider such things as the regional tectonic setting, geology, and historical seismicity; the characteristics of ground motion attenuation; near source effects; and the effects of subsurface site conditions. In ASCE 7-16, the lower of the PSHA- and DSHA-based spectra is scaled to a design level and compared to certain specified minimums to obtain the site-specific design spectrum.

The GMHA procedure can provide ground motion estimates at the surface in lieu of using standardized site coefficients. This procedure can also provide a target for spectral matching of ground motion inputs which are transformed (deconvolved) to base rock as used in an SRA. A site-specific GMHA has been allowed in previous editions of ASCE 7, but in ASCE 7-16, it is now required, unless exceptions per Section 11.4.8 are taken, for the following:

1. Seismically isolated structures and structures with damping systems on sites with S_1 greater than or equal to 0.6.
2. Structures on Site Class E sites with S_s greater than or equal to 1.0, and
3. Structures on Site Class D and E sites with S_1 greater than or equal to 0.2.

There are three exceptions listed in Section 11.4.8 which can be invoked to avoid a GMHA, which will be described later. It should be noted that ASCE 7-16 allows site-specific SRA or GMHA to be used for any structure, but is now requiring GMHA for the three specific instances listed above. As discussed later, these instances typically represent situations where the otherwise-used, code-based design response spectrum with its standardized shape may not adequately estimate expected spectral accelerations for a particular site.

In addition to the GMHA requirements, changes to the prescribed values for F_a are noteworthy with increases of up to 20% for Site Classes C and D. The F_v coefficient for Site Class E can be as high as 4.2 when developing a response spectrum in accordance with Chapter 11, which is again appreciably higher than values in previous ASCE 7 code iterations. If the exceptions in Section 11.4.8 are taken, the increases in design ground motions can be more than 50% from previous code iterations.

ASCE 7-16 recognizes that robust site-specific analyses are not practical for a great many sites and projects, which is why exceptions are provided that seek to alleviate the requirements of GMHA for smaller projects where long period accelerations are not likely applicable. Designers may opt to use the exceptions for Site Classes D and E, but with increases in prescribed design forces for longer periods as high as 50%. Note that the exception is not allowed for Site Class E soils when the building period, T, is greater than the value of T_s (which is equal to S_{D1}/S_{DS}: Use ASCE 7-16 Supplement 1 to get the value of F_v used to calculate the value of T_s).

One of the most important parameters used to characterize local dynamic soil effects is the average soil shear wave velocity in the upper 30 meters (or 100 feet) of the soil profile (V_{s30}). V_{s30} is commonly used to assign seismic site class, which is in turn used to assign site coefficients. It may be noted that in previous versions of ASCE 7, the reference site condition where site coefficients were 1.0 was Site Class B. In ASCE 7-16, this reference condition is now identified as the boundary between classes B and C, consistent with the site class “B/C” boundary conditions reflected in USGS’ national seismic hazard mapping. Hence, site coefficients F_a and F_v are now less than 1.0 for Site Class B when shear wave velocity is measured. However, absent such measurements, Site Class B coefficients are to be taken as 1.0, in this case to compensate for the uncertainty of not having measured the shear wave velocity.

ASCE 7-16 now also makes a distinction for Site Class D based on whether the site class is based on an engineering assessment (presumably using geotechnical data) or the site class is assigned by exercising the “default” classification allowed in the code (see ASCE 7-16 Section 11.4.3). In situations without data to base a site classification upon (default site class), the code has now increased the minimum value of F_a from 1.0 to 1.2 (an increase of 20%).

Changes in Design Response Spectra

Chapter 11 of ASCE 7-16 defines a design spectrum using only two points (anchor or control points), S_{DS} and S_{D1}, which are derived using F_a and F_v site coefficients. This "standardized" shape has a characteristic flat top at shorter periods and decreasing spectral accelerations at longer periods where the corresponding velocity spectrum is relatively constant. Technically, there is a third control point above which the shape of the spectrum is displacement-based when plotted on a tripartite plot. Based on maps provided in the code, this point, T_L, is commonly 6 to 8 seconds for most of Utah.

GMPEs used in GMHAs create smoothed, multi-period spectra. Studies have shown that multi-period spectra developed using GMHA per Section 21.2 of ASCE 7-16 for Site Classes A, B, and C are generally consistent with the code-based design spectra developed following the procedures of Chapter 11 of ASCE 7. However, comparisons with multi-period GMHA spectra for Site Classes D and E (i.e., less stiff site conditions) show code-based spectra developed using Chapter 11 of ASCE 7-16 to be unconservative, especially at mid to long periods. These concepts are illustrated in Figures 1 through 3, derived from spectra shown on the FEMA P-1050-1/2015 Edition document, *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures* (BSSC, 2015). For the purposes of the immediate discussion, the MCE_R spectra shown in the figures may be ignored, and focus placed on the design spectra. It can be seen that disparities exist between the black-colored "ELF design spectrum" (which is in essence the current ASCE 7 standardized shape design spectrum without the initial rising limb) and the cyan-colored "design multi-period response spectrum" which is based on a set of GMPEs applied to a wide range of periods. In the three figures, it can be seen that the current design spectrum is increasingly unconservative with the cyan curve plotting above the black curve as the sites become less stiff (i.e., site class change from C to E).

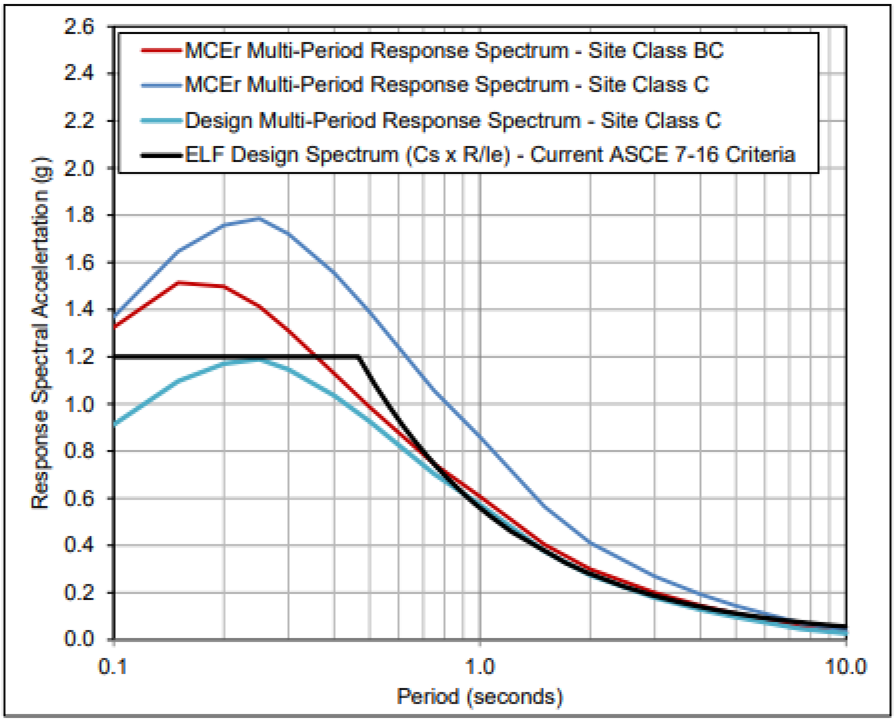

Figure 1 – Comparison of ELF and Multi-Period Spectra, Site Class C (from FEMA P-1050-1; BSSC, 2015)

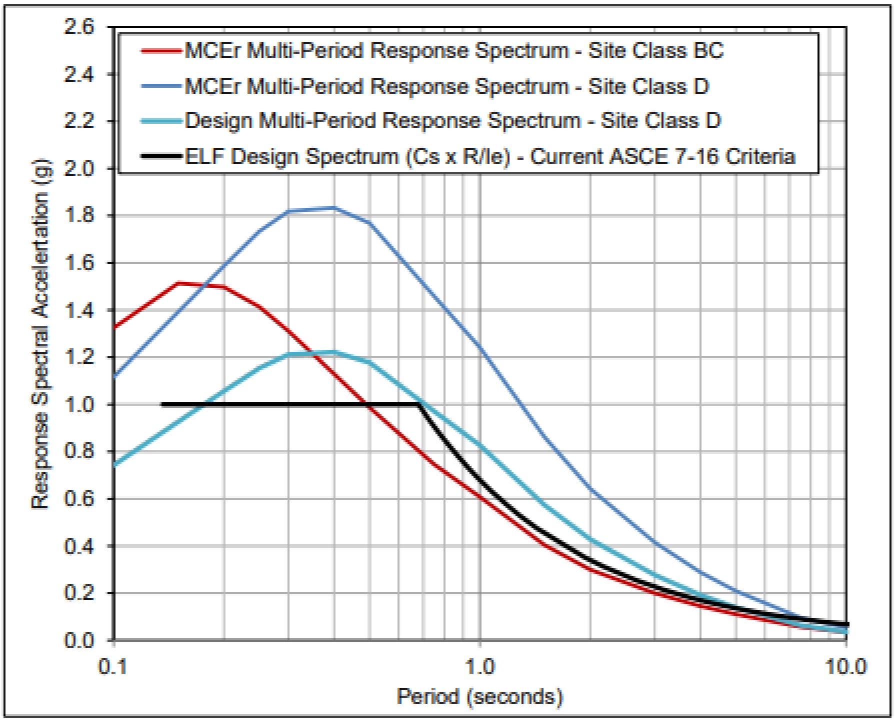

Figure 2 – Comparison of ELF Multi-Period Spectra, Site Class D (from FEMA P-1050-1; BSSC, 2015)

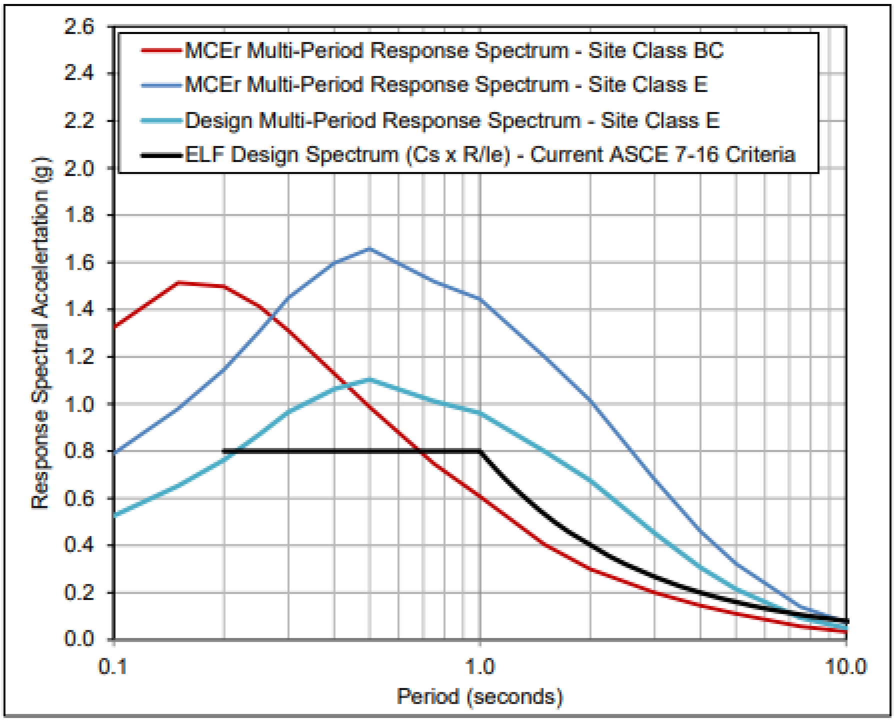

Figure 3 – Comparison of ELF Multi-Period Spectra, Site Class E (from FEMA P-1050-1; BSSC, 2015)

The updated provisions of ASCE 7-16 prescribe F_a and F_v values targeted toward overcoming the unconservative spectra. This is accomplished in two ways. First is to require GMHA for all sites designated as Site Class D or E with S_1 greater than or equal to 0.2 and/or for Site Class E sites with S_s greater than or equal to 1.0. The GMHA-based approach calculates design spectra based on a site-specific V_{s30} and other characteristics of the site, not on the code provided values of F_a and F_v. Using a GMHA provides spectral acceleration values (but not site coefficients) for each period at which calculations are performed (which is typically about 22 periods distributed logarithmically over a range of 0 to 10 seconds for most GMPEs). Not only does a GMHA provide a more refined and realistic spectral shape, it is believed that in many cases, the design spectrum will be less than the exceptions allowed by ASCE 7-16 (as described next and Topic #3 later on in this document).

The second way of overcoming deficiencies of the simplified design response spectrum from previous editions of ASCE 7 for Site Class D and E sites with high acceleration levels is to use the exceptions provided in ASCE 7-16 which allow designers to use the published values for F_a and F_v with adjustments that increase spectral acceleration values for both short and long periods. The result is that accelerations for short period buildings may increase by as much as 20 percent (using F_a taken as equal to that of Site Class C) and accelerations for longer period buildings may increase by as much as 50 percent (increasing C_s by 1.5 on Site Class D sites when building period is greater than $1.5xT_s$). These increases are meant to account for site response that is not captured unless a GMHA is performed. Hence, project stakeholders have the option of foregoing the GMHA, but the prescribed design forces for Site Classes D and E may be higher. Whether this option is prudent is a decision that must be made on a case-by-case basis in as the majority of structures where the exception would be applied are typically shorter-period buildings that are not likely to be affected by the potential 50% increase for Site Class E or an extended flat-top region for Site Class D.

Site Class F sites (which include sites having liquefiable soils; highly organic soils; very high plasticity clays; or very thick, soft to medium stiff clays [see ASCE 7-16, Section 20.3.1 for more defining details]) must have a site response analysis (SRA) performed. The base rock input ground motion for the analysis may be matched to spectra from Chapter 11 of ASCE 7-16 or from a GMHA. An SRA is also allowed to be used to define ground motions for any site class. One important exception to needing to perform an SRA for a liquefiable Site Class F site is in the case of structures having a fundamental period of 0.5 seconds or less (see ASCE 7-16, Section 20.3.1). Other exceptions exist for the non-liquefiable site type categories within Site Class F.

RECOMMENDATIONS FOR UTAH SEISMIC DESIGN PRACTICE

In developing the workshop, committee members discussed a range of issues (some new and some not so new) associated with the updated design provisions of IBC 2018 and ASCE 7-16 related to seismic ground motions. These issues were framed into questions which would serve as discussion points for the workshop panel session. Since the time of the workshop, other potential points of discussion have emerged as local engineering professionals have attempted to embrace the new seismic design requirements. The original questions formulated by the committee have been restructured herein as "Topics" to facilitate a written format and accommodate subsequently added thoughts. One particular topic (Topic #5) addresses the qualifications of those performing GMHAs and SRAs. Another topic (Topic #6) addresses what a report presenting the results of a GMHA or SRA should contain. It is the opinion of the authors and committee members that this document reflects generally sound seismic design practices, which when followed will help achieve sound seismic designs and provide the public with meaningful measures of seismic risk mitigation. It is hoped that this document will also impress upon readers and practitioners the committee's view that performing a GMHA and SRA is not a trivial matter.

***Topic #1: When Should a Site-Specific Seismic Study Be Performed*?** In short, a site-specific seismic study (GMHA and/or SRA) can be performed for any site. Excluding certain types of structures, as stated previously, a GMHA is required in the case of a site classified as D or E with a mapped S_1 parameter greater than or equal to 0.2 s, or in the case of a site classified as E with a mapped S_s parameter greater than or equal to 1.0 s. An SRA must be performed in the case of a liquefiable, Site Class F, site. An SRA is also required for the other subsurface conditions constituting Site Class F, these being highly organic soils; very high plasticity clays; or very thick, soft to medium stiff clays. However, the code documents allow exceptions to these GMHA and SRA requirements in certain instances (see ASCE 7-16, Section 11.4.8 and 20.3.1). Besides the explicit requirements of the code, it is strongly recommended that a GMHA or SRA be performed anytime when the structure represents a critical lifeline component. While not required by code, it is strongly recommended that a GMHA or SRA (with the former sometimes being preferred, all other things being equal, due to the latter's greater complexity and potential for errant results) be performed for all Risk Category III and IV structures. This reflects a philosophy that situations presenting greater risks merit more robust methods of analysis (or at least greater certainty in the representativeness of design parameters). In any event, the geotechnical and structural engineers-of-record should engage early in the design process by having a discussion regarding the seismic design of the structure to identify and develop a seismic design strategy for the structure.

Topic #2: Geotechnical Site Data Needed for a GMHA or SRA. As a general introductory statement, it should be recognized that additional field and laboratory data are usually required to complete an SRA as compared to a GMHA, and both types of analyses require information which has not been consistently collected in past geotechnical engineering practice that may have been strictly focused on developing foundation and earthwork recommendations. Owners and Clients need to be prepared for a greater commitment of resources when a GMHA or SRA is required instead of the standard seismic design spectrum. Shallow geotechnical data alone are insufficient to classify a site with respect to its anticipated seismic response or correctly perform a GMHA or SRA.

The standardized code-based spectrum is based on a seismic site class which is associated with a particular range of V_{s30} values (or alternately [and less preferably] SPT blowcounts (N-values) or undrained shear strengths). V_{s30} is the weighted, harmonic mean (not the arithmetic average) of shear wave velocity of the top 30 meters (or alternately the top 100 feet) of the subsurface profile. It is important to recognize that criteria in addition to shear wave velocity (or SPT blowcounts or undrained shear strength, by proxy) exist for evaluating potential site classes of E and F (see ASCE 7-16 Section 20.3 and Table 20.3-1). In particular, a site classification of E exists with any profile having more than 10 feet of soil with a plasticity index (PI) of more than 20, a moisture content of 40% or more, and an undrained shear strength of less than 500 psf within the upper 100 feet of the site). Locally, certain deep-lake deposits of Lake Bonneville will sometimes present a site classification of E, even when the V_{s30} values exceeds the threshold of 600 ft/sec for the class. Relative to this topic, it should also be noted that while SPT blowcounts or undrained shear strength may currently be used to evaluate site class, it appears likely that such options will be disallowed in future versions of seismic code documents.

For a GMHA, specificity greater than that provided by one of six site classes (A through F) is needed to describe the site response, and a V_{s30} value (rather than a site class) is used directly in calculations. In an SRA, even more detailed characterization of subsurface conditions is required, with a shear wave velocity (or alternatively a low-strain shear modulus) being assigned to each individual subsurface stratum (soil layer). Hence, one can see that there is a progression in the specificity and rigor with which subsurface data are collected and conditions are characterized as the methods of analysis become more complex.

As indicated above, as a minimum, a measured V_{s30} value is recommended for a site-specific analysis. Given that some geotechnical site investigations focus on shallow foundations and the method of field exploration may only consist of test pits, the question naturally arises as to how to assess deeper strata in order to obtain V_{s30}. This issue existed to some degree before adoption of the new codes. In the past, some engineers relied upon deeper data from adjacent sites while others considered the geologic setting and/or maps of geology-based site response units such as that of McDonald and Ashland (2008). In some measure, this may be acceptable in the case of non-site-specific based design response spectra in the code because a site class need only represent a range of potential values. However, for site-specific studies, the V_{s30} value is a discrete number or perhaps even a range of measured values. Regardless of whether a site class or V_{s30} value is used to assess seismic effects, individuals who quantify and present ground motions for design should clearly indicate the basis for the values used in their analyses.

There are several options available for measuring shear wave velocities as needed to perform ground motion studies. More obvious means are test holes or cone penetrometer test (CPT) soundings which extend to a depth of 100 feet, coupled with downhole (or in the case of test holes, even cross-hole) shear wave velocity measurement. One relative advantage of the CPT method is not only can shear wave velocity measurements be made at the same time, undrained shear strengths which may differentiate Site Class E from D are readily obtained by fairly reliable published correlations. Geophysical means such as spectral analysis of surface waves (SASW), multichannel analysis of surface waves (MASW), or microtremor array measurement (MAM, also popularly referred to as refraction microtremor or ReMi) can also be effective means of measuring shear wave velocities. It is recommended, however, that geophysical surveys only be performed by knowledgeable and experienced individuals. MASW and MAM methods have certain depth and resolution limits which, in some instances, make them inadequate for purposes of site-specific seismic studies, particularly SRAs. One might note that there can be a range of measured values using different methods for the same site. However, committee members believe that the effect of those differences will be much less than other variabilities, including the variances between individual GMPEs.

Shear wave velocities should be measured over multiple depth increments in order to assess potential impedance contrasts present in the subsurface profile. (This means that a single shear wave measurement at the bottom of a deep CPT sounding is an inadequate means of site characterization). If a site presents a large, near-surface impedance contrast (such as loose/soft soil over sound bedrock), conventional use of V_{s30} values to obtain site coefficients based on site class or ground motion prediction equations (GMPEs) as implemented in a GMHA may not be valid. Also, except perhaps at shallow rock sites, test pits alone, because of their limited depths, are inadequate means for evaluating V_{s30} values.

Recognizing the logistical and budgetary challenges associated with some projects, it was the opinion of committee/panel members that not all subsurface explorations need extend to a depth of 100 feet for relatively simple, low period structures. It is believed that a minimum depth of 50 feet for data collection should be used, and that below this depth, means of extrapolating data to 100 feet (30 m) such as that presented by Boore (2004) may provide reasonable results where significant changes in subsurface conditions to 100 feet are not anticipated. However, in such cases, one should consider the potential variability in the extrapolated portion of the soil profile and use the more stringent spectrum resulting from perhaps plus-or-minus one standard deviation (in other words, on should assess parametrically the sensitivity of the resulting design spectrum). Of course, one could avoid taking the more stringent spectrum by obtaining measurements to the full prescribed depth. This belief/recommendation regarding extrapolation of data is limited to Risk Category I or II structures, and situations not needing SE licensure for design. Extrapolation is not recommended for Risk Category III or IV structures or situations needing SE licensure for design.

While the foregoing discussion has focused on V_{s30}, there are other site variables (such as $Z_{1.0}$, the depth to the 1.0 km/s shear wave boundary) representing deeper site properties that are required for site-specific seismic analyses. In the case of GMPEs "default" values for such parameters are available, often developed by the GMPE authors. In many cases these correlations reflect subsurface conditions prevalent in seismically active portions of California and do not forcibly represent those in Utah. It is recommended that use of default values be avoided in favor of using Utah site-specific deep basin data from well logs, databases of shear wave velocities, and geophysical data (all items typically considered in the development of a basin velocity model).

Topic #3: Should I Take the "Exception" Instead of Having a Site-Specific Seismic Study Done? It is important to recognize that many of the new code requirements for having a site-specific seismic study performed are made in an effort to correct deficiencies in the simplified, code-base response spectrum that previously was not widely recognized. To alleviate the need for site-specific analyses in many cases, exceptions were created in the code wherein site coefficients and/or the spectral ordinates were increased to compensate for otherwise underrepresented spectral accelerations. Some individuals have referred to utilizing these exceptions as "taking a penalty." In reality, this is not an accurate description, in as exceptions (and any larger than typical site coefficients) are meant to correct (cover) a potential deficiency in former methods. To satisfactorily cover potential deficits, any increase in design seismic loads through site coefficients associated with the exceptions may be somewhat conservative for some combinations of structural period and site conditions. In other instances, the increased coefficients may be quite accurate (and hence not a penalty). At least conceptually, a site-specific analysis is intended to provide the "true" (or at least more accurate) response spectrum for a site. The only "penalty" per se would be any difference between a lower response spectrum from a site-specific analysis and the simplified response spectrum modified according to the exception. To the degree that the site coefficients are conservative, a site-specific analysis will provide lower seismic design forces. ASCE 7-16 typically permits up to a nominal 20% reduction in seismic design loads if a site-specific analysis is performed. It should also be noted that while site-specific analyses may lead to lower seismic demands for design, it is also possible that they may also lead to higher ones. Spectral accelerations based on the site-specific analyses are believed to be more accurate than strictly coded-prescribed ones for any particular site due to the use of site-specific information. As such, it is the opinion of the authors that site-specific analyses better quantify seismic risks. Parties wanting a more accurate assessment of ground motions and attendant seismic risks are encouraged to employ site-specific studies. It should be noted that ASCE 7 does not require the site-specific response spectrum to be used if that spectrum turns out to be higher than the simplified response spectrum.

Apart from the correction of potential deficiencies in the shape of the response spectrum, there are two situations when an increase in the site coefficients may more properly be termed a penalty, one being up to a potential 20% increase in the site coefficient Fa in the case of an assumed ("default") Site Class D, depending on acceleration levels (see ASCE 7-16, Section 11.4.4). In this case, the code recognizes the potential for mischaracterizing shorter period response when site conditions are assumed through means of a default (assumed) classification rather than using measured, or at least critically assessed, site characteristics. The other situation affecting site coefficients for Site Class B is somewhat similar. For a Site Class B site, in order to use tabulated values for F_a and F_v (which are less than 1.0), the shear wave velocity must be measured, otherwise the F_a and F_v values must be 1.0. If a geotechnical report identifies a site as Site Class B, the report should clearly state whether or not the shear wave velocity was "measured".

It is pointed out that for essentially all IBC-applicable projects along the Wasatch Front, designers should not be performing seismic design without a project geotechnical report (as required by Section 1803 of the IBC) which should provide a judicial assessment of the site class (no default or assumption of Site Class D should be required on the part of the Structural Engineer). The reader is referred to Topic #2 for related discussion). In other areas of Utah with relatively low ground shaking hazard, the choice of using “default” based site coefficients appears to be one of economics and the degree of interest in knowing what the best estimate of the hazard is for design.

Topic #4: Can’t I Just Use the Internet to Perform a Site-Specific Seismic Study? To the best of the committee’s knowledge, the answer to this question is no. Seismic design parameters such as S_s and S_1 which have traditionally been obtained from the seismic “Design Ground Motions” section of the USGS website (see USGS, 2019a) are based on both probabilistic and deterministic analyses. These design parameters also contain adjustments to account for orientation causing the maximum response and a 1% probability of structural collapse (the latter being the role of the risk coefficients, resulting in “risk-based” or “risk targeted” ground motions). Relatively recently, the USGS stopped supporting direct queries for engineering ground motion parameters on its online tools / website; these functions have been outsourced to third-parties. The USGS does still maintain a web-based “Unified Hazard Tool” (USGS, 2019b) which provides probabilistic-based spectral acceleration values for a few selected structural periods. This tool by itself, however, cannot provide design-basis values for a number of reasons. Neither the USGS or third-party tools provide enough spectral points to provide an adequately smoothed spectrum, and the accompanying site coefficients which may be provided are too imprecise to be site specific and reflective of either a discrete V_{s30} value or the response of a multilayered soil profile where the response depends upon uniquely defined impedance contrasts as revealed in a measured shear wave velocity profile. Other deficiencies in USGS-based data with respect to site-specific studies include omitted faults (a situation which becomes an increasingly common and greater issue away from the Wasatch Front). USGS-based ground motion characterizations also do not explicitly include site-specific basin or near-source effects. USGS-based calculations are also based on a relatively coarse spatial grid, being 0.05 to 0.1 degrees of latitude and longitude in Utah (which very roughly equates to a distance of 3 to 7 miles).

Topic #5: Qualifications for Professionals Performing a GMHA or SRA. Project stakeholders must understand the importance of engaging qualified professionals to undertake such work and ensure that those engaged demonstrate the requisite experience, expertise, and licensure to provide design ground motions for final design of structures consistent with State law. Beyond these considerations, the following minimum requirements are recommended:

Professionals performing site-specific GMHAs or SRAs should be well versed in the requirements of ASCE 7-16 Chapter 21 and the corresponding revisions contained in Supplement #1 of the same. This includes Sections 21.2, 21.3 and 21.4, not just Section 21.1. As stated elsewhere herein, it is critical that professionals performing the analysis have an adequate background in earthquake engineering as well as PSHA and DSHA concepts. Professionals should be experienced in interpreting seismic analyses beyond a basic, USGS characterized hazard.

Professionals performing GMHA or SRA studies should possess a combination of advanced academic training, on-the-job mentoring, and professional experience in performing site-specific seismic studies for projects of similar size and scope. As such, professionals should have a demonstrable understanding of strong ground motions; time histories and response spectra; and both seismic source and site characterization.

Specifically with respect to those performing GMHAs, professionals should have a demonstrable understanding of: probabilistic and deterministic assessments of ground motions; ground motion prediction equations (GMPEs); recurrence models; non-linear soil effects; hazard curves; deaggregation; fragility and risk-based design concepts; near-source effects; and modeling of uncertainties.

Specifically with respect to those performing SRAs, professionals should have a demonstrable understanding of: criteria used for selecting input time histories; convolution and deconvolution; bedrock base motions versus outcrop motions; spectral matching; equivalent-linear versus non-linear analyses; time versus frequency domain analyses; and modeling of dynamic soil properties. It should be recognized by all parties involved that nonlinear SRA is considerably more complex than equivalent linear SRA and requires a much more comprehensive subsurface investigation, estimation of dynamic soil properties from laboratory testing or correlations, and understanding of soil constitutive model and damping schemes.

Professionals performing either GMHA or SRA studies should be able to: run applicable computer codes; explain the analytical methods used in the codes; not be reliant upon default parameters; and distinguish between “good” and “bad” inputs as well as critically assess quality of analysis results.

Professionals performing either GMHAs or SRAs should have a demonstratable record of performing site-specific seismic studies analyses whose rigor is commensurate with the effort needed for the subject project, and such studies should include peer review by an independent party. It is suggested that parties seeking GMHA or SRA services request a resume as well as a previously performed site-specific seismic study to help demonstrate the provider’s qualifications.

***Topic #6: Contents of a Site-Specific Seismic Study (GMHA or SRA) Report**.* For a GMHA, it is recommended that the written report include, as a minimum, the following:

- Identification of the seismic site classification, together with justifying data and discussion. Provide V_{s30} value(s) for the site (including the method and data used to determine the value) as well as an assessment of any liquefaction triggering.
- Description of the inputs used, including seismic source model and GMPEs; incorporation of uncertainties; and any adjustments for near-source and other effects not captured in GMPEs.
- Hazard curves from probabilistic assessments, and response spectra from probabilistic and deterministic assessments at applicable hazard levels (probability of exceedance or percentile). Response spectra should include a sufficient number of periods to produce a smoothed curve at or near the period of interest for the structure(s).

- Description of the relative contribution to hazard by specific seismic sources, including deaggregation(s) at periods of interest and list of mean and modal magnitude-distance pairs.
- Development of final site-specific risk-targeted MCE_R and design response spectra.

For an SRA, it is recommended that the written report include, as a minimum, all of the items previously articulated for a GMHA as well as the following:

- Description of the input ground motion parameters used, including seed time histories; selection criteria; target spectrum; adjustment/spectral matching methods; convolutions and deconvolution methods.
- Description of the site and soil profile model used, including soil types; layer and sublayer thicknesses; groundwater conditions as required by the model; basis of depth to "bedrock", shear wave velocity profile(s); pertinent soil index properties; and shear modulus degradation (and damping, if decoupled) methods or relationships.
- Description of analysis method used (e.g., equivalent-linear in the frequency domains); base layer spectra; effective stress/strain levels; amplification factors; and dynamic pore water pressure generation model (if used).

Both types of reports should present results including the Maximum Considered Earthquake-level, risk-based, (MCE_R) acceleration response spectrum which accounts for local site soil effects as quantified in standard GMPEs; a Design-Level, risk-based, acceleration response spectrum derived from the MCE_R spectrum, together with design parameters S_{DS} and S_{D1}, and the MCE, geometric mean-based, peak ground acceleration (PGA_M). While not strictly required, it is recommended that full, probabilistic-based spectra and both median (50th percentile) and 84th percentile deterministic-based spectra be presented in reports for those clients who may wish to explore/use higher-than-minimum required ground motions.

All reports (GMHA or SRA) should be signed and sealed by a geo-professional licensed in the state of Utah. It should be recalled that engineers and licensed professionals should only practice within their area of expertise and competency; sealing a report prepared by others (such as may be the case of a report prepared out of state) without overseeing, critically reviewing, and assessing its contents and conclusions would constitute a legal and ethical violation.

Topic #7: How Does the Structural Engineer, Architect, or Building Official Know If the Geotechnical Engineer is Recommending or has Performed the Correct Type of Analysis? It is suggested that the following steps be taken to help assure that the correct work is being performed: 1) select a geo-professional who demonstrates adequate qualifications (see Topic #5), 2) understand and trace the components of the proposed analysis/output back to the relative content requirements described/discussed in the codes and commentaries (note that a written proposal can address the previous two points), 3) use your network of fellow professionals to "ground truth" the consultant's recommendations, and 4) use the independent peer review process, starting at the beginning of the work.

It is the opinion/experience of the committee/panel that more often than not, a GMHA will be performed rather than an SRA (and if an SRA is done, a GMHA is often performed to provide input to the SRA). Softer ground conditions and higher period structures are typical reasons for performing a GMHA over the simplified general procedure response spectrum provided in the code. If the site classification is F due to the presence of liquefiable soils, ASCE 7-16 requires a SRA be performed, unless exempt due to the structural period (fundamental period of vibration) being 0.5 seconds or less. (Here, it should be mentioned that there are other site conditions which can result in a site classification of F [the reader is referred to Section 20.3.1]). It is further pointed out that not all methods of SRA are applicable to all sites. Equivalent-linear methods are suspect in situations involving soft soils and high ground accelerations, and one-dimensional SRAs may lose accuracy as structural periods exceed the natural period of the site. A GMHA may not be applicable if the site presents significant impedance contrasts (has significant step changes in the shear wave velocity profile).

Topic #8: Peer Review. While peer review is required by ASCE 7-16 in certain instances (such as when using performance-based procedures [see ASCE 7-16, Section 1.3.1.3.3 and 1.3.1.3.4]), it is not explicitly required to be part of a GMHA or SRA. There is subjective, yet professional, judgment that goes into the decisions made in GMHA and SRA analyses that impacts the life and safety of building occupants. The purpose of peer review is to help assure project quality, provide broader consensus regarding subjective aspects involved in the analyses, and to ultimately provide a measure of additional assurance regarding the expected performance of a project once completed. It is recommended that SRAs and GMHAs be peer reviewed as a general practice in Utah until the experience base matures. It is also recommended that a peer review always be performed for Risk Category III and IV structures, regardless of the level expertise employed. In terms of qualifications, a peer reviewer should be recognized by his peers as a competent professional in the field of earthquake engineering and is able to perform the scope of study that is the subject of the review.

It is recommended that peer reviewers be identified and involved early on in a project in order to support the framework and pertinent analysis/assessment details for the site-specific seismic study. Involvement of a peer reviewer only at the end stage of the design process precludes consensus building, increases the potential for conflict, and increases the risk of additional analyses to address late-coming questions. Peer review is not intended to replace the design responsibilities of the engineer of record, nor is it a plan check for detailed determination of the compliance of developed plans to requirements of applicable codes and standards.

Topic #9: "What If I've Never Performed a GMHA / SRA Before, and I Want to Learn How to Do One?" Persons initially engaging in GMHA /SRA are encouraged to first seek out the necessary background through education and training. With this prerequisite in place, it is recommended that the person (or firm) team up with another professional (or firm) who has demonstrated experience and other qualifications to oversee their work. Early in a study, a third-party reviewer should be engaged to provide feedback. After multiple studies have been complete, the person will have hopefully acquired (and be able to be successfully demonstrate) adequate experience. It also requires on-going learning in as the seismic field is continually evolving – from new earthquakes which provide more data to improve ground motion prediction models to more fault trenches which better define (or even redefine) recurrence models. As a professional, one should not (and is legally and ethically required to not) practice outside one's area of experience and expertise. Purchasing and learning to use relevant software is a good step, but true competence requires much more. This guidance is not meant to discourage or exclude persons from performing site-specific seismic analyses. Continued development of this expertise within the engineering community is encouraged, but the learning and skill associated with performance of site-specific seismic studies must be sufficient to obtain meaningful results and protect the public and profession from defective work product.

CONCLUSION

The seismic design provisions of IBC 2018 and ASCE 7-16 present a need to revise typical seismic design performed in the State of Utah. These changes have resulted in revised mapped B/C boundary seismic values S_s and S_1 as well as updated site coefficients (with the coefficients typically being larger). Perhaps the greatest change results from requirements for site-specific seismic studies in situations involving moderate to large magnitude ground motions on softer soil sites, which includes many Site Class D or E sites in Utah. This particular change is motivated by deficiencies in the standardized, code-based design response spectrum where spectral accelerations are potentially unconservatively represented. Code allowed exceptions to performing site-specific studies are made in some cases, but at the potential cost of elevated design values.

Depending upon the particular circumstances, site-specific seismic studies will consist of a GMHA and/or SRA. In order to perform site-specific seismic studies, appropriate geotechnical subsurface data are needed. In particular, the shear wave velocity of the upper 100 feet of the soil/rock profile needs to be assessed. Shallow geotechnical data (as might commonly be collected for a shallow foundation project) alone are insufficient to classify a site with respect to its anticipated seismic response. As such owners, stakeholders, and clients need to be prepared for a greater commitment of resources when a GMHA or SRA is required instead of using the standard seismic design spectrum.

Performance of a GMHA and SRA is not a trivial matter, and given the implications regarding public safety, such analyses require qualified individuals to perform them. Recommendations regarding those qualifications as well as the content of the reports produced have been provided. Given the complexity, and the subjectivity with respect to some aspects, of GMHAs and SRAs, peer review of such analyses is strongly recommended.

WORKSHOP/PANEL MEMBERS AND DOCUMENT ENDORSEMENTS

Committee members for the ASCE 7-16 seismic ground motions workshop also serving as workshop panel members (in alphabetical order, with their Utah-based licensing credentials) consisted of Dorian Adams, SE; Matt Francis, PE; Kevin Franke, PhD, PE; Travis Gerber, PhD, PE; Eric Hoffman, SE; Jerod Johnson, PhD, SE; Chris Kimball, SE; and Zia Zafir, PhD, PE. Other committee members included Brent Maxfield, SE; and Ryan Maw, PE who served as committee chair and moderator for the workshop. These committee members present a broad range of expertise and background including: geotechnical and structural engineering; geologic and seismologic practice; academic research and education; and building code enforcement.

The views, opinions, and recommendations presented in this document have been endorsed by the Utah Geo-Institute Chapter of the American Society of Civil Engineers (ASCE), the Structural Engineers Association of Utah (SEAU), the Utah Section of ASCE, the Utah Chapter of the Earthquake Engineering Research Institute (EERI) and the Utah Chapter of the Structural Engineering Institute (SEI).

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